

# Carob tree

*Ceratonia siliqua* L.

I. Batlle  
and J. Tous



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## Foreword

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

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

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I. Batlle and J. Tous  
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## 1 Introduction

The carob tree has been grown since antiquity in most countries of the Mediterranean basin, usually in mild and dry places with poor soils. Its value was recognized by the ancient Greeks, who brought it from its native Middle East to Greece and Italy, and by the Arabs, who disseminated it along the North African coast and north into Spain and Portugal. It was spread in recent times to other Mediterranean-like regions such as California, Arizona, Mexico, Chile and Argentina by Spaniards, to parts of Australia by Mediterranean emigrants and to South Africa and India by the English.

The carob tree is an important component of the Mediterranean vegetation and its cultivation in marginal and prevailing calcareous soils of the Mediterranean region is important environmentally and economically. Traditionally, grafted carob trees have been interplanted with olives, grapes, almonds and barley in low-intensity farming systems in most producing countries. Carob pods with their sugary pulp are a staple in the diet of farm animals and are eaten by children as snacks or by people in times of famine. However, currently the main interest is seed production for gum extraction. Kibbled pods have been shipped from producing countries to all over Europe. Because of low orchard management requirements the carob tree is suitable for part-time farming and shows potential for planting in semi-arid Mediterranean or subtropical regions. The trees are also useful as ornamentals and for landscaping, windbreaks and afforestation. Cattle can browse on leaves and the wood is suitable for fuel.

World production is estimated at about 310 000 t/year produced from some 200 000 ha with very variable yields depending on cultivar, region and farming practice. Spain is the leading carob producer, producing on average 135 000 t/year (MAPA 1994), followed by Italy, Portugal, Morocco, Greece, Cyprus, Turkey, Algeria and some other countries. A full account of the main carob-producing areas is presented in section 10.

Carob has been neglected with respect to both cultural practices and research and development. Apart from a few classic works written by interested scientists like Rullán and Estelrich (1882), Bassa (1896) and Lleó (1901) in Spain, Pereira (1900) and Da Matta (1952) in Portugal, Russo (1954) in Italy, Mitrakos (1988) in Greece, Orphanos and Papaconstantinou (1969) in Cyprus, and various reports especially from Israel (Goor *et al.* 1958) and the United States (Condit 1919), references on this crop are scarce. We have tried to review most of the work published over the last 100 years and make useful information available to producers, processors, students, scientists and amateurs.

The information presented in this publication has been compiled within the context of the carob Research & Development programme conducted at IRTA-Mas Bové since 1984; this has two main aims. The first was to collect and study the genetic resources available in the Mediterranean region and other production areas – IRTA's carob germplasm collection is the widest in the world with over 90 introductions under evaluation. The second aim was to assess the potential yield

of this crop when grown in modern orchards with minimum management – a nonirrigated trial in Tarragona, Spain, with 12% of pollinators and with 500 mm of annual rainfall, is yielding about 5000 kg/ha of pods 10 years after planting.

This monograph describes the genetic resources of carob (*Ceratonia siliqua* L.) and reviews various aspects of its taxonomy, botany, origin, ecology, properties, uses, diversity and breeding. In addition, a full account of the crop production areas, agronomy, limitations, market, prospects and research needs is presented. An important scope of this work is to contribute to the conservation of the diversity of the cultivated carob and wild relatives. Thus exchange of information as well as germplasm is made possible. The authors hope that the thriving features, current situation of the genetic resources, potential prospects and research needs of carob as a plant and crop for Mediterranean regions are clearly presented.

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## 2 Names of the species and taxonomy

The scientific name of carob tree (*Ceratonia siliqua* L.) derives from Greek *keras*, horn, and Latin *siliqua*, alluding to the hardness and shape of the pod. The common name originates from the Hebrew *kharuv*, from which are derived the Arabic *kharrub* and later *algarrobo* or *garrofero* in Spanish, *carrubo* in Italian, *caroubier* in French, *Karubenbaum* in German, *alfarrobeira* in Portuguese, *charaoupi* in Greek, *charnup* in Turkish, and *garrofer* or *garrover* in Catalan. Various names are used in different regions of Italy: *ascenedda*, *soscella* (Basilicata); *carrua*, *carrubbi* (Sicilia); *carruba*, *sciuscella* (Campania); *carrubbio*, *carrubo*, *cornola*, *corue*, *pselocherato*, *pselocherea* (Puglia); *suscella* (Campania and Puglia); and *garrubaro*, *garrubbo* (Calabria) (Hammer *et al.* 1992). In Asia the following names are used: *chiao-tou-shu* (China), *gelenggang* (Malaysia) and *chum het tai* (Thailand) (Kruse 1986). The carob is also known as St. John's bread or locust bean in reference to the presumed use of its 'locusts' as food by St. John the Baptist and, from that derives *Johannisbrothbaum* in German. Jewellers used its uniform seeds as a unit of weight (200 mg), the carat.

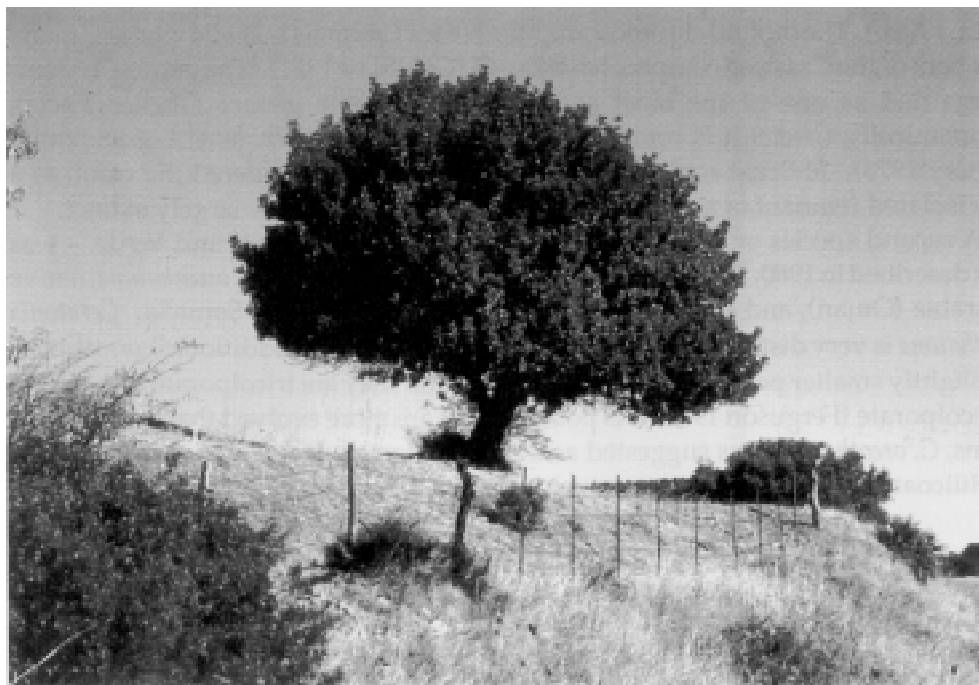
The genus *Ceratonia* belongs to the family Leguminosae (syn. Fabaceae) of the order Rosales. Legumes are important members of tropical, subtropical and temperate vegetation throughout the world. This is one of the largest families of flowering plants and includes 650 genera and over 18 000 species (Polhill *et al.* 1981) and is extremely variable in morphology and ecology. The carob tree is generally placed in the tribe Cassieae of the subfamily Caesalpinioideae; however, several authors doubt *Ceratonia*'s position in the Cassieae (Irwin and Barneby 1981; Tucker 1992a, 1992b). The diploid chromosome number for *Ceratonia* is  $2n=24$  whereas many members of the Cassieae complex have  $2n=48$  (Goldblatt 1981). The genus *Ceratonia* is regarded as one of the most archaic of the legume genera (Tucker 1992a). Taxonomically, *Ceratonia* is completely isolated from all other genera of its family (Zohary 1973). Hillcoat *et al.* (1980) and Tucker (1992a) considered the carob as a very isolated remnant of a part of the family Leguminosae now largely extinct.

A second species of *Ceratonia* – *C. oreothauma* Hillcoat, Lewis and Verdc. – was only described in 1980. Two subspecies were distinguished: subsp. *oreothauma*, native to Arabia (Oman), and subsp. *somalensis*, native to the north of Somalia. *Ceratonia oreothauma* is very distinct morphologically from *C. siliqua*. In addition, *C. oreothauma* has slightly smaller pollen grains than *C. siliqua* and they are tricolporate rather than tetracolporate (Ferguson 1980). As pollen grains are more evolved than tricolporate grains, *C. oreothauma* was suggested as the wild ancestor of the cultivated *C. siliqua* by Hillcoat *et al.* (1980).

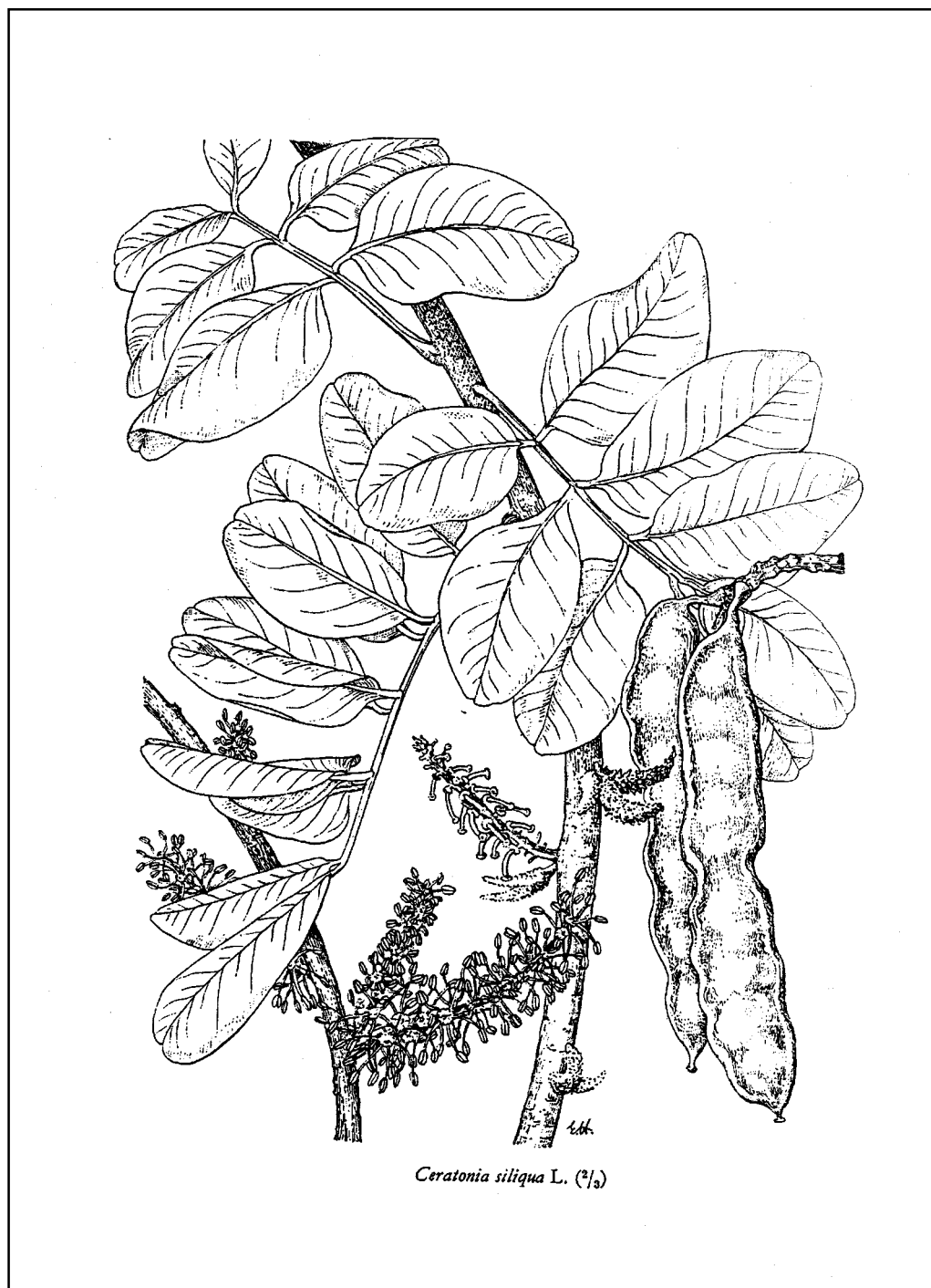
### 3 Botanical description

The carob tree grows as a sclerophyllous evergreen shrub or tree up to 10 m high, with a broad semispherical crown and a thick trunk with brown rough bark and sturdy branches (Fig. 1). Leaves are 10-20 cm long, alternate, pinnate, with or without a terminal leaflet. Leaflets are 3-7 cm long, ovate to elliptic, in 4-10 normally opposite pairs, coriaceous, dark green and shiny above, pale green beneath and finely veined with margins slightly undulate, and tiny stipules. The leaves are sclerophyllous and have a very thick single-layered upper epidermis, the cells of which contain phenolic compounds in the large vacuoles, and stomata are present only in the lower epidermis and arranged in clusters (Mitrakos 1988). Relevant parts of the plant are shown in Figure 2. Carob does not shed its leaves in the autumn but only in July every second year, and it only partially renews leaves in spring (April and May) (Diamantoglou and Mitrakos 1981).

The carob is a dioecious species with some hermaphroditic forms; thus male, female and hermaphrodite flowers are generally borne on different trees. Unisexual and bisexual flowers are rare in the inflorescence. The flowers are initially bisexual, but usually one sex is suppressed during late development of functionally male or female flowers (Tucker 1992a); dioecy is not common among Leguminosae. In evolutionary terms, unisexuality is generally regarded as a derived character from bisexual ancestral state.



**Fig. 1.** Carob tree growing in Seville, Andalusia, Spain.

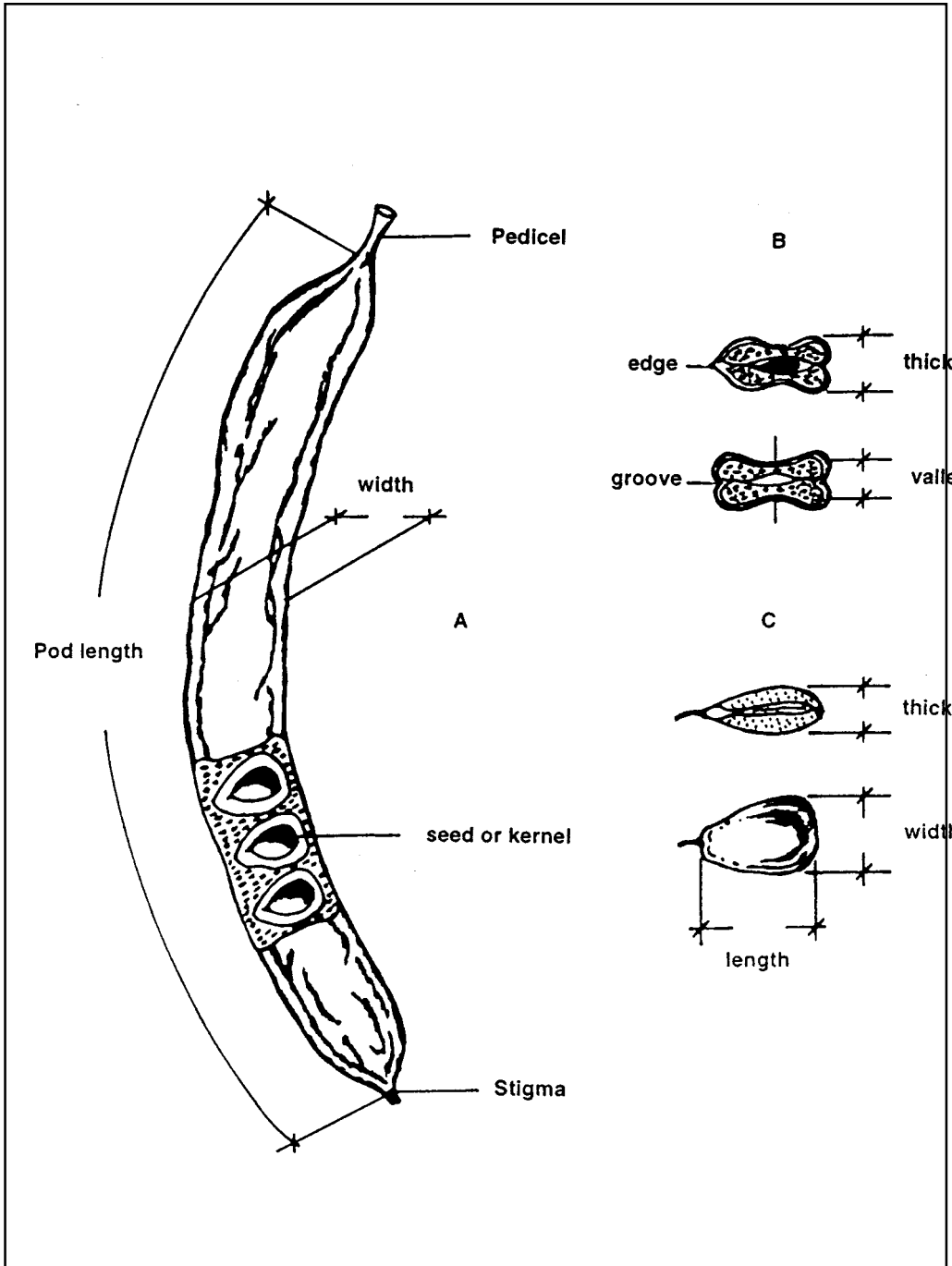


**Fig. 2.** Shoots, leaves, leaflets, male and female inflorescences and pods (from Zohary 1973, reprinted with permission).

Flowers are small and numerous, 6-12 mm long, spirally arranged along the inflorescence axis in catkin-like racemes borne on spurs from old wood and even on the trunk (cauliflory). Flowers are green-tinted red. Flowers show pentamerous symmetry with calyx but not corolla placed on a short pedicel. The calyx is disc-shaped, reddish-green and bears nectaries. Female flowers consist of a pistil (6-8.5 mm) on a disk and rudimentary stamens, surrounded by 5 hairy sepals. The ovary is bent, consisting of two carpels 5-7 mm long and containing several ovules. The stigma has 2 lobes. Male flowers consist of a nectarial disk with 5 stamens with delicate filaments surrounded by hairy sepals. In the centre of the disk there is a rudimentary pistil. Hermaphrodite flowers are a combination of both types, containing a pistil and a complement of 5 stamens. Pollen grains released from the anthers are of spheroidal shape and are tetracolpate (Ferguson 1980). Pollen diameter is 28-29  $\mu\text{m}$  at the poles and 25-28  $\mu\text{m}$  at the equator (Ferguson 1980; Linskens and Scholten 1980).

The fruit is an indehiscent pod, elongated, compressed, straight or curved, thickened at the sutures, 10-30 cm long, 1.5-3.5 cm wide and about 1 cm thick with blunt or subacute apex (Fig. 3). Pods are brown with a wrinkled surface and are leathery when ripe. The pulp comprises an outer leathery layer (pericarp) and softer inner region (mesocarp). Seeds occur in the pod transversally, separated by mesocarp (Fig. 3). They are very hard and numerous, compressed ovate-oblong, 8-10 mm long, 7-8 mm wide and 3-5 mm thick; the testa is hard and smooth, glossy brown, the hilum minute.

The haploid chromosome number of *Ceratonia* is  $n=12$  and differs from other Cassieae (base number  $n=14$ ) according to Goldblatt (1981), who suggested it might be aneuploid.



**Fig. 3.** Important parts of the carob pod (A), section of pod (B) and seed (C).

#### 4 Reproductive biology

Many basic aspects of carob reproductive biology, such as floral biology, pollination compatibility between different sexual types and also cultivars, and flowering and fruiting phenology remain largely unknown. However, progress has been made by McLean Thompson (1944), Russo (1954), Schroeder (1959), Meikle (1977), Leshem and Ophir (1977), Haselberg (1988), Passos de Carvalho (1988), Linskens and Scholten (1980), Retana *et al.* (1990, 1994), Bosch *et al.* (1996), Ortiz *et al.* (1996) and Rovira and Tous (1996). In carob, Condit (1919) reported the tree ratio of female to male is about 50:50 including a few hermaphrodites.

Floral morphology of carob is complex. Meikle (1977), from literature and observed specimens in Cyprus, summarized five types of inflorescences:

- male, the flowers having long filaments and abortive pistils
- male, the flowers having short filaments and abortive pistils
- hermaphrodite, the flowers having fully developed stamens and pistils
- female inflorescences, the flowers with abortive staminodes and fully developed pistils
- polygamous inflorescences, some of the flowers male, some female and some hermaphrodite.

Schroeder (1959) grouped into five floral classes 59 carob cultivars growing in California based on the expression of their sex throughout the season. The five groups were: pistillate, pistillate with occasional perfect flowers, perfect with occasional staminate flowers, perfect and staminate. He reported that while adult trees maintained their floral types, young trees showed variation in the development of stamens. The provision of pollinators will prove to be essential for cultivars in the first three groups in order to ensure adequate commercial fruit set. He also noted that cultivars that were hermaphrodite early in the season showed some tendency toward pistil development failure later in the season.

A simple carob inflorescence type classification would be:

- male inflorescences (Fig. 4a)
- female inflorescences (Fig. 4b)
- hermaphrodite inflorescence (Fig. 4c).

Hillcoat *et al.* (1980) reported from the available material of *C. oreothauma* that flowers are either purely male or female with minute, completely sterile, primary anthers. Thus variation in sexuality and morphology of flowers of this species is not as wide as in the cultivated carob.

It is difficult to find carob trees of all flower types in naturalized populations of the same area. In the Mediterranean Spanish coast, female and male types are common and hermaphrodite forms rare. However, hermaphrodites are more frequently observed in the Eastern coast of Spain than in the South or in the Algarve in Portugal (Batlle and Tous 1994). In the Balearic Islands the frequency of hermaphrodites is higher than in the Iberian peninsula.

There are many different forms of males, but the two main types observed in Italy, Portugal and Spain are often locally named after their anther colour as 'Red'



a



b



c

**Fig. 4.** Male inflorescence (a), female flowers and pods (b) and hermaphrodite flowers (c).

or 'Yellow'. This feature has proven to be insufficient for their classification as it is determined independently of other flower characteristics (Haselberg 1988). It appears that blooming of 'Red' males is more extended than that of 'Yellow' males.

The carob is the only Mediterranean tree with the main flowering season in autumn (September-November), similar to many truly tropical plants. However, the time and length of the flowering period depends on local climatic conditions as in most fruit and nut trees. In very hot places male and female trees have been observed in full bloom during June (Leshem and Ophir 1977). Its blooming period in some places overlaps partially with that of the loquat tree (*Eriobotrya japonica*). The extended flowering season in carob compensates for the unstable weather at that time of the year, and ensures that at least some flowers will be pollinated in a spell of good weather and insect activity. *Ceratonia oreoethauma* flowers in March and April in its native places in which was first reported (Hillcoat *et al.* 1980). Thus hybridization between both species is only feasible artificially.

Pollen transport from staminate to pistillate flowers is effected by insects, mainly bees, flies, wasps and night-flying moths (Retana *et al.* 1990, 1994; Ortiz *et al.* 1996) but also by wind (Passos de Carvalho 1988; Tous and Batlle 1990). Flowers of all three sexes secrete nectar, though volume of nectar and sugar content is higher in female flowers than in male (Ortiz *et al.* 1996). Male and hermaphrodite flowers emit a semen-like odour which attracts insects. Different insect groups tend to visit flowers at different hours. Bees are scarce in autumn when carobs are blooming, both in number of species and individuals. How far windborne pollen is effective is unknown, but isolated female trees have produced light crops. Currently, the role of the wind on carob pollen transport is being re-emphasized (Martins-Loução *et al.* 1996a).

The developmental stages of both female and male flowers are six and five, respectively, and were first defined and described by Haselberg (1988) (Fig. 5). Flowering and fruiting phenology of some male, female and hermaphrodite cultivars have been studied by Retana *et al.* (1994) and Bosch *et al.* (1996). Development of inflorescences is more protracted in female and hermaphrodite cultivars (2 months or more) than in male ones (1-1.5 months). So two Spanish female cultivars ('Negret' and 'Rojal') bear inflorescences in as many as six developmental stages, whereas 'Red' and 'Yellow' male trees never carry inflorescences of more than four developmental stages (Retana *et al.* 1994).

Ferguson (1980) reported up to 36% of morphologically abnormal pollen grains in male plants of carob, although this appeared to be unrelated to a reduction in pollen fertility. Sfakiotakis (1978) observed high pollen germination variability *in vitro* among wild male trees in Crete, their germination percentages ranging from 4.3 to 69%. However, Ciampolini *et al.* (1986) found less difference in pollen germinability: from 5.2 to 38.6% in males and from 7.1 to 26% in hermaphrodite types. Some pollen abnormality also occurred in *C. oreoethauma* (Ferguson 1980).

Leshem and Ophir (1977) reported higher levels of endogenous gibberellins in the leaves and inflorescences of female than of male carob trees. In addition, they



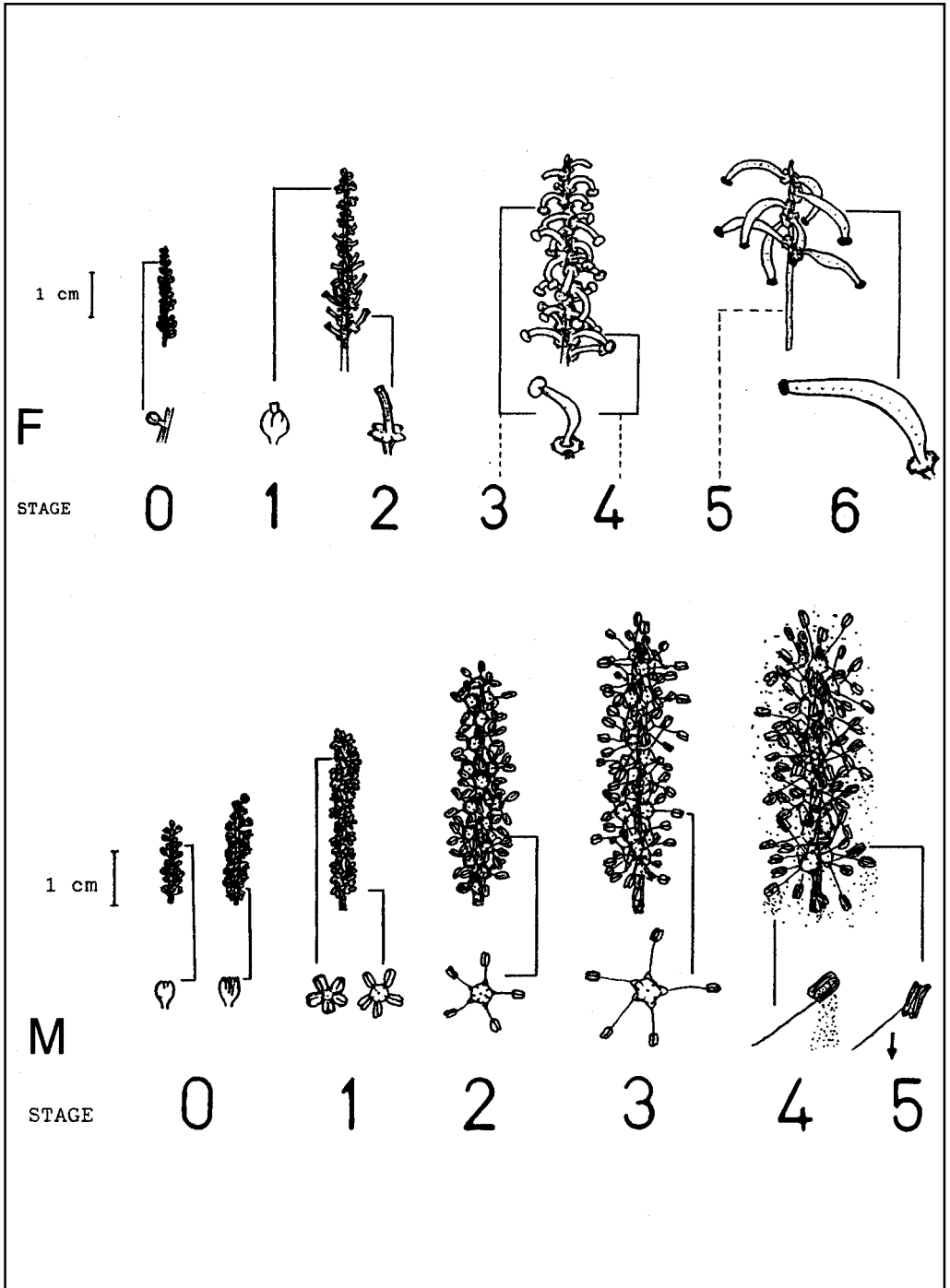


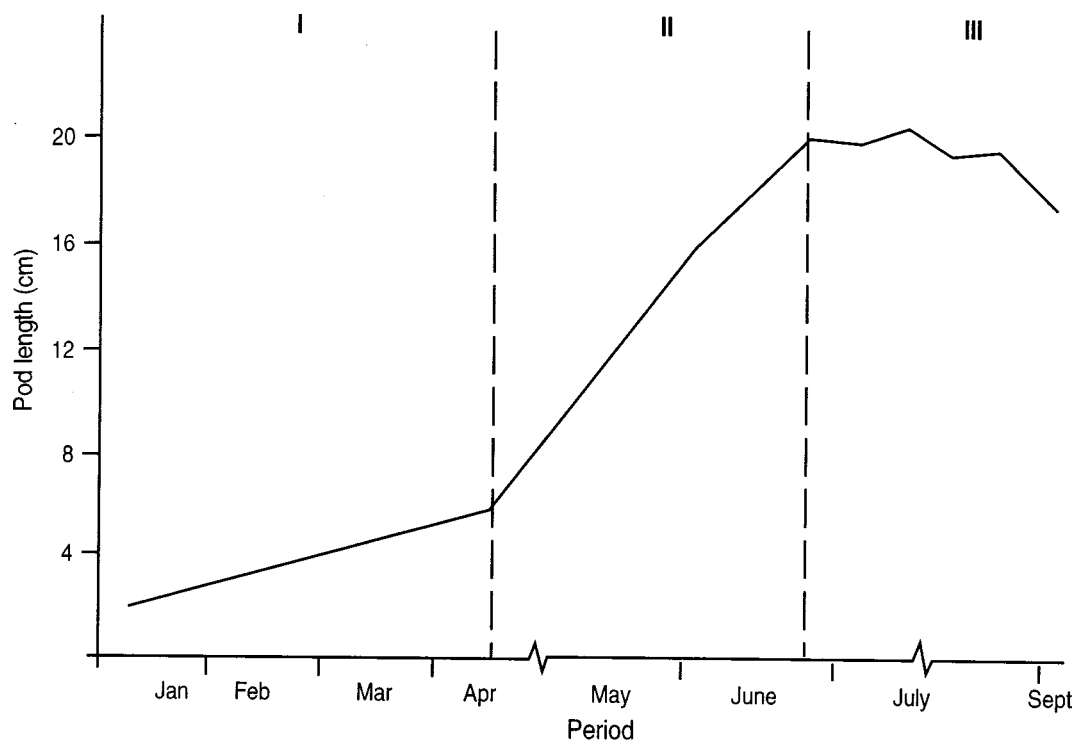
Fig. 5. Stages of development of female (F) and male (M) flowers of carob (from Haselberg 1988,

observed that the switch from vegetative to generative growth in both the male and the female may be associated with a low concentration of endogenous gibberellins in June in a multi-hormone complex (auxin, ethylene, etc.) presumably needed for flower induction. They also found that vegetative spring growth is related to enhanced gibberellin activity. Although physiological differences between male and female trees have been described, further research is needed.

Female and hermaphrodite inflorescences carry a mean of 17 and 20 flowers, respectively, but few produce a pod and only a small proportion of inflorescences set more than two fruits (Retana *et al.* 1994). Bosch *et al.* (1996) found low pod initiation (from 12 to 38%) of 'Negra' and 'Rojal' flowers. The overall fruit set is normally around 3-5% in Italian, Portuguese or Spanish cultivars (Russo 1954; Haselberg 1988; Rovira and Tous 1996). Bosch *et al.* (1996) observed fruit set to be from 1 to 11% in two consecutive years. Haselberg (1996) observed fruit set of 1% and even 0.05% in years of profuse blooming in 'Mulata'. Haselberg (1996) found a positive correlation between flower intensity and fruit drop and also that pods with a low number of seeds aborted more frequently.

Shedding of carob flowers and young fruits occurs mainly from October to December, then slows down during January-February and rarely occurs from June to early August (Bosch *et al.* 1996; Rovira and Tous 1996). Bosch *et al.* (1996) observed pod shedding of 59-90% and that it takes place mainly in spring. They reported that on larger inflorescences of the two female cultivars, higher rates of fruit initiation, fruit set and seed set per flower occurred than on smaller inflorescences. Haselberg (1996) reported that variations in flowering intensity and pod yield are likely to be more influenced by endogenous factors related to alternate bearing than by climatic conditions. However, unfavourable environmental conditions may significantly reduce yield by fruit set reduction, thus increasing production risk in marginal growing sites.

Ilahi and Vardar (1976) determined that carob pod development follows a sigmoidal growing curve like many other fruits (Fig. 6) and could be divided into three stages. During stage I (slow growth), after fertilization in October and during autumn and winter, the bean shows hardly any weight (fresh and dry) increase. Stage II (fast growth) starts at the beginning of spring when the pod enters an active period of growth (April to June). In stage III the fruit grows slowly, ripens and starts becoming dry in June and changes colour from green to brown. Bosch *et al.* (1996) reported a similar pattern of pod growth. The pod matures after some 10 months. The green pods are much heavier than the ripe ones, containing about 70% water whereas pod water content at maturity is about 12-18%.



**Fig. 6.** Stages of carob pod development (from Ilahi and Vardar 1976, reprinted with permission).

## 5 Origin and centres of diversity

### 5.1 Origin

The centre of origin of *C. siliqua* is not clear. It was placed by De Candolle (1883) and Vavilov (1951) in the eastern Mediterranean region (Turkey and Syria). However, Schweinfurth (1894) regarded carob as native to the highlands of southern Arabia (Yemen). More recently it has been considered by Zohary (1973) as originating from a xerotropical Indo-Malesian flora, grouping it with *Olea*, *Laurus*, *Myrtus*, *Chamaerops* and others and placing the origin of its genus also on the Arabian peninsula. *Ceratonia oreothauma*, the only known carob-related species, is considered to have its centre of origin in southeast Arabia (Oman) and around the African horn (north of Somalia) (Hillcoat *et al.* 1980).

Climatically the centres of origin of the subfamily Caesalpinoideae were warm and moist initially, but after the Cretaceous period vast drying and elevation of the lands occurred so that cooler, much drier, even desert, conditions evolved. Other caesalpinoid legumes are mainly tropical and subtropical (Cowan 1981). In addition, Mitrakos (1988) suggested that the carob tree seems to have evolved under a climate other than Mediterranean.

### 5.2. Distribution

The original distribution of *C. siliqua* is not clear as it has undergone extensive cultivation since ancient times. Hillcoat *et al.* (1980) suggested its range in the wild included Turkey, Cyprus, Syria, Lebanon, Israel, southern Jordan, Egypt, Arabia, Tunisia and Libya and that it moved westward at an early stage. Carob is believed to have been spread by the Greeks to Greece and Italy and then by the Arabs along the coast of northern Africa into the south and east of Spain, from where it migrated to the south of Portugal and the southeast of France. Its wild occurrence in the western Mediterranean is doubtful according to Zohary (1973). Spontaneous carobs occur in many places around the western Mediterranean basin but they are regarded as feral derivatives of the fruit crop which probably evolved under domestication.

As a food source, carob pods could be stored and transported long distances. In most of the Mediterranean region wild and naturalized carobs are distributed in more or less the same geographic and climatic belt as the cultivated. Forms of spontaneous carobs are particularly common at low altitudes along the Spanish Mediterranean coast, southwest Spain, southern Portugal, the Balearic Islands, southeast France, the shores of southern Italy including Sicily, the Adriatic coast of Croatia, the Aegean region in Greece and Turkey, along the northern and southern ranges of the isle of Cyprus, in the islands of Malta, in the maritime belt of Lebanon and Israel, the north and south of Morocco and the coastline in Tunisia. The proposed centre of origin and world distribution of carob are presented in Figure 7.

The carob tree was likely introduced into the United States from Spain by the US Patent Office in 1854. In the 1950s W. Rittenhouse and J.E. Coit promoted this species

in California and introduced budwood of selected cultivars from Cyprus, Israel, Tunisia, Greece, Yugoslavia, Crete, Portugal, Italy and Spain. Seedling trees grown for shade on the streets of cities in southern California and Arizona were selected for commercial production on the basis of their floral and fruit characteristics (Condit 1919; Coit 1949, 1967; Schroeder 1952; Coit and Rittenhouse 1970; Brooks and Olmo 1972).

In Mediterranean countries, the distribution of the evergreen sclerophyllous species like *C. siliqua* is controlled by winter cold stress (Mitrakos 1981). The closely related species *C. oreothauma* seems to be even more cold sensitive (J.H. Brito de Carvalho, pers. comm.) and thus its limits are more restricted. Carob is one of the most characteristic and dominant trees in the lower zone (0-500 m and rarely up to 900 m asl) of the Mediterranean evergreen maquis (Zohary and Orshan 1959; Folch i Guillen 1981). In some areas along the shores of the Mediterranean sea, wild carobs occupy places not disturbed by cultivation. Distribution of *C. oreothauma* is restricted to Oman and Somalia, which might be due to it being an uncultivated species. It is not clear if the distribution of the two related species overlaps. Both species, apart from probable dispersal by animals, are dependent on dispersion by fruit.

### 5.3 Domestication

Scant information is available on the origin and domestication of the carob tree. Liphshitz (1987) reported that early archaeobotanical findings (charred wood and seeds) in Israel showed that the carob existed in the eastern Mediterranean long



Fig. 7. World carob distribution and centres of origin.

before the start of Neolithic agriculture (4000 BC), although it is not among the prehistoric species listed by Renfrew (1973). Zohary (1973) suggested that the Mediterranean region has been at least one of its domestication centres. Zohary (1996), on the basis of literature sources and archeological evidence, reported that the carob was brought into cultivation relatively late with the 'second wave' of fruit crops domesticated in the Old World. He attributed this lateness of domestication to the difficulty of propagating carob vegetatively. Remains of carbonized pods have been found in archeological excavations near the Vesuvio volcano in Campania, Italy, post-dating its eruption in AD 79 (Meyer 1980).

Zohary and Spiegel-Roy (1975) analyzed two kinds of information – evaluation of fossil evidence and examination of wild relatives of the cultivated crops – and concluded that olive, grapevine, date palm and fig were the first important horticultural crops added to the Mediterranean grain agriculture. These 'first wave' fruit trees were most likely domesticated in the Near East in prehistoric times (4th and 3rd millennia BC); they were very important crops in the Early Bronze Age.

Zohary (1996) suggested that similarly to most Old World fruit crops, domestication of *C. siliqua* was based on shifting from sexual reproduction (in the wild) to vegetative propagation (under cultivation). In carob, as in other fruit and nut trees, the shift to vegetative propagation is the cultivator's solution to the problem of wide variability which is characteristic of sexual reproduction in cross-pollinated plants. In addition, as a predominantly dioecious tree, carob includes about 50% males and 1% hermaphrodites (Condit 1919). Thus spontaneous promising seedlings showing superior features have been empirically selected by growers and then clonally propagated. As a consequence, wild carob trees currently growing in Mediterranean countries are not identical to the species type (Mitrakos 1988). Hillcoat *et al.* (1980) reported that its cultivation in ancient times would have been unnecessary since wild trees were common in the eastern Mediterranean.

Wild and escaped carobs reproduce by seed while cultivated varieties are propagated vegetatively as clones. The carob does not root easily by cuttings and is only easily multiplied by budding. The propagation predominantly of female clones can change the sex ratio in a carob-production area. The three main fruit traits that distinguish domesticated carobs from their wild relatives are larger bean size, more pulp and greater sugar content. Increase in the size and number of seeds is less evident. These pod features together with productivity and environmental adaptation seem to have been the most important selection criteria for growers.

The small difference in size between the pollen of the two species of this genus seems unlikely to be associated with polyploidy but is more likely to be a result of cultivation (Ferguson 1980; Graham and Barker 1981). Ferguson (1980) reported that similar differences in pollen size between specimens of *Olea europaea* (cultivated olive) and *Olea laperrinei* (wild olive) have been observed.

## 6 Properties

The two main carob pod constituents are (by weight): pulp (90%) and seed (10%). Chemical composition of the pulp depends on cultivar, origin and harvesting time (Orphanos and Papaconstantinou 1969; Davies *et al.* 1971; Vardar *et al.* 1972; Calixto and Cañellas 1982; Albanell *et al.* 1991). Carob pulp is high (48-56%) in total sugar content (mainly sucrose, glucose, fructose and maltose) (Table 1). In addition it contains about 18% cellulose and hemicellulose. The mineral composition (in mg/100 g of pulp) is: K=1100, Ca=307, Mg=42, Na=13, Cu=0.23, Fe=104, Mn=0.4, Zn=0.59 according to Puhan and Wielinga (1996). Rendina *et al.* (1969) found the lipids to consist of approximately equal proportions of saturated and unsaturated acids. Vardar *et al.* (1972) found five amino acids in pod extracts (alanine, glycine, leucine, proline and valine) and Charalambous and Papaconstantinou (1966) also reported tyrosine and phenylalanine.

**Table 1. Average composition of the carob pulp**

Constituent	%
Total sugars	48-56
Sucrose	32-38
Glucose	5-6
Fructose	5-7
Pinitol	5-7
Condensed tannins	18-20
Non-starch polysaccharides	18
Ash	2-3
Fat	0.2-0.6

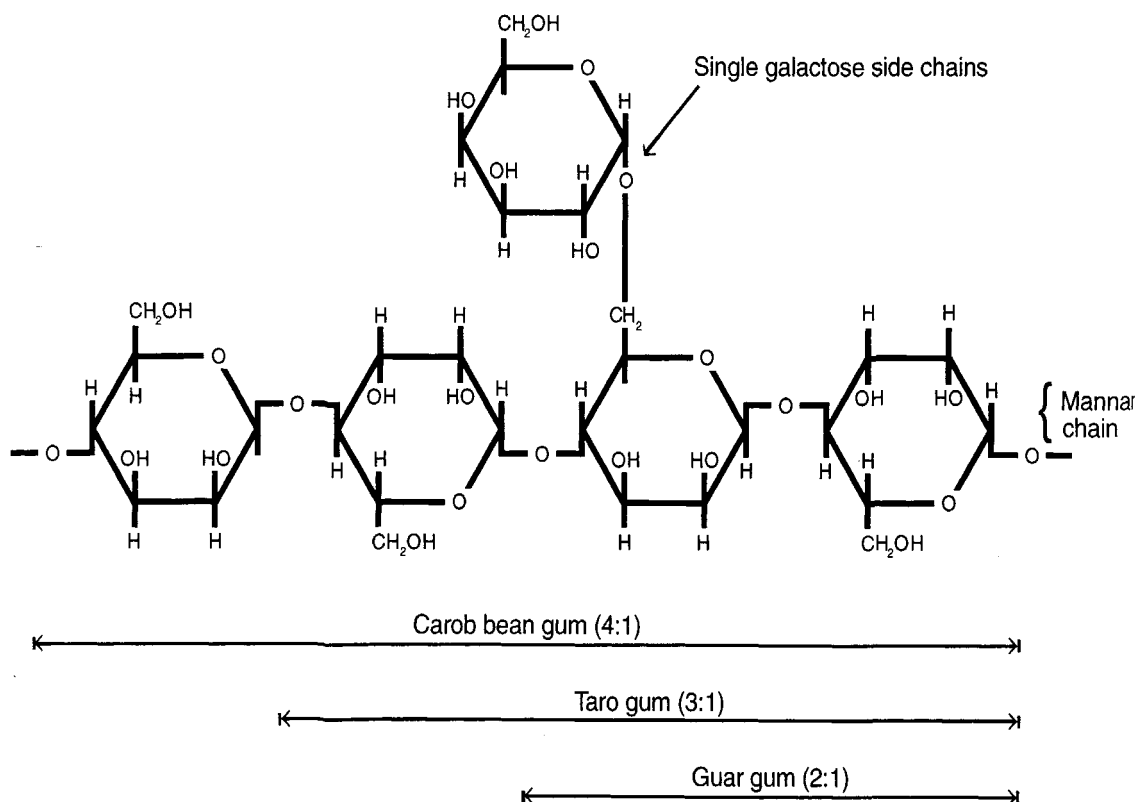
Source: Puhan and Wielinga (1996).

Ripe carob pods contain a large amount of condensed tannins (16-20% of dry weight) (Würsch *et al.* 1984). Feeding trials showed that carob pulp contains only 1-2% digestible protein and is relatively low in metabolizable energy (Vohra and Kratzer 1964). In food value, carob pods are similar to most cereal grains (NAS 1979). The protein has a low digestibility because it is bound with tannins and fibre (Loo 1969). Some researchers have suggested that condensed tannins account for observed growth-depressing effects on animals fed with a diet high in carob meal (Kamarinou *et al.* 1979) while others believe that this effect is due to its low energy content for which animals can compensate by increasing consumption (Louca and Papas 1973).

Constituents of the seed are (by weight): coat (30-33%), endosperm (42-46%) and embryo or germ (23-25%) (Neukom 1988). The seed coat contains antioxidants (Batista *et al.* 1996). The endosperm is the galactomannan carob bean gum (CBG). It is a polysaccharide molecule composed of mannose and galactose sugar units (ratio 4:1) rather similar to guar gum (ratio 2:1) and tara gum (ratio 3:1) (Fig. 8).

The main property of this natural polysaccharide is the high viscosity of the solution in water, over a wide range of temperature and pH (García-Ochoa and Casas 1992). Two other important properties of CBG are its high water-binding capacity to form very viscous stable solutions in high dilution (1% and lower) and its potential interaction with other polysaccharides, having a synergistic effect (Puhan and Weilinga 1996). Functional properties of CBG are given in Table 2. The germ meal, which is obtained from the cotyledons and has a 50% protein content, is suitable for human and animal nutrition (Table 3).

**Table 2. Functional properties of carob bean gum (CBG)**



**Fig. 8.** Molecular structure of three galactomannans (from Puhan and Wielinga 1996, reprinted with permission).



Function	Example	Use level (%)†
Adhesion	Glaces, juices	0.2–0.5
Binding agent	Pet foods	0.2–0.5
Body agent	Dietetic beverages	0.2–1.0‡
Crystallization inhibitor	Ice cream, frozen foods, bread	0.1–0.5
Clouding agent	Fruit drinks, beverages	<0.1
Dietary fibre	Cereals, bread	0.2–0.5
Foam stabilizer	Whipped topping, ice cream	0.1–0.5
Gelling agent	Pudding, desserts, confectionery	0.2–1.0
Moulding	Gum drops, jelly candies	0.5–2.0
Protective colloid	Flavour emulsions	0.2–0.5
Sterilizing agent	Salad dressings, ice cream	0.1–0.5
Suspending agent	Chocolate milk	<0.1
Swelling agent	Processed meat products	0.2–0.5
Synergistic agent	Soft cheeses, frozen foods	0.2–0.5
Thickening agent	Jams, pie fillings, sauces, baby food	0.2–0.5

† As such or as component in an appropriate blend.

‡ Depending on degree of polymerization or viscosity of CBG.

Source: Puhan and Wielinga (1996).

**Table 3. Average composition of commercial carob germ meal**

Constituent	%
Water	7
Lipids (neutral)	8
Ash	6
Crude protein (N x 6.25)	52
Carbohydrate (by difference)	27

Source: Puhan and Wielinga (1996).

## 7 Uses

The carob is one of the most useful native Mediterranean trees. In producing countries, carob pods have traditionally been used as animal and human food and currently the main use is the seed for gum extraction. Carob pods provide fodder for ruminants (Louca and Papas 1973) and nonruminants (Sahle *et al.* 1992). In the wild, carob shelter, foliage and beans attract browsing animals. The pods contain indigestible and valuable seeds. Carob timber is hard and close-grained, and has been used to make utensils as well as fuel. Carob wood also was traditionally used to make slow-burning charcoal. *Ceratonia oreothauma* is extensively used for goat fodder in its native ranges (Hillcoat *et al.* 1980).

The pods are used after crushing to separate seed and pulp. The main products derived from the carob pod and some uses are presented in Table 4.

**Table 4. Main products derived from the carob pod (pulp and seed) and some major uses**

Product	Processing	Uses
<b>Pulp</b>		
Kibbles	Any	Animal feed (horses and ruminants)
	Milled	Human food and animal feed (ruminants and nonruminants)
Powder	Extraction and purification	Sugar and molasses
	Fermentation and distillation	Alcohol and microbial protein production
	Extraction	Tannins as antidiarrhoea
	Washing, drying, roasting and milling	Food ingredient; cacao substitute; preparation of dietary and pharmaceutical products
<b>Seed</b>		
Endosperm	Grinding	CBG or E-410; food additive (stabilizer and thickener); dietary fibre; pet food; pharmaceuticals; cosmetics
Embryo	Grinding	Germ meal; human and animal nutrition
Coat	Extraction	Tannins for leather tanning

Source: Battle (1997).

The pulp can be ground into a fine powder for use in human nutrition. Carob powder consists of 46% sugar, 7% protein and small amounts of numerous minerals and vitamins and is thus quite nutritious (Whiteside 1981). After oven-drying, the

powder can be added to cakes, bread, sweets, ice creams or drinks as a flavouring (NAS 1979; Vidal 1985; Fig. 9a). Carob powder 'cocoa' has advantages over chocolate in that it has fewer calories and neither caffeine nor theobromine (Whiteside 1981; Craig and Nguyen 1984). Its flavour is not as rich as dark chocolate but resembles milk chocolate.

Owing to the high sugar content of the pod and its relatively low cost, carob pulp was among the first horticultural crops used for the production of industrial alcohol by fermentation in several Mediterranean countries (Merwin 1981). In some countries, e.g. Egypt, carob syrup is a popular drink obtained by extracting carob kibbles with water. Single-cell organisms have been used to convert carob pulp into a high-protein feed; sugar solutions extracted from carob pods are an



a



b

**Fig. 9.** Carob products for confectionery (a), and carob trees used as ornamentals in Los Angeles, California (b).

excellent substrate for culturing fungi such as *Aspergillus niger* and *Fusarium moniliforme* and the dried mycelium is a palatable and nutritious feed containing up to 38% crude protein by weight (Imrie 1973; Sekeri-Pataryas *et al.* 1973).

Milled and chopped carob pomace, which are two by-products of the carob molasses industry, were tested in Lebanon as a potting medium for plants and have shown good promise as substitutes for peat-based mixtures in nurseries (Rishani and Rice 1988). The possible use by the food industry of natural antioxidants contained on the carob seed coat as a by-product of the CBG industry recently has raised some interest (Batista *et al.* 1996).

The carob product most widely used, especially for the food industry, is the carob bean gum (CBG), or locust bean gum (LBG). This gum comes from the endosperm of the seed and chemically is a polysaccharide, a galactomannan. By weight, about a third of the seed consists of gum and it is obtained from the kernel after removal of the coat and grinding. One hundred kg of seeds yields an average of 20 kg of pure dry gum (Jones 1953). Carob gum is produced in various degrees of purity depending on how well the endosperm is separated from the embryo and seed coat. Specks of cotyledons and testa are usually present in commercial CBG preparations. For use as a natural food additive, known as E 410, only high grade is admitted; for pet food more residues are allowed.

This mucilaginous gum, also known as 'tragasol', is used in a wide range of commercial products as a thickener, stabilizer, binder and gelling or dispersing agent. The food industry uses CBG for the production of a large number of different commodities: ice creams, soups, sauces, cheese, fruit pies, canned meats, confectionery, bakery products and pet foods. Technical applications of CBG include cosmetics, pharmaceuticals, film emulsions, paints, polishes, ceramics and adhesives (Salari 1982; Johnsen *et al.* 1988; Neukom 1988; Tous and Batlle 1990) and are summarized in Table 5. In the 1980s, CBG applications were: food industry (about 75%) and technical (about 25%); however, this has changed in the 1990s (because of a CBG price increase) to about 90 and 10%, respectively (Batlle 1997). Consumption of hydrocolloids in some European countries and the USA is presented on Table 6.

Carob is widely planted as an ornamental and shade tree on the streets of California, Australia and elsewhere; male trees are preferred as they do not provide litter from pod fall. However, the carob's value as a drought-tolerant, air-pollution tolerant, low-maintenance tree for street and landscape planting could be limited by the large mature size and strong, invasive roots (Coit 1951; NAS 1979). Carob is now being used in xerogardening in Mediterranean countries. And since it requires little if any cultivation, tolerates poor soils and is long-lived, carob tree is often recommended for reforestation of degraded coastal zones threatened by soil erosion and desertification. It also has been recommended for planting as a windbreak around orchards (NAS 1979; Esbenshade and Wilson 1986) and could even have some use for buffering noise from factories, roads and railways because of its dense foliage.

**Table 5. Carob bean gum uses and technical applications**

Industrial use	Applications
Pharmaceuticals	Anticoeliac products, pomades, pills, toothpaste
Cosmetics	Emulsions and foams, shaving foam
Textiles	Colouring thickener
Paper	Flotation product for recovering material; thickener for surface treatment
Chemicals	Glues, colouring, polishing, dyeing, matches, pesticides
Petroleum	Flocculation additive to increase stability and thickness of welling
Mining	Flotation product
Well sinking	Wall reinforcement, moisture absorbent
Concrete	To strengthen solidification
Explosives	Water binder for explosives

Source: Adapted from Droste (1993).

**Table 6. Hydrocolloids consumed (grams per person per year) as food additives in different countries**

Hydrocolloids	USA	D, F, I and UK†
Starch products	1300	1281
Gelatine	65	122
Agar-agar	2	3
Alginates	10	10
Carrageenans	11	18
Guar gum	34	39
Arabic gum	22	59
Carob bean gum (CBG)	8	18
Carboxy methyl cellulose (CMC)	23	6
Other cellulose derivatives	6	1
Xanthan gum	13	3
Pectin	11	19
Total	1505	1579

† D=Germany, F=France, I=Italy, UK=United Kingdom, and USA=United States of America.  
Source: Puhon and Wielinga (1996).

## 8 Genetic resources

### 8.1. Existing genetic variation

Wild carob trees are still frequently found in the most eastern Mediterranean regions and are naturalized in the west. Throughout the Mediterranean region wild or naturalized carob trees *in situ* were often used as stocks for budding with selected cultivars. In some areas, such as in Mediterranean Turkey or in the south of Spain and countries like Morocco, pods from ungrafted spontaneous trees are collected (Vardar *et al.* 1980; Ouchkif 1988; Batlle and Tous 1994).

Since antiquity, the cultivated carob has been propagated, first by seeds and later by budding too. Thus, carob cultivars originated from chance seedlings selected from local populations and later established in commercial orchards. Zohary (1973) pointed out that the cultivated carob has not diverged much from its wild ancestor. This may be true in some areas but certainly not in all as large morphologic differences in trees and fruit are observed. Carob seedling 'escapes' from plantations into the surrounding countryside are frequently observed.

Centuries of cultivation have resulted in a number of local cultivars differing in habit, vigour, size and quality of pods, seed yield, productivity, and pest and disease resistance. Most cultivars are of unknown origin and represent the germplasm of each region. In the world, fewer than 50 named cultivars of limited distribution are reported in the literature (Tous and Batlle 1990). Carob cultivars show high genetic variation in morphologic, agronomic and technologic characters. However, isoenzyme and DNA analyses have revealed low polymorphism between cultivars of different (Tous *et al.* 1992; Batlle *et al.* 1996) and the same origin (Barracosa *et al.* 1996). In addition, cultivated and naturalized carobs were isoenzymically similar (Batlle *et al.* 1996). This was unexpected as this species is more or less an obligate outcrosser. However, this lack of diversity suggests the narrow origin of the cultivated carob. Thus genetic drift and selection pressure which produce genetic erosion may have represented important drawbacks for the conservation of the genetic variability of this species. Isoenzymic differences in sex (female or hermaphrodite) or patterns of geographical variation were not observed (Tous *et al.* 1992; Batlle *et al.* 1996).

Female plants always have been selected in preference to the hermaphrodite ones, as they are better pod bearers. The most common cultivars in commercial orchards are female, only a few hermaphrodites having sufficiently desirable attributes. Hermaphrodites are never the main producing trees in orchards, and often, male pollinators are isolated seedling trees or branches left on the rootstocks after budding female cultivars. However, hermaphrodites are of interest as pollinators; some Italian types like 'Bonifacio' and 'Tantillo' were selected for this purpose (Russo 1954) and some Spanish types are being evaluated at IRTA's collection (Tous *et al.* 1996).

The main selection objectives have traditionally been large pod size and high pulp and sugar content. It is known that pulp and seed content show a negative

correlation. Thus growers have been selecting against seed yield which is currently more valuable commercially. For this reason some collecting from wild (naturalized) populations has been carried out in Andalusia, Spain (Batlle and Tous 1994; Tous *et al.* 1995) and should be undertaken in countries like Morocco and Turkey.

The most interesting features of the domesticated carob genetic resources are:

- low number (less than 50) and antiquity of named cultivars
- limited diffusion of cultivars, mainly local
- high genetic variation for some traits:
  - morphological (size, shape and colour of the pod, seed yield, etc.)
  - agronomical (vigour, habit, resistance to pest and diseases, productivity, etc.)
  - technological (flavour and sugar content, quality and gum content, etc.)
- low polymorphism for molecular markers (isoenzymes and DNA).

The main cultivars grown in Spain and in other countries are listed in Tables 7 and 8, respectively.

**Table 7. Main carob cultivars grown in Spain**

Cultivar	Growing areas	Estimated production	
		t	%
'Negra'	Tarragona, Castellón, Barcelona	24.726	18.31
'Matalafera'	Valencia, Alicante	13.110	9.70
'Duraió'	Majorca, Ibiza	9.062	6.71
'Rojal'	Tarragona	5.820	4.31
'Bugadera'	Majorca	4.600	3.40
'Costella d'Ase'	Majorca	3.750	2.80
'Mollar'	Murcia	3.200	2.40
'Lindar'	Alicante	2.072	1.53
'Melera'	Valencia, Alicante	2.053	1.50
'Sayalonga'	Málaga	1.650	1.20
'Comuna'	Alicante	1.647	1.20
'Boval'	Ibiza	1.250	0.92
'Del Pom'	Castellón	0.988	0.73
'Banyeta'	Castellón	0.710	0.52
'Borrera'	Alicante	0.693	0.51
'Cacha'	Valencia	0.490	0.40
'Banya de Cabra'	Barcelona	0.400	0.30
'Casuda'	Castellón, Alicante	0.354	0.26
Other cultivars		58.425	43.30
Total		135.000	100.0

**Table 8. Main carob cultivars grown in countries other than Spain**

Country	Region or district	Cultivar or type
Italy	Sicily	'Gibiliana', 'Racemosa', 'Saccarata'
	Apulia	'Amele di Bari'
Portugal	Algarve, Alentejo	'Mulata', 'Galhosa', 'Canela', 'AIDA'
Morocco	Fes, Marrakech, Agadir	ungrafted wild trees
Greece	Crete	'Hemere', 'Tylliria'
Cyprus	All islands	'Tylliria'
	Turkish area	'Koundourka', 'Koumbouta'
Turkey	Mediterranean coast	'Wild' and 'Fleshy' types
	Izmir	'Sisam' type
Tunisia		'Sfax'
Israel		'Tylliria', 'Sandalawi', 'Habati', 'Aaronsohn nos.'
USA	California	'Santa Fe', 'Clifford', 'Bolser', 'Grantham'
Australia	South Australia	'Bath', 'Irlam', 'Maitllan'
	Western Australia	'KP-1', 'Princess', 'Marshall no. 1'

Source: Tous *et al.* (1996).

Spanish cultivars are largely characterized by high pulp content and medium seed yield (8-10%). Some cultivars from the Balearic Islands give a high seed yield (16%) and spontaneous ecotypes from Andalusia even higher but the main cultivar 'Negra' yields only around 8%. Italian cultivars tend to have medium pulp and seed content. Most Portuguese cultivars produce medium to high (10-12%) seed yield and beans with round kernels well suited for gum extraction. In Cyprus, carob trees constitute a remarkably uniform group for some features but produce low to high seed content (8-15%) having relatively flat seeds, such as 'Tylliria' which is widely grown (Orphanos and Papaconstantinou 1969). In Turkey, where carob distribution is restricted to the coastal of the Aegean and the Mediterranean, three types of pods can be found (wild, fleshy and 'sisam' or intermediate) (Seçmen 1976). Turkish production is 70% wild type and the rest fleshy and 'sisam', which are considered as grafted (Vardar *et al.* 1980). In Crete, where Greek production is concentrated and carob trees grow wild and cultivated, there is a wide range of seed yield in cultivars. However, most bean production (around 80%) comes from 'Hemere' which gives a seed yield of 9% (Kalaitzakis *et al.* 1988). Spontaneous populations from Morocco produce high seed yielding (15%) pods with round kernels and scanty flesh (Ouchkif 1988). In Tunisia most trees are wild (Crossa-Raynaud 1960) so presumably seed yield would be high. The description of 27 cultivars is presented in Appendix I.



Information on the morphologic, agronomic and technologic characteristics of carob cultivars is scanty. Most are female and originated at least 100 years ago, presumably as seedling selections. Some work has been done on cultivar description and characterization (Da Matta 1952; Russo 1954; Goor *et al.* 1958; Coit 1967; Orphanos and Papaconstantinou 1969; Seçmen 1976; Vardar *et al.* 1980; Carlson 1986; Batlle 1985; Tous 1985; Spina 1986; Crescimanno *et al.* 1988; Marakis *et al.* 1988; Batlle and Tous 1990; Tous and Batlle 1990).

Carob cultivars vary widely in a number of characteristics which are of commercial importance to growers. Some important agronomic and commercial characteristics of the main carob cultivars are presented in Table 9.

To assess and select cultivars for commercial production in Mediterranean countries the following traits should be considered (Tous *et al.* 1996).

### **Sex**

On the basis of the flower structure male, female and hermaphrodite cultivars could be recognized. The female cultivars are the most important trees in commercial groves of Mediterranean countries. Males and hermaphrodites are normally used as pollinators. There is no agreement between the different authors on the best density of pollinators for commercial orchards. However, there is sufficient information to recommend around 12% (1:8) of pollinators distributed regularly (as in Fig. 7) (Tous and Batlle 1990). Hermaphrodites have a special value provided that they are self-fertile and/or cross-compatible, so that no space in the orchard needs to be wasted for unproductive male trees.

### **Resistance to environmental stress**

Carob trees grow best in calcareous soils, preferably near the sea. They are drought resistant but tolerate only light frost. Sensitivity to frost is a serious problem in this crop. The extent of frost damage depends on the temperature within the orchard and the physiological state of the trees. As several spells of frost have occurred in various places since records began, some cultivar differences have been observed. The Portuguese cultivar 'Galhosa' seems to be more cold tolerant than 'Mulata' (Brito de Carvalho 1988a). In Andalusia ungrafted local types known as 'Bravia' seem more tolerant than the grafted cultivars (Tous *et al.* 1995). Susceptibility to wind is revealed by broken branches after storms. It is related to wood health, tree shape and size and thus to cultivar and management.

### **Production (precocity, yield and alternate bearing)**

High yield is an important characteristic for farmers, but regular bearing also has to be considered as most cultivars show alternate bearing, such as 'Amele di Bari' in Italy (Crescimanno 1982), 'Tylliria' in Israel (Goor *et al.* 1958) and 'Cacha', 'Negra' and some hermaphrodite cultivars in Spain (Martorell 1987; Tous and Batlle 1990). In addition to these genetic traits, other factors affect yield, such as amount of pollination, cultural practices, environmental conditions (dry or irrigated orchard), etc.

**Table 9. Agronomic characteristics of main carob cultivars**

Cultivar	Origin	Sex†	Growth habit	Precocity	Resistance to fruit abscission	Susceptibility to <i>Oidium</i>	Podsize‡	Pod shape§	Pulp content¶	Sugar content in pulp(%)	Seed yield (%)††	Endosperm content (%)‡‡
'Negra'	Spain	F	open	medium	high	high	short	S	high	–	7-9	-
'Matalafera'	Spain	F	open	medium	low	low	medium-long	S	medium	–	12-14	58.0
'Duraio'	Spain	F	weeping	early	medium	medium	medium	S	low-med.	–	16-17	58.0
'Rojal'	Spain	F	erect	very early	low	low	long	C	medium	–	10-11	56.2
'Sayalonga'	Spain	F	open	early	low	low	long	C	medium	–	13-14	56.0
'Ramillete'	Spain	H	weeping	very early	high	medium	medium-long	C	high	–	8-10	50.6
'Banya Cabra'	Spain	F	open	late	medium	medium	long	T	low	–	13-14	54.3
'Gibiliana'	Italy	F	open	medium	high	medium	medium	C	high	38-40	8-10	53.1
'Amele di Bari'	Italy	F	erect	medium	low	low	medium	S	high	53-54	8	–
'Mulata'	Portugal	F	open	early	low	low	medium	C	medium	40-50	12-14	55.8
'Galhosa'	Portugal	F	open	late	medium	low	short-medium	S	low	–	14-16	58.3
'Tylliria'	Cyprus	F	erect	medium	high	medium	medium-long	C	high	51-52	8-11	49.0
'Koundourka'	Cyprus	F	weeping	–	low	low	short	S	low	49-50	14-15	58.0
'Hemere'	Greece	–	–	–	–	–	short-medium	C	high	56-57	–	–
'Sfax'	Tunisia	F	open	early	low	low	long	C	med.-high	51-52	9	47.2
'Santa Fe'	California	H	open	very early	medium	high	long	C	medium	47-48	10-12	–

† F=female; H=hermaphrodite. - ‡ Medium pod length about 15 cm. - § S=straight; C=curved; T=twisted. - ¶ Pulp dry weight. - †† Medium seed yield=10%. - ‡‡ % of seed dry weight.

Source: modified from Tous *et al.* (1996).

The trait precocity is highly desirable in carob to reduce the otherwise unproductive vegetative phase of the first years and to pay off quickly the costs of establishment. Some cultivars start to bear early, 4 to 5 years after budding ('Rojal', 'Ramillete', 'Mulata', 'AIDA', etc.), while others bear some years later ('Banya de Cabra', 'Cacha', 'Sandalawi', etc.). Regarding the vegetative period of cultivars held in Spanish carob collections it was observed that the hermaphrodite types normally bear sooner (2nd to 3rd year after budding) than female cultivars (Navarro 1992; Tous *et al.* 1993, 1996). Graça (1996), in trials with 'Mulata' in the Algarve, Portugal, budded the year before planting, obtained significant pod production (11.2 kg/ha) 5 years after establishment. Most cultivars begin bearing early when orchard management and rainfall, or supplementary water, are adequate.

### **Fruit quality (pulp and seed)**

The quality of beans depends mainly on the seeds and the pulp in which the seeds are embedded. Seeds are currently the most important part of the pods as they are used to extract the valuable carob bean gum (CBG). Pulp value depends on its use (livestock feed or human food industry) and the contents of sugar, fibre, tannins and flavour (Coit 1961). Chemical composition of carob pods differs widely according to cultivar and climate. Thomson (1971) found in 40 cultivars the following percentage ranges by weight at 10% moisture: total sugars (37-62%), crude protein (2.2-6.6%), crude fibre (4.2-9.6%) and ash (1.5-2.4%). Pods also contain from 0.46 to 1.46% crude fat (Binder *et al.* 1959) and 2.6-6.7% tannins by dry weight (Louca and Papas 1973; Marakis *et al.* 1988).

The pulp is the main constituent of the pod. Pulp content in the pod ranges from 73 to 95% (Caja *et al.* 1988; Crescimanno *et al.* 1988; Marakis *et al.* 1988), with corresponding seed contents. Seed yield is an important fruit characteristic that varies with climatic and soil conditions but is also strongly cultivar related (Brito de Carvalho 1988a). Wild carobs have produced higher seed yield than cultivated (Marakis *et al.* 1988; Di Lorenzo 1991; Tous *et al.* 1995). In Mediterranean cultivars the variation recorded ranges from 5 to 27% (Caja *et al.* 1988; Crescimanno *et al.* 1988; Marakis *et al.* 1988). Albanell *et al.* (1996) observed that number of kernels per pod is more important than length or weight and in relation to gum content they found that seeds should be heavy, thick and short.

The content and quality of gum are also important features. They vary with climate, soil and cultivar (Brito de Carvalho 1988a). Endosperm, from which the gum is derived, ranges from 42 to 60% in dry weight (Albanell *et al.* 1988; Crescimanno *et al.* 1988). Ungrafted trees seem to produce seeds with more gum content than cultivars (Marakis *et al.* 1988). Gum content differs considerably between cultivars. Under the same environmental conditions cultivars 'Duraio', 'Matalafera' and 'Galhosa' produce more gum than 'Rojal', 'Melera' and 'Negra' (Tous *et al.* 1996). There are also cultivar-related differences in gum quality, especially regarding viscosity grade, gel strength and content of galactomannans. The current trend is to grow good dual-purpose cultivars (pulp and kernel), so that high production of carob kernel can be avoided in the future to stabilize the CBG market.

Pulp flavour is also an important consideration for carobs grown for the food industry. A test on pulp flavour of 31 cultivars, ranging from 37.1 to 51.6% of total sugar (reported as glucose), indicated that flavour preference is not directly related to high sugar content. The hermaphrodite cultivar 'Santa Fe' was rated highest; it has a sweet, nutty flavour and high sugar content (47.5%) (Binder *et al.* 1959). Carobs of the better cultivars contain 45-55% of total sugar; poor cultivars contain 35-45%.

### **Ease of harvesting**

Harvesting is the major cost in carob production owing to the expensive and scarce labour in most developed countries. Manual harvesting of the pods represents 30-35% of the total production cost for an orchard (Orphanos 1980; Tous 1995b). This cost can be divided between knocking (or shaking) and collecting operations. Knocking is a traditional operation performed with thin long poles to knock down ripe pods. Manual or mechanical harvesting by trunk shakers and manpower shakers is affected by size and growth habit of the trees, pod distribution in the branches and pod abscission. Collecting operations depend on yield, size and shape of pod, and orchard density. The main aim for new carob orchard establishment should be mechanical harvesting. Some agronomical features of the tree are important to improve mechanical harvesting of carob.

### **Tree vigour and growth habit**

Current cultivars, especially when well-managed in warm coastal climates, can reach a large size (6 m high) and the fruit-bearing branches usually droop, obstructing trunk shakers used in mechanical harvesting. Small trees make harvest easier. In respect of growth habit there are big differences between cultivars (Table 9, Fig. 10). The current need, if shakers are to be used, is to grow trees (orchard density about 150 trees/ha), which are reduced in size, with upright growth habit and rigid fruit-bearing branches (Tous *et al.* 1996).

### **Fruit ripening and abscission**

The physiological ripening of the pods starts in May-June and is a gradual process closely related to natural fruit drop. These two phenomena can affect harvest efficiency. Some cultivars are more prone to fruit abscission than others when knocked or shaken. For example 'Matalafera', 'Rojal', 'AA2' and 'Banya de Cabra' are more prone to abscise pods than 'Negra', 'Tylliria' and 'Ramillete'. Generally, hermaphrodite types need greater force for fruit removal than female cultivars (Tous 1985).

The main consideration should be to choose cultivars that produce pods which ripen simultaneously during the period of maximum abscission, to ease collection from the ground. Early ripening cultivars would avoid not only flower damage with the sticks but also rainfall which is frequent at harvesting time (September-October) in Mediterranean countries.

**a****b****c**

**Fig. 10.** Growth habit: upright – cv. 'Rojal' (a), open – cv. 'Matalafera' (b), and weeping – cv. 'Duraió' (c).

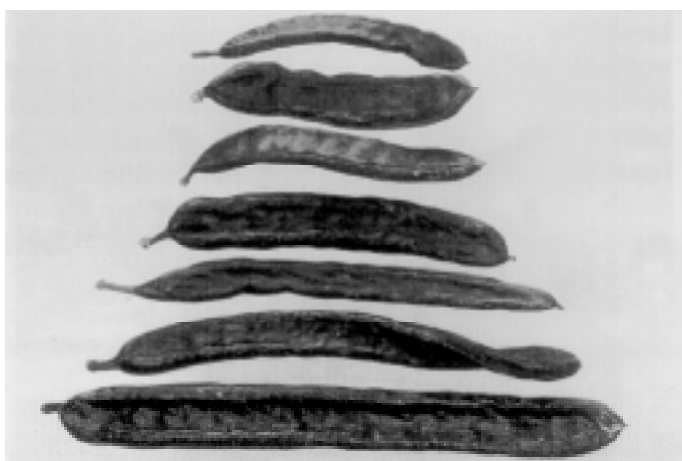
### Fruit shape and size

Carob bean size is a highly variable character influenced by many environmental factors as well as level of pollination and fruit set. Generally, grafted cultivars produce larger fruits than unselected wild types. This trait eases both manual and mechanical harvesting. Pod shape is also highly variable (Table 9, Fig. 11). For easier and cheaper collection, straight fruits are preferred to curved or twisted pods (Brito de Carvalho 1988a). The easiest pods to collect are large and straight. Carob pod size is also important for resistance to strong winds in spring to prevent premature fruit drop.

The most promising female cultivars studied at IRTA are: 'Rojal', 'Duraió', 'Mulata', 'AIDA' and 'Sayalonga'. Other cultivars like 'Banya de Cabra', 'Matalafera', 'Galhosa' and 'Tylliria' also show some commercially interesting characteristics (Tous *et al.* 1996). As promising hermaphrodite pollinating cultivars, 'Clifford', 'Santa Fe', 'Ramillete' and 'A-19' can be considered. Some outstanding cultivars from different origins like 'Amele', 'Sfax', 'Tylliria', 'Casuda', 'Santa Fe' and 'Clifford' perform well in many countries. This shows that carob cultivars are able to adapt outside their region of origin.

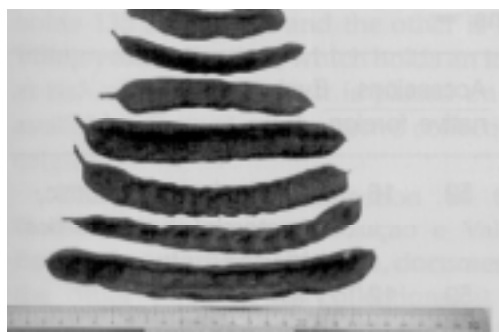
### 8.2 Conservation

The main aim is conservation of variability through a wide range of different genotypes and, less so, individual genotype preservation. Currently, there are eight field carob collections in the world (Table 10, Appendix II). The best documented is maintained at IRTA-Mas Bové, Spain and is supported by the Spanish Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA). This Germplasm Bank comprises field collections placed in two sites, Reus and Tortosa (80 km away), with two types of Mediterranean climate (Tortosa is warmer than Reus). Altogether 93 cultivars and selections from eight origins are held for evaluation. There is some duplication to safeguard against frost damage.



**Fig. 11.** Variation in pod morphology of carob types from Greece (a) and Andalusia, Spain (b); and of cultivars: 'Negra' – Spain (c), 'Matalafera' – Spain (d), 'Mulata' – Portugal (e), 'Rojal' – Spain (f), 'Ramillete' (hermaphrodite) – Spain (g), 'Banya de Cabra' – Spain (h), and 'Banya de Marrà' – Spain (i).

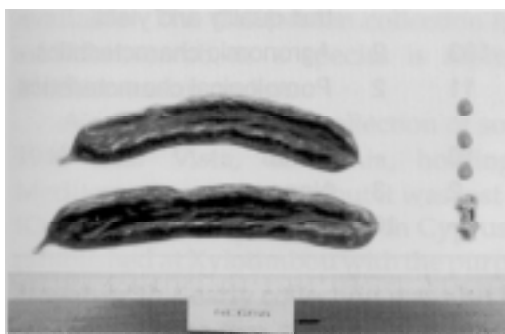
a



b



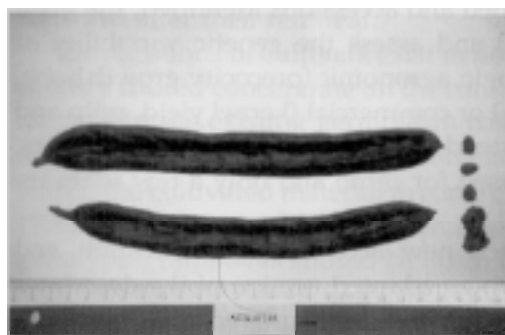
f



c



g



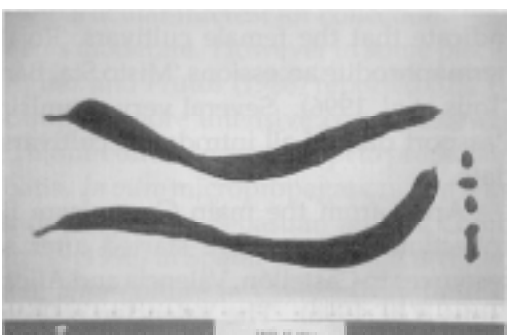
d



h



e



i

**Table 10. World carob germplasm collections**

Country	Place, district†	Area (ha)	Planting year	Accessions		Evaluation
				native	foreign	
Spain	Reus, Tarragona	1	1987	52	16	Phenological, agronomic, commercial characteristics and yield
	Tortosa, Tarragona	0.8	1989	59	12	Yield
	Palma, Majorca	0.5	1990	39	1	Phenological characteristics, fruit quality and yield
	Villajoyosa, Alicante	1.5	1986	133	2	Agronomic characteristics
Portugal	Tavira, Algarve	0.5	1988	11	2	Pomological characteristics and yield
Tunisia	Ariana		1950	10	–	None
USA	San Diego, California		1960	2	3	None
Australia	Loxton, S. Australia	0.3	1985	–	10	Yield

† For full addresses see Appendix II.  
Source: modified from Tous *et al.* (1996).

Once the field collections were established and accessions identified, the main aim has been to characterize the material and assess the genetic variability of important characters, particularly morphologic, agronomic (precocity, growth habit, production, pest and disease resistance, etc.) or commercial (kernel yield, pulp and gum quality, etc.). Such studies could be extended by trials with selected cultivars. However, this approach has hardly been used for carob and only a few trials are known.

After recording passport data for each new accession, identification and characterization are carried out according to an adapted version of the descriptor list developed by the authors and completed with isoenzyme records (Tous *et al.* 1992; Batlle *et al.* 1996). So far, in the 1995-96 cropping year 15 cultivars have started bearing at Reus and 6 at Tortosa. The preliminary results (8th year after budding) indicate that the female cultivars 'Rojal', 'Banya de Cabra' and 'Ralladora' and hermaphrodite accessions 'Misto Sta. Bárbara', 'Ramillete' and 'A-19' are promising (Tous *et al.* 1996). Several very promising cultivars have yet to be fully assessed. Passport data of all introduced cultivars are available as well as some evaluation data.

Apart from the main Germplasm Bank at IRTA, Spain has two other carob collections. They were started after surveying and cataloguing carob genetic resources in Castellón, Valencia and Alicante (Navarro 1992) and the Balearic



Islands (Tous *et al.* 1996). The Valencian collection is located in Villajoyosa, Alicante and holds 135 accessions and the other is in Palma, Majorca with 40 accessions. The Villajoyosa collection, which holds an important number of hermaphrodite types, is at risk of being lost as it is placed on private land and accessions are not freely available. Records of these two collections are scarce and generally limited to their origin.

The carob field collection of the Associação Interprofissional para o Desenvolvimento da Produção e Valorização da Alfarrova (AIDA) in Tavira, Portugal contains 13 cultivars, documented with passport and evaluation data. For the other three living collections, it should be noted that only very limited information is available. In the Tunisian collection at INRAT Ariana, Crossa-Raynaud (1960) reported that at least one tree of the local cultivar 'Sfax' was still available. The Californian collection is kept in a public garden at San Diego. In addition, carob as a species is represented in most botanical gardens of the Mediterranean region.

A carob germplasm collection of some 60 clones was assembled by J.E. Coit in 1949 near Vista, California, holding both North American selections and Mediterranean cultivars, but it was lost in the 1970s owing to housing development (Coit and Rittenhouse 1970). In Cyprus, in the 1950s a large cultivar collection was established at Xylotimbou with the purpose of cultivar characterization (Ticho 1958). However this early collection was also lost some decades later (P.I. Orphanos, pers. comm.). These two genebanks were the first recorded attempts to maintain and characterize carob genetic resources in the world and presumably some accessions were lost after their removal.

Duplications of cultivars exist in field collections but not of wild material. Each country should concentrate on the conservation of its native resources. Information on gaps in the existing germplasm collections is largely unknown. However the expected genetic variation contained in heterogeneous species has not been found within the cultivated material in some *ex situ* collections (Tous *et al.* 1992; Batlle *et al.* 1996). As most of the remaining carob natural populations contain high seed yielding genotypes, initiatives should be taken to conserve this potentially interesting wild material. Among the gaps, the lack of any wild material from Morocco and Turkey is probably the most important. The existing naturalized populations of the south of Spain were surveyed and genotypes collected recently (Batlle and Tous 1994; Tous *et al.* 1995). Hermaphrodite genotypes are of particular interest for collection.

The threat of genetic erosion on carob seems moderate. However in some places like Murcia in the southeast of Spain, Rodriguez and Frutos (1988) reported 37% of trees lost, mainly due to replacement of carob by more intensive crops in newly irrigated areas. Vinterhalter *et al.* (1992) used tissue culture in an attempt to propagate genotypes which were almost extinct in Croatia. *In vitro* micropropagation, as a way of conserving outstanding trees, has been developed by Sebastian and McComb (1986) in Australia and by Alorda and Medrano (1996)

in Spain. Androulakis (1994) attempted to propagate selected types by *in vitro* culture in Crete. Only limited success has been achieved using these methods.

The wild species *C. oreothauma* (with its two subspecies) is not represented in the existing field collections. It is only conserved *ex situ* as a few potted trees in a greenhouse at The Royal Botanical Gardens Kew, in London, England. It was botanically studied by Hillcoat *et al.* (1980) in its native ranges. In 1991 a collecting expedition in the mountains of northern Oman was carried out by IBPGR in collaboration with the Ministry of Agriculture, Fisheries and Food of that country; 6 accessions were collected (IBPGR 1992).

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## 9 Genetic improvement

To date, improvement of carob cultivars has been carried out only empirically by growers selecting promising chance seedlings and budding them onto less fruitful genotypes as rootstocks. The lack of any planned carob breeding programmes may be due to its relatively minor importance. Breeding programmes mean considerable costs associated with raising and selecting progenies, and as more than 8 years may elapse from seed to flower, progress can only be slow. In due course the use of molecular markers, particularly for sex, could speed early selection and thus the process. However, the breeding system including pollination mechanisms and expression of sexuality in response to environmental conditions is not well understood.

Clonal variability in old carob cultivars could be exploited by selecting the best clones which have accumulated different spontaneous mutations over a long period of time. Clonal selection is a valuable approach when used for a cultivar which has achieved commercial success. In Spain, some work is underway with 'Rojal'. It might also be interesting to make some clonal selection in cultivars like 'Duraió' if morphologic or agronomic variation is observed.

### 9.1 Breeding objectives

The chosen objectives will depend on the use envisaged for the resulting cultivars. The main challenges for carob improvement are: to reduce vegetative period (i.e. increase precocity in bearing) and to increase cold hardiness, and pod and seed yield. Other features like vigour, productivity, uniform ripening, easy harvesting, kernel size and shape, content and quality of pulp and gum are also important.

Some differences in cold tolerance appear between carob genotypes (Brito de Carvalho 1988a; Tous *et al.* 1995), but as reported in the Genetic Resources section, there are no records of deliberate collection of types from the colder places. This variability has not been exploited and may not be enough to select adapted types for different environments and crossing. Wider adaptation through interspecific hybridization seems difficult to achieve as hardy carob-related species are unknown.

### 9.2 Breeding methods

Conventional breeding by controlled crosses has not been reported in carob, only empirical selection by growers looking for productive trees of sweet and fleshy pods in the wild. Identification and propagation of superior phenotypes in natural populations of chance seedlings, mainly based on seed yield performance, is an alternative as in some regions of Morocco and Turkey large wild populations still remain untouched.

As carob is largely a dioecious species, genetic improvement for fruit characters is hampered by lack of information for the male parent regarding these characters. However the use of hermaphrodite types to cross together or with female cultivars seems feasible so that both potential parents could be chosen after fruit assessment.

Mass selection after intercrossing the best individuals on the basis of their phenotypes would be the simplest method. This is based on the relatively high additive variance affecting the inheritance of most traits in fruit and nut trees (Bringhurst 1983). No inheritance of a character has been described in carob. Choice of parents with complementary characters from diverse geographical regions and available in *ex situ* collections should be criteria to be considered.

Information on pollen and seed management, hybridization and handling seed populations has not been reported for carob, and thus should be adapted from other fruit and nut tree crops. Pollen collection is easy and it seems storable in a fridge for several months (M. Rovira, pers. comm.). Pollen application with brush or fingers is feasible, flower insect exclusion is necessary. Seed germination and tree raising are described in the Agronomy section

Interspecific crosses between *C. siliqua* and *C. oreoethauma* have not been reported, but would be worth trying. Both species have the same chromosome number ( $2n=24$ ) (Hillcoat *et al.* 1980). However, knowledge about *C. oreoethauma* and its genetic potential is still very limited. As *C. oreoethauma* is adapted to higher altitudes (1500-1800 m asl) than carob, Hillcoat *et al.* (1980) suggested that a cross between them would produce a more useful forage plant. However, *C. oreoethauma* may be less hardy than carob (J.H. Brito de Carvalho, pers. comm.) in which case any hybrids are likely to be hardy. As rooting potential is inherited and, if *C. oreoethauma* shows higher rooting potential than carob, it would be incorporated through hybridization, but hybrid seedlings would only be useful if are hardy and show good adaptation.

## 10 Production areas

As indicated earlier carob production has a long tradition, mainly for animal feeding, in most countries bordering the Mediterranean sea. It is thought the Greeks and Arabs were responsible for the spread of carob within the Mediterranean basin from the Near East. More recently, it was introduced in different periods in some warm semi-arid zones of Australia, California, Arizona, Chile, Mexico, South Africa, etc. However, commercial carob production is currently concentrated in the Mediterranean region.

The total carob-production area in the world is around 200 000 ha (Table 11) of which the southern countries of the European Union (Spain, Italy, Portugal and Greece) with some 148 000 ha account for 74% of the growing area and about 70% of the world production (Table 12).

**Table 11. Area of carob in producing countries**

Country	Area (ha)	% of total production
Spain	82 000	41.0
Italy	30 000	15.0
Morocco	25 000	12.5
Portugal	21 000	10.5
Greece	15 000	7.5
Cyprus	12 000	6.0
Other†	15 000	7.5
Total	200 000	100

† Algeria, Australia, South Africa, Turkey, USA, etc.  
Source: Batlle (1997).

Commercial world production of carob pods is estimated currently around 310 000 t, and it is mainly concentrated in Spain, Italy, Portugal, Morocco, Greece, Cyprus, Turkey, Algeria and other countries (Table 12). There is some production in Croatia, Tunisia and Malta and small amounts are also produced in Australia, California and South Africa. Pod and seed production in different countries are not parallel because of differences in seed yields of cultivars and wild types.

Carob production in the world has declined dramatically over the past 50 years, from 650 000 t in 1945 (Orphanos and Papaconstantinou 1969) to 310 000 t today. In Spain alone, production has fallen by 400 000 t, from 550 000 t in 1930 to 150 000 t in 1990 (MAPA 1994). The main reasons are low prices coupled with farming mechanization and coastal planning development. Farmers' interest in carob in most Mediterranean countries diminished because of low pod prices and home consumption, and use of coastal land for roads, housing development and industrial estates (Batlle 1997).

**Table 12. World carob pod and seed production**

Country	Pod production		Seed production	
	t	%	t	%
Spain	135 000	43.5	12000	37.5
Italy	45 000	14.5	4000	12.5
Portugal	30 000	9.7	3600	11.3
Morocco	26 000	8.4	4800	15.0
Greece	20 000	6.5	1800	5.6
Cyprus	17 000	5.5	1700	5.3
Turkey	15 000	4.8	1800	5.6
Algeria	7 000	2.3	800	2.5
Other†	15 000	4.8	1500	4.7
Total	310 000	100	32000	100

† Australia, South Africa, USA, etc.

Source: Authors' compilation.

In the past, carob expansion in Spain took place in two main phases: first the agricultural development during the 17th century when marginal lands were brought into use, and later when vineyards were pulled out because of a phylloxera outbreak in the 19th century and were replaced by this crop in coastal areas (Tous and Batlle 1990). The largest growing area (190 000 ha) was reached in the 1930s (MAPA 1994). Spanish production has halved between 1970 and 1995 (MAPA 1994). The current Spanish growing area and production (82 100 ha and 135 000 t) is distributed in five regions: C. Valenciana (54 200 ha and 60 500 t), Catalonia (12 700 ha and 28 000 t), Balearic Islands (12 200 ha and 30 500 t), Andalusia (1000 ha and 11 000 t) and Murcia (2000 ha and 5000 t) (MAPA 1994). There are estimated to be 182 000 isolated trees (not in orchards), some of which are intercropped with other species such as almonds, olives, figs, grapevines, etc. An important number of naturalized trees thrive in Andalusia.

Carob production in Italy (45 000 t) is mainly located in the island of Sicily (provinces of Ragusa, 21 000 t; Siracusa 11 000 t; elsewhere, 5000 t) and the mainland (Apulia and Campania, 8000 t). Production in Sardinia is negligible. Italian production has halved between 1955 and 1995. The current tendency is to reduce the area (Licitra 1996).

The carob-growing region in Portugal is concentrated in the south with some 21 000 ha and 30 000-35 000 t of production, depending on years (Droste 1993). The Algarve is the main producing region and around 60% of the total surface is located in four places: Silves (3200 ha), Faro (3000 ha) and Loulé and Tavira with 2500 ha each. In the Alentejo region there are also some orchards in Mértola (100 ha)

(Martins-Loução and Brito de Carvalho 1989). The Portuguese carob production has declined over the past 20 years and the area under cultivation has reduced by at least 25% (Droste 1993).

Carob production in Morocco has increased over the last 15 years and it is estimated to be about 26 000 t (Batlle 1997). The main spontaneous populations are concentrated in the regions of Tafechma in the north and Ait Ishaq in the south (Ouchkif 1988). However, three areas are commercially known: Fes, Marrakech and Agadir. Acreage of spontaneous carob in Morocco is estimated around at 30 000 ha. Carobs thrive together with a number of other species of the maquis (*Pistacia*, *Olea*, *Quercus*, etc.). Some new orchards have recently been planted and Moroccan production is expected to rise moderately in the coming years. Carob pod production in Tunisia is also from spontaneous trees and was estimated in the 1950s to be about 2800 t (Crossa-Raynaud 1960); however, no records are available since then.

Total Turkish production is about 15 000 t, which is collected from isolated trees (360 000) as there are no carob orchards. The production is concentrated along the coast in the Aegean (4%) and Mediterranean (96%) regions from Urla (Izmir) to Samandag (Hatay) (Vardar *et al.* 1980). The main producing provinces are İçel, Antalya, Mugla, Adana, Burdur and Aydin.

In Israel, Goor *et al.* (1958) reported some 250 000 carob trees scattered in forests. In the early 1950s about 2000 ha were planted either as groves, on grazing land, as forests or as roadside trees. Currently some plantings are still productive but the tonnage seems to be decreasing.

In California during the 1950s there was a well-publicized 'Carob crusade' promoting this species as a dryland crop needing little irrigation, and several plantings were made throughout the south. However, mainly owing to low productivity of the tree under dryland culture and the high cost of land and processing, the project failed (Coit and Rittenhouse 1970; Ferguson and Arpaia 1990).

In Australia, the crop was introduced around 1850 by Mediterranean emigrants. However, it was only in the 1980s that interest in carob led to planting some orchards, mainly in Western and South Australia but also in New South Wales and Victoria. The Australian carob-growing area is only about 170 ha and there are also some 30 000 isolated trees. Its production is estimated to be around 750 t per year (Tous 1995a).

## 11 Ecology

The carob is a long-lived evergreen and thermophilous tree thriving in habitats with mild Mediterranean climates. It grows well in warm temperate and subtropical areas, and tolerates hot and humid coastal areas. Carob and orange trees have similar temperature requirements but carob tolerates poorer soils and needs much less water. The carob tree is more tender than the olive. For resistance to dry environments it is surpassed only by pistachio (Evreinoff 1955). It is also a xerophytic species well adapted to the ecological conditions of the Mediterranean region, by virtue of its efficient hydric regulation by stomatic adjustment and its foliar structure and anatomy (Catarino *et al.* 1981). Leaf wax synthesis increases in dry conditions reducing cuticular permeability and thus protecting the plant from excess transpiration (Baker and Procopiu 1980). Carob, together with *Pistacia lentiscus* L. and *Olea europaea* L. var. *sylvestris*, forms one of the most characteristic associations of the lowest zone of the Mediterranean vegetation and thus is considered to be a climax community (*Oleo-Ceratonion*).

Like other Mediterranean species with long-lived leaves and an extended flowering period, mechanisms have evolved that optimize water, carbon and nitrogen use for reproduction (Correia and Martins-Loução 1995). Several studies have shown that carob trees can maintain stomata open and high leaf water content even under low soil water availability (Nunes *et al.* 1989). This is allowed by a sharp reduction of leaf water potential in response to small water losses (Lo Gullo and Salleo 1988).

The two main growing flushes are in spring and autumn as in most Mediterranean trees. Vegetative growth slows below 10°C. Thus, it seems that this species enters some kind of 'light' dormancy, at least in most cool latitudes. However in some very warm places and under favourable conditions, carob grows without becoming dormant either in winter or summer (Liphshitz and Lev-Yadun 1988). The cambium can be active throughout most of the year (Fahn 1953), or all year with low rates of activity in January (Arzee *et al.* 1977). Investigations on the annual rhythm of cambial activity in Italy by Scaramuzzi *et al.* (1971) showed that cambium is active from February to the end of September and inactive during winter months owing to low temperatures.

The rooting habit of carob is similar to pistachio; its extensive root system penetrates the soil deeply. Carob develops roots under stressful conditions to explore deeper soil layers where water may be available (Christodoulakis 1992). It can thus survive long periods of drought. In addition, Nunes *et al.* (1989) reported that carob leaves can maintain turgor under situations of soil drought, using different strategies according to the season.

Although the carob tree is a legume, like most Caesalpinioideae it does not nodulate and thus is unable to fix nitrogen (Martins-Loução and Rodríguez-Barrueco 1982; Martins-Loução 1985). Arbuscular mycorrhizal (AM) fungi have been shown to colonize carob roots, but no ectomycorrhizal association was found (Martins-Loução *et al.* 1996b). The colonization by AM can increase nitrogen uptake



by the plant. Since carobs often grow on nutrient-deficient soils lacking nitrogen and phosphorus in particular, AM fungi can improve nutrition.

### 11.1 Climate requirements

Areas suitable for carob should have a subtropical Mediterranean climate with cool, not cold, winters, mild to warm springs, and warm to hot dry summers. These Mediterranean-like areas range from approximately 30° to 45° in northern latitudes (Mediterranean basin, California and Arizona) and between 30° and 40° in southern latitudes (Australia, South Africa and Chile).

Adult trees require no winter chilling; they can be damaged when temperatures fall below -4°C and can only withstand winter temperatures of not lower than -7°C. However, trees can withstand summer temperatures of 40°C and hot dry winds. From 5000 to 6000 hours above 9°C are needed for pods to ripen. Strong winds can break adult tree branches and detach pods. Wind can also damage young trees (Tous and Batlle 1990). Autumn rains can interfere with pollination and affect fruit set. High humidity in spring promotes *Oidium* infection on both leaves and pods.

### 11.2 Soil requirements

Carob trees can adapt to a wide range of soil types from poor sandy soils and rocky hillsides to deep soils, but they cannot withstand waterlogging although the root system is usually deep. In areas with shallow rocky soils, tree size and productivity are reduced. The best soils are sandy well-drained loams but calcareous soils with high lime content are also suitable. Carob also appears to tolerate salinity well (Rebour 1971). Winer (1980) reported tolerance to a soil salt content of up to 3% NaCl.

### 11.3 Water requirements

Carob, as a xerophyte, can survive dry climates without irrigation and is well adapted to dry environments with annual average rainfall between 250 and 500 mm per year (Tous and Batlle 1990). It has developed some drought-resistance mechanisms (Nunes *et al.* 1989; Salleo and Lo Gullo 1989) as mentioned in the Agronomy section. Although drought resistant, carob trees do not bear commercial crops unless they receive at least 500-550 mm per year (NAS 1979), but 350 mm of annual rainfall are considered enough for fruit set (Coit 1949; Ticho 1958; Crescimanno 1982).

## 12 Agronomy

### 12.1 Propagation

Carob rootstocks are raised from open-pollinated seeds and these seedling rootstocks vary widely in vigour, habit and cold resistance. No rootstock trials have been carried out and no rootstock selections are available. It is essential that rootstocks produce a well-developed rooting system. The seedling stocks should be budded 1 year after germination, in the nursery, or 2 years from germination, after planting in the orchard. Vegetative propagation by cuttings is not yet commercially available. Young seedlings are very sensitive to frost damage and thus in frosty places they should be protected.

#### Seed germination

The seeds used for sowing should be completely ripe and extracted from pods of the last harvest. Sowing should be done early in the spring, about March-April. Before sowing, the light, empty or wormy seed should be removed; this can be done by soaking in water when most of the faulty seeds float on the surface and can be easily removed. Although carob seeds have remained viable for as long as 5 years stored dry at low temperatures in sealed containers (Goor and Barney 1968; Hong *et al.* 1996) it is advisable to use seeds from the current season. Seeds are presumably viable after passing through an animal's digestive tract.

Carob seeds germinate easily, but as the coat is very hard they require scarification with acid or hot water treatment. Germination can be hastened by treating them with tap water, boiling water, sulphuric acid ( $H_2SO_4$ ) or gibberellic acid ( $GA_3$ ). Carob seeds do not need to be kept in a cold store to break dormancy. At IRTA-Mas Bové good results were obtained using fresh seed sown in March-April, with any of the following methods or combinations of methods:

- soaking in tap water at room temperature for 15 days
- soaking in boiling water, stirring briskly for 10 minutes and then immersion in cold water for 24 hours
- soaking in concentrated sulphuric acid for 1 hour and then rinsing with tap water to prevent complete digestion of the seed coat
- soaking in gibberellic acid (25 ppm) for 24 hours.

Frutos (1988) scarified carob seeds with sulphuric acid solutions (10, 20, 30, 40 and 80%) for 30 minutes and then soaked them in water for 24 hours and placed them in Petri dishes at 23°C; he obtained the best germination (99.1%) using sulphuric acid at 80%. However, he observed no effects on seed germination after treatment with  $GA_3$  at 50, 100, 200 and 400 mg/L for 24 hours. After treatment and washing, seeds are usually soaked for another 1-2 hours before planting and are sometimes surface-sterilized with dilute bleach. After soaking, water is drained away and the seeds are sown either into polyethylene trays on greenhouse benches and kept at 20-30°C or directly into tall plastic pots (12-15 cm diameter and 35-40 cm deep) placed outside under shading.

Optimum temperature for carob seed germination was found to be 25°C by De Michele *et al.* (1988) and 27.5°C by Mitrakos (1981). However, in its native ranges when these temperatures prevail (June-September) no water is available. It seems likely that some germination occurs naturally in November and seedlings survive when winter is mild (Mitrakos 1988). There is good evidence from Hillcoat *et al.* (1980) that the optimum temperature for *C. oreoethauma* seed germination is similar to that reported for carob. Work on the effect of water stress on germination has been done by Spyropoulos and Lambiris (1980).

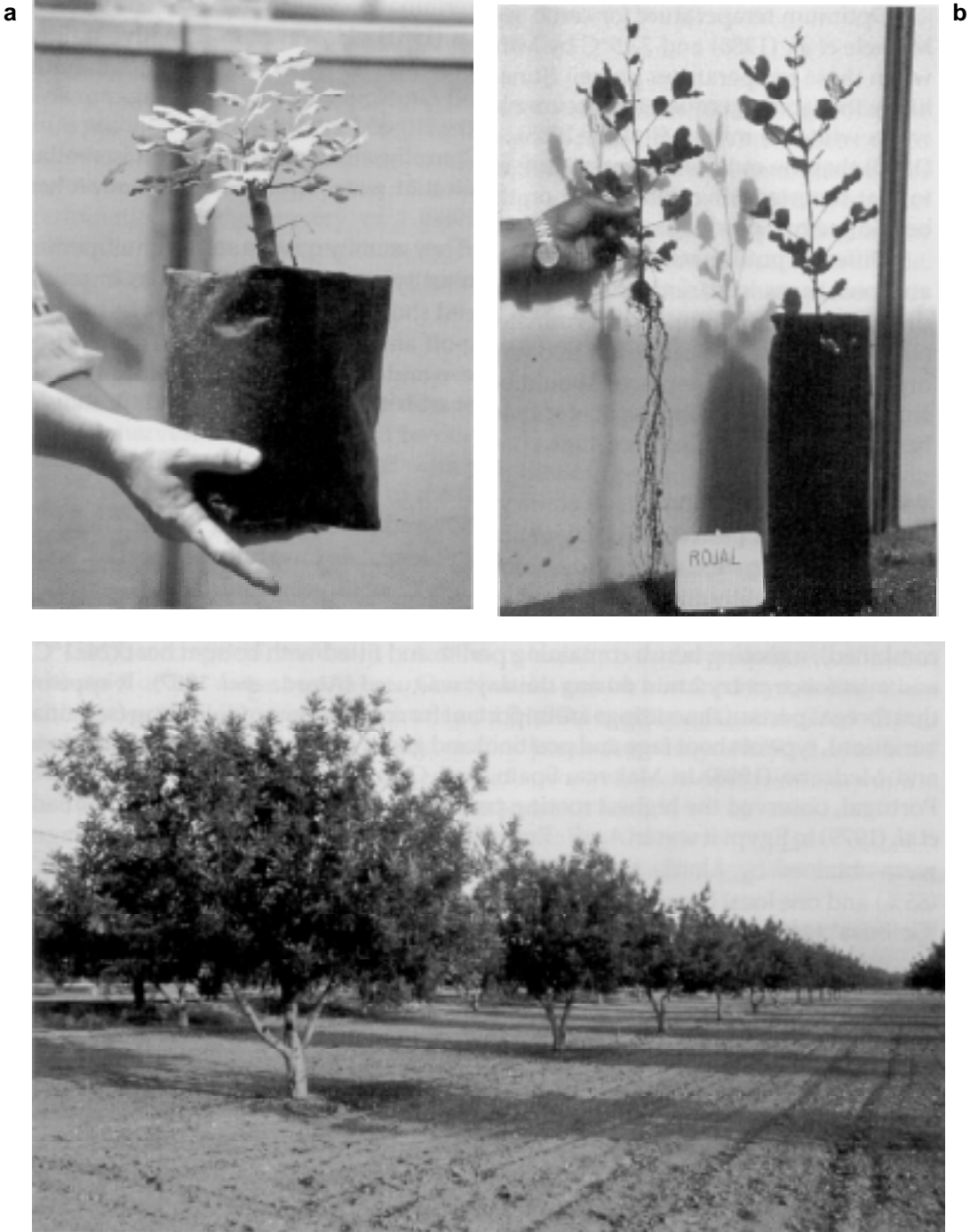
Different potting mixtures can be used. They usually contain soil, humus, perlite and peat moss in various ratios, and are usually amended with sand to improve drainage and structure. The germinated seed should be watered regularly, but not overwatered, as this can result in damping-off and root rot diseases. The benches on which the trays are placed should be clean and sterile, as several pathogens can survive on dirty benches and infect young carob rootstock seedlings. Care should be taken when handling seedlings.

### Vegetative propagation

Carob has been described by Lee *et al.* (1977) and Hartmann and Kester (1983) as difficult to root. Its adventitious rooting potential is low, but rooting has been obtained on subterminal hardwood cuttings (2 or 3 years old) (Fig. 12a), after treatment with sulphuric acid and a high concentration of hormone (IBA or IBA combined); a rooting bench containing perlite and fitted with bottom heat ( $24\pm 1^\circ\text{C}$ ) and mist (once every 2 min during the day) was used (Alorda *et al.* 1987). It appears that three aspects of the cuttings are important for rooting: time of collecting (seasonal variation), type of shoot (age and position) and genotype (rooting potential). Alorda and Medrano (1988) in Majorca, Spain, and Cabrita *et al.* (1988) in the Algarve, Portugal, observed the highest rooting percentage in March cuttings while for Fadl *et al.* (1979) in Egypt it was in April. Regarding genotype the best rooting percentages were obtained by Alorda and Medrano (1988) using 'De la Mel' (syn. 'Negrillo') (85%) and one local hermaphrodite selection (45%) and by Cabrita *et al.* (1988) using 'Galhosa' (44%) rather than 'Mulata' (27%). Alorda and Medrano (1988) reported success after transplanting to the field with irrigation while Cabrita *et al.* (1988) described plant failure after transplanting to a soil mixture under greenhouse conditions. De Michelle and Occorso (1988) in Sicily obtained the highest rooting percentage (57.9%) using semihardwood cuttings with leaves taken in March and treated with IBA (8000 ppm).

Micropropagation of carob using both juvenile and adult tissues has been attempted (Martins-Loução and Rodriguez-Barrueco 1982; Sebastian and McComb 1986; Vinterhalter *et al.* 1992; Androulakis 1994; Alorda and Medrano 1996). However, there are no reports of plants from *in vitro* culture being successfully established in the field.

It seems that vegetative propagation by cuttings has not yet been successfully resolved in carob to give consistent results and thus to be suitable for mass production in commercial



**Fig. 12.** Hardwood cutting propagation (a), seed propagation (b) and modern orchard, 8 years old, in Tarragona, Spain (c).

nurseries. The information available on cutting propagation is more useful now than 15 years ago. Attempts have been made but it has not yet been solved. Research is underway at IRTA. If an easy way to root cuttings is developed, propagation of cultivars would be simpler and much cheaper.

### **Planting and transplanting of seedling rootstocks**

Seedling rootstocks, before or after budding, are usually planted from pots directly into the orchard. As carob is an evergreen and seedlings are sensitive to frost and root drying, late transplanting in February or March is recommended after danger of frost is past; the use of bare-rooted trees is not advisable.

Trees with well-developed roots should be used for transplanting (Fig. 12b) and proper care during and after planting is essential. Unlike other fruit trees, carobs are not usually budded in the nursery; field budding 1 year after planting has proven superior for vigour. The plastic pot is removed by cutting it from the top to the bottom with a sharp knife. Trees should be well watered immediately after planting, and soil moisture should extend below the root zone. This also helps to eliminate air pockets. A second irrigation follows within 2 weeks, followed by regular fertilization, using mainly nitrogen in the ammonium form rather than nitrate because of its easier uptake (Cruz *et al.* 1993). Rootstocks should be staked on the downwind side to ensure straight tree growth for budding and to protect them from excessive wind, which is common in coastal areas around the Mediterranean. It is essential to water 2 or 3 times during the first summer after planting in the orchard to wet the root mass and adjacent soil for successful establishment and for growth to reach a good size for budding the following spring.

The potential use of *C. oreothauma* as rootstock for carob seems not feasible as it is more tender than the cultivated species (J.H. Brito de Carvalho, pers. comm.).

### **Budding**

Scion cultivars are propagated with standard budding techniques. Some research on this matter has been reported (Brito de Carvalho and Graça 1988; Tous and Batlle 1990). The main types of budding used are T-bud, chip bud and patch bud. Budding is usually done in spring (from April to early June) when the scion buds are mature and the bark on the rootstock is slipping and active. When planting a new carob orchard, rootstocks are planted in late February or March and usually budded the following year in spring.

T-budding is the most efficient and common method in spring (April-May) with well-developed buds from scion wood of the year before on rootstocks of 1-2 cm diameter. Patch budding requires a larger rootstock diameter (bigger than 2 cm) and is thus more likely to be made in the field in spring or autumn. Bud take in rootstocks of less than 1 cm of diameter is low. Chip budding could be useful for these types of plants, but an accurate matching of cambia is required for this method.

Both T and patch budding are performed when the rootstocks bark is slipping

during spring. If bud take is unsuccessful, rootstocks are rebudded in September. For successful budding a sharp knife should be used to make smooth cuts. Budding wraps can be made of various materials, but plastic is the most common and widely used.

### 12.2 Orchard design

Tree densities in carob orchards of Mediterranean countries have traditionally been low and variable, within the range of 25–45 trees/ha which means square tree spacing from 20 x 20 m to 15 x 15 m. Rectangular planting has also been a common design. Intercropping with species like olive, grapevines or almond is frequently found. Most of the areas where carob trees will grow are semi-arid or marginal for good horticultural production. In modern orchards there is a tendency to reduce spacing with the aim of intensifying the crop. Carobs are long-lived trees and a well-designed orchard should ensure early economic bearing, maximum production potential, adequate pollination and sufficient space for management (Fig. 12c).

A carob orchard reaches its maximum bearing potential when space over the soil is filled by pod-bearing trees with sufficient light penetration to keep fruiting wood productive. As the orchard develops, and before maximum bearing potential is reached, bean yield is directly related to the number of trees per hectare. Currently, for dryland orchards on poor soils of the Mediterranean coast, tree densities between 100 and 175 trees/ha are recommended, i.e. spacings from 9 x 9 m to 7 x 8 m (Tous and Batlle 1990).

When carobs are to be planted in fertile soils, high-density planting and tree thinning later may be considered. Early yield can be maximized by initially planting more trees per hectare than will be needed for maximum bearing potential. As trees grow, half of them may be removed, but at considerable expense, to avoid tree crowding. Crowding results in yield losses from tree competition for light, nutrients and water, excessive pruning costs, and difficulty in conducting cultural and harvest operations. The closer the plantings, the more likely thinning will be required. In California, Coit (1951) suggested a spacing of 9 x 4.5 m and tree removal some 10 years after planting to obtain a spacing of 9 x 9 m. In good soils of the Algarve, Portugal, an initial density of 6 x 4 m and later thinning to a density of 6 x 8 m was proposed (Brito de Carvalho 1985). When the filler trees should be removed depends on tree growth. However, most new orchards are being planted at permanent tree density as tree removal is often not convenient for growers.

Another alternative in young carob orchards is intercropping with early bearing species such as peach, almond or even vegetables. Planting an annual or perennial crop between the rows may give early returns to the investment. Care should be taken to choose pesticides compatible with the nonbearing carobs. In most cases intercropping may damage carob orchard and cause problems for the grower.

### 12.3 Pollination

As described earlier, carob trees are generally dioecious with occasional hermaphrodite types. Thus female, male and hermaphrodite flowers are borne on separate trees. The need for pollination and fertilization in carob has been clearly shown by Russo (1954). This also may be deduced from the fact that all pods contain seeds, assuming that seeds are not formed

apomictically, and that where a seed is missing the pod does not grow to its full width (Orphanos and Papaconstantinou 1969).

The arrangement of pollinating trees in carob orchards has been traditionally disregarded by growers. This may have caused low yield or even have contributed to the abandonment of the crop. In the island of Crete, Sfakiotakis (1978) reported crop failure due to unfruitfulness resulting from lack of pollination. In Morocco, there is a project underway to graft male trees to increase pod production (S. Padulosi, pers. comm.). Pollination has traditionally been achieved either by keeping a male branch from the rootstock in the centre of the tree, if the rootstock is male, or by budding a male or hermaphrodite into the tree if the rootstock is female. Spontaneous trees (around 50% males) may be found in the neighbourhood, near paths or tracks, but generally in insufficient number. If male or hermaphrodite trees are planted as pollinators they must be interspersed around and within the orchard in a regular pattern. It is important to use different types of male or hermaphrodite pollinators to overlap with female cultivars' bloom, as main cultivars often display a long blooming season (3-4 months between August and November). Since male trees have a shorter flowering period than hermaphrodites, the latter usually show better overlapping.

Neither the optimum density of pollinators in the orchard nor the possible differences between using males or hermaphrodites have been determined. The ideal ratio of male or hermaphrodite to female trees presumably depends on insect and wind activity in the orchard during flowering and also on pollen germinability. The proposed range varies from the 4% of Coit (1949) to the 20% of Merwin (1981). However, it seems enough to plant around 12% of pollinating trees (males or hermaphrodites) (Tous and Batlle 1990), e.g. a ratio of 8 females to 1 male or hermaphrodite, with pollinators planted in every 3rd row and separated by two female trees within the row. Additional staminate trees could also be planted in border rows upwind of the orchard. In California, Thomson (1971) recommended an orchard pollination design of hermaphrodites on alternate or every third row of trees for adequate pollination. In existing groves showing pollination deficiencies, some female trees can be top-worked and grafted with male or hermaphrodite scion wood.

#### 12.4 Training systems and pruning

The carob tree is a species that needs little pruning, unlike other fruit and nut trees, which require pruning annually. After the basic framework of the tree has been established only light pruning is necessary. This fact is due to carob's specific growth and fruiting habits. While pruning, it is necessary to consider several important characteristics of carob (Tous and Batlle 1990):

- its natural tendency to form a central axis with a strong prevalence of side shoots
  - fruiting on wood 2 years and older
  - sensitivity to big cuts, which heal very slowly.
-

### Young trees

The traditional training methods were based on usually spherical or open vase forms, with a tall trunk and branching (first scaffold) from 1.5 m above the ground. Currently pruning is simple and straightforward. Short trunks (low first scaffold) favour a short vegetative (unbearing) period whereas longer trunks are advisable for mechanical harvesting using shakers. Thus the carob should be trained according to the harvesting system (manual or mechanical) foreseen, as free vase or modified central axis forms, respectively.

### Free vase

This respects the natural shape of the young tree, pruning being very light or none at all during the first years. It is only necessary to eliminate the shoots that come out from around the soil and to break some of them to avoid excessive growth on the lower branches. After fruiting, the first shaping pruning should be done. This consists of removing the lowest branches over 2 years to produce a clean trunk of 0.5-0.7 m. With this training system small trees will develop less in height and more in width, easing manual harvesting using poles.

### Modified central axis

It consists of leaving four or five primary branches well spaced and distributed along the axis of the trunk. The first can be located at a height of approximately 0.9-1 m. During the first years some lower branches can have their tips clipped in the summer, instead of being cut off totally. This training system gives a more upright crown and is more suitable for mechanical harvesting. It is important to stake the young trees to provide support for a number of years.

### Adult trees

They are usually slightly pruned and this operation should be carried out only occasionally after harvesting. Mature female, male and hermaphrodite carob trees produce flowers on wood of all ages and require light pruning only every 3-4 years to remove dead wood and encourage fruit-bearing wood by letting sunlight filter into the top middle section of the tree. This operation should be carried out particularly in years where a significant crop is expected. It is necessary to maintain an equilibrium between vegetative growth and production and it is particularly important to confine growth and production to the space allotted in the orchard.

For fruiting, the best time to carry out pruning is at the beginning of autumn immediately after collecting the crop. Branches should be removed when they are not too thick (5-7 cm diameter) and the length of the annual shoot is less than 25-30 cm. Dead branches must also be removed as well as those which are crossed or excessively upright growing.

Old neglected orchards or abandoned trees can be rejuvenated by thinning to increase and regularize production. If branches are broken in gales they should be removed with a clean cut and mastic applied to the cut surface to keep out rain as



rotting can start easily, especially in mature trees at the peak of production.

### 12.5 Fertilization

Traditionally, carob orchards have hardly been fertilized. This species has always been considered extremely adaptable to very poor soils and only some manure, when locally available, has been applied. However, in recent years, the revaluation of the crop has led some farmers to apply various types of fertilizer, either mineral or organic.

Most bibliographic references highlight the benefits of nitrogen in increasing fruit production in old carob tree plantations (Lloveras and Tous 1992; Correia and Martins-Loução 1993). It has been shown that this leguminous tree is unable to fix atmospheric nitrogen (Martins-Loução and Rodríguez-Barrueco 1982; Martins-Loução 1985).

In traditional orchards (density of 50 trees/ha) with average production of 2500-3000 kg/ha, an application of 50 kg of N, 20 kg of  $P_2O_5$  and 50 kg of  $K_2O$  per hectare can be advisable (Tous and Batlle 1990). It is recommended to apply phosphorus/ potassium-based fertilizer and 25% of nitrogen in autumn after harvesting. The remaining nitrogen fertilizer can be applied in February as ammonium sulphate. In plantations receiving some irrigation, one can apply N and K in the months of May and June which coincides with the stage of fast growth of the fruit. It is important to stress the benefit of applying organic matter as with all other fruit and nut trees. It is recommended to apply 30-40 kg of manure per tree, every 3-4 years during autumn tilling.

Work on carob fertigation by Correia and Martins-Loução (1995) in Algarve, Portugal, using mature trees of 'Mulata' and testing three levels of irrigation (0, 50 and 100%) based in water loss by evaporation, and two N amounts, as ammonium nitrate (21 and 63 kg ha<sup>-1</sup> year<sup>-1</sup>) per each level has shown that predawn water potentials were always higher than -1.1 MPa. Midday leaf water potential values presented large seasonal variations and low values independently of treatments. The low leaf water potentials observed for fertigated trees during summer suggested that this parameter may be related not only to the evaporative demand but also to growth investment. The amount of fertigation was positively correlated with vegetative growth increment and fruit production. These results also suggested that under standard conditions in the Mediterranean region, N applications are effective even without irrigation. In addition, the results obtained are in agreement with the 'water spending' strategy proposed by Lo Gullo and Salleo (1988) for the carob tree as a drought adaptation mechanism.

### 12.6 Irrigation

In the Mediterranean region, where water resources are scarce, irrigation is reserved for the more profitable horticultural crops. Therefore, the carob tree is planted in dry land. However, the availability of water is a requirement for good production. In this drought-resistant species the supply of water should be

considered as occasional irrigation and within certain limits of dose and time of the year. Esbenshade and Wilson (1986) and Tous and Batlle (1990) observed a positive effect of irrigation on fruit production. Some experiments on young trees also resulted in a positive effect of irrigation on pod production (Esbenshade and Wilson 1986).

Some authors indicate that, to ensure a good harvest, approximately 500 mm of rainfall per year are required (NAS 1979), but when rainfall is below 400 mm some complementary water supply is required (Tous and Batlle 1990). The main periods of irrigation in this species are considered to be spring, the beginning of summer (probable floral induction and fast pod growth) and autumn (flowering and accumulation of reserves).

In carob orchards without irrigation (nearly all) it is worthwhile to apply some water with a tractor and tank in late spring and summer in the first 2 years after planting. This watering helps the start of tree growth and cropping. In those areas with scarce water supply, drip irrigation shows good results. In adult orchards with water doses of 100 mm per year, benefits are clearly reflected in the yield (Tous and Batlle 1990).

### 12.7 Soil maintenance

Soil maintenance in carob orchards has traditionally been carried out by tilling weeds to reduce evapotranspiration and improve water penetration. It is advisable to till the soil only to 15-20 cm depth, to prevent disrupting the shallow and active root system as this soil zone is generally the more fertile and better aired. Shallow tillage using a harrow or a cultivator is effective. Farmers in Spain usually till three times during the year, the first time in autumn before the rainy season starts, the second in spring and the third when the pods start to ripen in early summer.

In some orchards in Spain weed control is accomplished through the mixed system of tillage and herbicide applications with good results (Tous and Batlle 1990). The most commonly used chemicals have been simazine (pre-emergent, residual), paraquat, ammonium glyphosinate and glyphosate (post-emergent). It is advisable to avoid the application of residual herbicides before the 4th or 5th year. Weed control is especially important in young plantations, since heavy weed competition for water and nutrients can significantly reduce tree vigour and productivity.

### 12.8 Pests and diseases

The carob tree is normally free from severe insect and disease troubles and is a crop which traditionally has not been sprayed. In Spain, the most damaging insect is the polyphagous larva of the leopard moth (*Zeuzera pyrina* L.) which attacks the wood of trunk and branches, causing severe damage to young trees. Cultivars tested in Spain were all susceptible to various degrees (Martorell 1987; Tous and Batlle 1990). In isolated cases, it can be controlled by introducing a wire into the galleries to destroy the larvae or by filling the holes with pesticide paste.

The pods of many cultivars sometimes become infested with the small and polyphagous larva of the carob moth (*Myelois ceratoniae* Z.) while maturing and before harvest is complete. It also attacks stored carobs extensively where it can be controlled by fumigating. Coit (1961, 1967) reported different susceptibility of several cultivars to the carob moth in California. Black aphids attack mainly the terminal shoots of young trees, and some hermaphrodite cultivars appear to show more susceptibility than females (Tous *et al.* 1996). In Cyprus, Orphanos (1980) reported carob midge (*Asphondylia* spp.) attacks on pods at a very early stage, which caused stunting. High humidity seems to soften the pods, making entry by worms much easier.

The mildew disease caused by *Oidium ceratoniae* C. attacks pods, leaves and twigs in different periods of the year, mainly in spring and in autumn. Severe damage occurs only in some cultivars. For example, 'Rojal', 'Matalafera', 'Amele di Bari' and 'Racemosa', are fairly resistant to this disease while 'Negra', 'Melera', 'Costella', 'Santa Fe' and 'AA-2' are susceptible (Goor *et al.* 1958; Graniti 1959; Martorell 1987; Tous and Batlle 1990). Thus a cultivar grading to *Oidium* susceptibility exists. Another fungus, *Polyporus sulphureus*, can destroy branches in old trees. Young carob trees growing under greenhouse conditions have shown resistance to root rot caused by *Armillaria* (*A. mellea* and *A. obscura*) infection (Loreto *et al.* 1993).

Other pests that occasionally cause severe damage to carob orchards are small rodents like gophers (*Pitymys* spp.) and rats (*Rattus* spp.). Gophers can severely damage the root system of young trees. In California, Thomson (1977) reported that it was almost impossible to establish a young orchard unless gophers are controlled. In Cyprus (Orphanos 1980) and other Mediterranean countries, rats are major pests. Rats can strip the bark not only of young shoots but also of older shoots and even limbs and by girdling a limb or branch can kill it. Several types of baits in traps can be used to control these rodents. However, the best control is natural predation by the wild native fauna, conservation of which is essential. Cattle, horses, sheep and goats all browse on the foliage of young and adult trees and can kill young unprotected trees.

### 12.9 Yield

Carob orchards are known to enter slowly into production. This has two main causes: the slow growth of the tree and its long vegetative period, and other environmental and cultural factors. In plantations located in marginal areas, the nonbearing period is long, from 6 to 8 years, while in others, where the conditions are better, cropping starts 3 or 4 years after budding. The production increases to achieve full bearing at 20-25 years of age and then stabilizes (Batlle 1985). Goor *et al.* (1958) reported that carob trees start to bear fruit in the 5th to 6th year when budded trees are planted and in the 7th or 8th year when seedlings are used for planting and later budded.

It is also important to recognize that carob shows alternate or biennial bearing.

The causes, in addition to genetics include climatic conditions such as scarce and variable rainfall, frost, fog, lack of pollination, damage of the inflorescence during harvesting (knocking down of the fruit), and deficiencies in orchard management (fertilization, pruning, etc.). Haselberg (1996) in Algarve, Portugal, has observed in 30 to 40-year-old 'Mulata' trees that the presence of pods in 'on' years has an inhibitory effect on the current season's flower differentiation, mainly during the period of most intensive fruit and seed growth (April to June).

The productive potential of the carob is variable and scarcely known under good cultivation conditions. In Spain, average orchard productivity is around 1500 kg/ha (MAPA 1994), which can be regarded as very low. In Portugal, the average yield is 1700-2700 kg/ha (Droste 1993). In Tarragona, Spain, orchards which receive minimum management tend to produce 2000-3000 kg/ha, giving an average yield of 50-70 kg per tree. Some modern orchards 10 years old in Spain and Portugal give high yields, about 5000 kg/ha in dry conditions and 7000 kg/ha with deficit irrigation (Tous *et al.* 1993). In Israel, on fully bearing trees in nonirrigated groves but with 550 mm of annual rainfall the yield can be about 7400 kg/ha and in irrigated orchards an average of 12 300 kg/ha can be reached (Goor *et al.* 1958). A well-grown adult tree could yield about 100-200 kg/year. Some big isolated trees can produce 250-300 kg in exceptional years.

#### 12.10 Harvesting

Carob harvesting is usually carried out at the end of summer or the beginning of autumn depending on cultivar and region. Harvesting can be manual or mechanical. In Mediterranean countries, carob groves are mainly hand-harvested by knocking down the pods with the help of long bamboo poles or wooden sticks and collecting them on fibre nets which are laid out under the trees. This operation needs careful handling since at this time of the year the carobs are in full bloom. The striking action of the poles can damage flowers and the next crop might be partially destroyed. This task constitutes the most significant part of the total cost of cultivation since it requires much hand labour, being currently about 30-35% of the total production costs (Orphanos 1980; Tous 1995b). In Spanish orchards the quantity of pods manually harvested, in average crop years, varies between 250 and 280 kg/day per worker (Tous and Batlle 1990). Mechanical harvesting using trunk or branch shakers has not been practised in most producing countries, mainly because of the small size of most orchards. However it seems feasible to adapt conventional harvesters used for other tree crops (olive, almond, pistachio, walnut, etc.) as carob branches are thick and stiff. To reduce harvesting cost, pods of a given cultivar should all be harvested at one time.

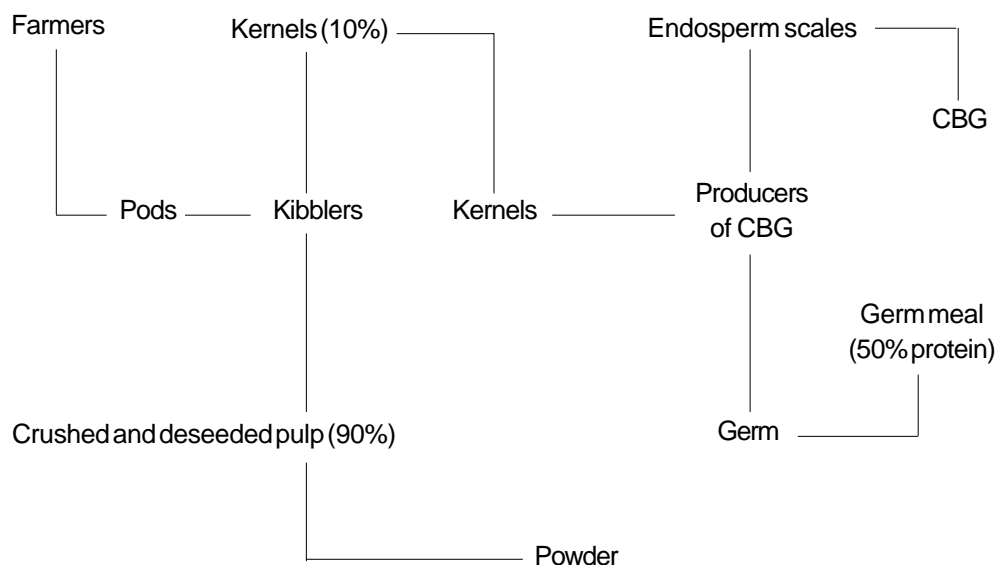
Fruit ripeness, and therefore its optimal harvesting time, is indicated by the complete darkening of the pedicel just prior to natural detachment from the branch. This is a reliable sign that pods are ripe and have reached their full sugar content. Sometimes pod drop is hastened by the wind. Carobs should be harvested when they have 12-18% water content. After harvesting, carobs are either delivered to the processor or stored under shelter. Moisture will gradually decrease during the subsequent months of storage.

## 12.11 Processing

Most of the carob pods harvested are brought to the processing plant. When carobs arrive, moisture content is variable (10-20%) depending on harvesting conditions and autumn rainfall. Pods require further drying and thus are stored under shelter in dry and ventilated places to reduce moisture to around 8% and to avoid rotting. Insects in stored carobs, mainly carob moth, can be controlled by fumigation. Pods are kibbled to separate the two main components: pulp and seeds.

Carob pods are crushed mechanically using a kibbler, then are separated from the kernels. The processing of the carob beans and the products obtained are shown in Figure 13. This first coarse grinding can be followed by fine grinding of the pod pieces (kibbles) either at the same plant or at the feed or food factories. The feed factory grinds the deseeded pulp to different sizes in relation to the kind of livestock to be fed. The food industry processes the pulp further by roasting and milling to obtain a fine powder which is traded as carob powder.

The carob seeds are transported in bulk by lorry to the gum factories. The kernels are difficult to process, since the seed coat is very hard. Kernels are peeled without damaging the endosperm and the embryos (germs). The two main procedures applied to remove seed coat are: acid (seeds treated with sulphuric acid to carbonize the coat) or roasting (kernels roasted in a rotating furnace to peel off the coat) (Puhan and Wielinga 1996). After the peeling process the endosperm can be split from the cotyledons because of their different friabilities. When the peeled



**Fig. 13.** Processing of the carob pod.

seeds are forced through a splitting machine the brittle embryos turn out as a fine powder (germ meal) and can be separated from the unbroken endosperm scales by a sifting operation. Subsequently the endosperm is ground on roller mills to the desired particle size (gum). The carob bean gum is the ground endosperm and the carob germ meal is a by-product of the seed processing.

Grower payout is calculated more and more in relation to the kernel yield of the cultivar delivered and also on amount of debris. Before carobs are stored, a grading sample is drawn from each delivery. This sample is processed individually using a small kibbler to determine kernel percentage. The two major components in determining return to the grower are weight delivered and percentage by weight of kernels.

## 13 Limitations of the crop

There are factors limiting the planting of carob in new areas, especially insufficient cold-hardiness, and factors limiting the profitability of the crop in existing areas, in particular factors that determine the suitability for modern orchards. In addition external economic factors limit the crop.

### 13.1 Cold-hardiness

Carob's main limitation is insufficient cold-hardiness. A frost of  $-4^{\circ}\text{C}$  or below may damage or kill young trees or even shoots, flowers and young fruits in mature trees (Tous and Batlle 1990). A more severe frost can kill adult trees as has occurred several times in the Mediterranean region (in 1956 and 1985). Generally, carobs should not be planted above 500 m of altitude or in places where risk of frost is high. Acclimatization to low temperatures requires days to weeks for maximum chilling stress tolerance to develop. Photoperiod also seems to be involved in the acclimatization process in carob as in many other evergreen species.

### 13.2 Suitability for modern orchards

The main aim of new carob orchards should be to maximize seed production per hectare. Ideally cultivars should combine high seed yield and high productivity. However, useful cultivar information is only partially available. As the main labour requirement in carob groves is harvesting, efforts should be addressed to reduce this input which represents 30-35% of the total management cost (Orphanos 1980; Tous 1995b) and thus cultivars that ripen uniformly and are easy to shake should be used for mechanical harvesting.

### 13.3 Market situation

From the market situation over the past 15 years it can be seen that carob pod prices tend to be cyclic with long gaps, and high peaks as in the years 1984 (US\$0.25/kg) and 1994 (US\$0.80/kg). This makes the market unsettled and produces a negative effect on demand. In addition, highly variable prices favour market speculation. However, the industry needs a steady and regular raw supply and stable prices on which customers can rely. In addition, carob seed prices are even more fluctuating than carob kibble prices. As the main industrial application is the CBG this recurrent situation affects carob demand and thus its multiple uses. Big fluctuations in carob seed prices should be avoided in the future.

## 14 Prospects

Since the start of the 1980s this crop has raised a considerable interest because of generally sustained demand and increasing prices of the carob pods (pulp and seed). However, this trend has been sharply modified twice in the last 10 years: in 1984-85 and 1994-95 when prices peaked. The high pod prices led to a loss of competitiveness of the carob bean gum versus other natural (guar and tara) or artificial hydrocolloid substitutes, both times producing a subsequent decline of pod prices.

Carob price stabilization in the market would improve the future outlook of this crop. The revaluation of the carob pulp in animal feeding and carob powder as human food, could help to increase its demand and then to reduce the final dependency of the pod price on the kernel. In addition the 'healthy' and 'light' component of derivatives of the carob pulp (confectionery, bakery and drinks) should be fully explored.

The carob tree shows some outstanding features like rusticity, drought resistance, reduced orchard management, etc. and it is also well suited to part-time farming. In addition, modern carob orchards start bearing earlier (4th year after budding) than traditional ones and increase their yield steadily in response to minimum cultural care and lack of irrigation. The development of a useful method of propagation by cuttings would have a favourable impact on carob growing.

Agricultural sustainability has been increasing in importance over the years. Although carobs produce reduced yields in old plantations (1500-3000 kg/ha), in modern orchards production potential is higher (5000-7000 kg/ha). In addition, in optimum conditions carob requires a minimum of inputs compared with most other fruit, nut or vegetable crops. In many semi-arid regions and marginal soils where carob is well adapted and cultivated, the quantity and quality of irrigation water are major limitations to production. This crop has received little attention until now but is currently being re-emphasized as an alternative in dryland areas with subtropical Mediterranean climates for diversification of coastal agriculture.

Although it seems that the overall world carob production trend is rather stationary (Tous and Ferguson 1996; Batlle 1997) some countries will continue to reduce their production while a few will probably increase theirs. Production in Morocco is likely to increase in the coming years to supply its local industry for gum extraction which benefits from low labour costs. Australia also seems to be a future potential producer of pods, mainly for livestock feeding in agroforestry systems (Esbenshade and Wilson 1986; Tous 1995a; Race and Curtis 1996).

Another factor to be considered is that the total harvested carob production is partially affected by the price level. It was assessed in commercial groves in Sicily, Italy by Licitra (1996) that 10-15% of the whole production is only collected when pod prices are rewarding for growers and even more than 50% on spontaneous isolated trees. The main production is usually harvested every year. This is also happening in some other Mediterranean growing areas.



The reviewed information on genetic resources shows that carob cultivars vary widely in many characteristics, such as yield, season of maturity, susceptibility to pests, precocity, ease of harvest, sugar content, kernel yield, gum content and quality.

Most CBG factories are placed in Mediterranean countries of the European Union (EU) (Spain, 5; Portugal, 2; Italy, 1) as this is the leading world carob-producing region and is expected to remain so in the future. However, newly established industries are operating in developing African countries like Morocco (which has 2). There is also a small processing plant in Turkey. The current CBG world demand by the food and pet food industries of around 15 000 t should be supplied yearly; otherwise, the consumer industry will change to other gums with a consequent loss of market. Although supply and demand of CBG show some flexibility annually (around 2750 t), any market loss is usually hard to recover.

One strength in the carob sector is that it is fairly well organized in the main producing countries. Thus although growers, cooperatives, kibblers, factory managers, the agrofood industry and R & D institutions have some different interests, all rely on proper prices for pods and kernels and are aware that a better-organized sector (from producer to consumer) would be mutually beneficial. Most of the companies that produce carob bean gum have belonged since 1972 to the Institut Europeen des Industries de la Gomme de Caroube (INEC) which is located in Brussels, Belgium. INEC has a Technical Committee and a Secretariat General which is based at ETH in Zürich, Switzerland.

INEC was launched by most of the important producers of CBG as a cooperative nonprofit organization to meet the extensive toxicological investigations requested by the FAO/WHO and the EU on food additives to be considered harmless. The INEC could play an important role in supporting studies on production and application of the CBG as the natural gum with best properties for the food and pharmaceutical industries. In addition, the INEC could foster programmes to conserve the carob crop and develop crop technology, encourage new plantings in developing regions, and improve the use and economics of carob kernels.

At present, it is mainly growers of Spain, Portugal, Greece and Italy who seem to be interested in carob as a crop. Most remaining Mediterranean countries maintain carob as a native tree, useful environmentally and for landscape recreation. Currently, this tree crop is included in the EU aid programme. Actions are considered in the Nut and Carob Production Organizations scheme (European Regulation number 2159/89). In addition, the carob tree was included in forestry actions of the EU (European Regulation number 2080/92).

A decision to establish, expand or replant a carob orchard requires knowledge of current and potential consumption (domestic and abroad) and price evolution (variability and projection). It is also important to know competition and market volatility. Its future possibilities in an ever-more competitive horticulture with increasingly low inputs (labour, water, fertilizers, sprays, etc.) are promising

provided that the CBG market prices stabilize. Production costs can be reduced by increasing the ease of harvest. In addition, its use as an ornamental species for xerogardening and for landscaping is increasingly being recognized.

An interesting initiative to promote carob growing was the establishment of the Associação Interprofissional para o Desenvolvimento da Produção e Valorização da Alfarrova (AIDA) in 1985 in the Algarve, Portugal. This independent association brings together efforts of interested people and institutions involved in carob production, processing and marketing.

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## 15 Research needs

Carob has been traditionally neglected by Research & Development programmes so that knowledge about existing cultivars in the Mediterranean region is still poor. Centuries of carob cultivation have given rise to a number of cultivars differing in agronomic characters, and large natural populations remain untouched in countries like Morocco and Turkey as described in the Genetic Resources section. Thus surveys and a cooperative project to compare and characterize most useful cultivars and types selected from the wild are much needed.

In 1973, the Mediterranean Group for Applied Plant Physiology (MPP) chose the carob tree as a suitable Mediterranean species meriting R & D effort to improve the knowledge of its physiology and environmental adaptation. Since this initiative, three International Carob Symposia have been held with the participation of physiologists, pomologists, chemists, pharmacists and processing managers. As the main group involves physiologists, the main output has been on physiology-related subjects.

These three Symposia were held in 1978 in Aldeia das Açoteias, Portugal (Catarino 1980), in 1987 in Valencia, Spain (Fito and Mulet 1988), and in 1996 in Cabanas, Portugal. It is clear that the knowledge on genetic resources, propagation, agronomy, potential productivity, agroforestry, afforestation and uses of carobs is still too limited compared with other Mediterranean tree species. In 1986, a meeting was held in INIA Oeiras, Portugal on carob research activities in which the main working lines of several research groups from some producing countries were discussed (Brito de Carvalho 1988b).

Work on characterization and documentation of carob cultivars is scarce worldwide (Grainger and Winer 1980). In addition to some classic work by Russo (1954) in Italy, Coit (1967) in California, Orphanos and Papaconstantinou (1969) in Cyprus and Vardar *et al.* (1980) in Turkey, some countries like Italy, Portugal and Spain have recently made surveys on their native genetic resources and collected material to be studied and conserved in collections and genebanks (Tous *et al.* 1996). The carob research programme at IRTA-Mas Bové was started in 1984 (Batlle and Tous 1988), after a wide survey of the carob native genetic resources and possibilities of this crop in Catalonia had been carried out by Batlle (1985).

Although several descriptors outlines have been proposed for carob (Coit 1949; Russo 1954; Donno and Panaro 1965; Batlle 1985; Brito de Carvalho 1988a; Crescimanno *et al.* 1988; Tous *et al.* 1996) the development of a generally accepted scheme for cultivar characterization and evaluation, ideally with the support of IPGRI, is much needed. It would be possible for IRTA to take this initiative. A good starting framework for a descriptor list would be the last scheme proposed by Tous *et al.* (1996) which is presented with some modifications in Appendix III. Passport, management, and environmental and site descriptors are omitted.

In the existing carob collections it seems that enough genetic diversity exists for crop improvement. However, as the main use for carob pods is currently the seeds, whereas most cultivars maintained in collections were selected for high pulp

content, it is worth selecting and collecting more wild types with high seed yield and characterizing/evaluating them in orchards. A survey of isoenzymes or other molecular markers in appropriate populations will allow the level and distribution of genetic diversity within and between the two *Ceratonia* species to be estimated. This is of potential interest if the two species hybridize. It could be interesting to compare diversity of cultivars with diversity in the wild. It could also help to locate species polymorphism for collecting and conservation. A marker for sex also would be useful if carob breeding is attempted.

Although progress has been made on carob propagation by cuttings (Alorda *et al.* 1987; Alorda and Medrano 1988; Cabrita *et al.* 1988; De Michelle and Occorso 1988), efforts are needed to transfer this technique to the nursery industry. A simple and cheap method for producing trees by cuttings would make budding unnecessary and might provide a shorter vegetative period.

Pollination in carob either by insect or wind is not yet clearly understood. It is a key component of orchard design and production and consequently should be studied further. A wide range of flowering types (male and hermaphrodite) should be included in any work to be carried out. Pollen germination tests (*in vivo* and *in vitro*) are necessary to select and propagate male and hermaphrodite pollinators. In addition, flower induction is a critical step for fruit production and thus for orchard management but is poorly understood and needs to be studied in the near future.

More information is also needed on tree density and potential yield. The precise nutrition and water requirements of the carob are yet to be determined. In addition, more research work on carob cambial activity and potential differences between cultivars and sites, under irrigated and nonirrigated conditions, is needed to schedule water supply and stop growth before winter.

Alternate or biannual bearing causes problems for both farmers and the stock market. CBG factory managers need to know every year the potential carob pod production to plan their purchases. Thus developing techniques for early assessment of the anticipated production is of particular interest to CBG factory operators. So the companies which belong to INEC might be interested in collaborating on projects to forecast carob yield (e.g. from pollen fluxes, meteorological data, etc.) in the future.

The use of carob for afforestation and soil conservation in warm Mediterranean areas with degraded vegetation or to prevent erosion is often raised but has not yet been investigated. It seems that carob is not a forest species as it thrives in the maquis; however, its role and potential suitability to cover bare land will be worth assessing. In addition, its response to fire, which is common in the Mediterranean region, is unknown. Sprouting ability would be a determining factor in natural regeneration. The carob tree showed some regeneration capacity after aerial killing by deep frost (-15°C) on the Mediterranean Spanish coast in 1956 and 1985 (Batlle 1985). As carob cannot withstand competition with other forest and maquis trees and shrubs, its germination in nature is rare. It thrives well and regenerates by seeds on dry and warm sites in Israel (Lipshitz 1987). The development of

mycorrhiza inoculation in carob nurseries could improve the establishment and growth of new orchards and afforestation plantings.

To summarize, the research needs for carob improvement are:

- development of a descriptor list
  - characterization and evaluation of existing collections
  - selection of promising wild types (female and hermaphrodites)
  - development of a useful method of propagation by cuttings
  - pollination studies (insects and wind)
  - tree density and potential yield
  - reforestation capacity.
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## Appendix I. Cultivar description

A description of the main features of 27 carob cultivars from 6 different countries is presented (Cyprus 3, Italy 6, Portugal 2, Spain 11, Tunisia 1 and USA 4).

### Cypriot cultivars

The information given has been reported by Orphanos and Papaconstantinou (1969), Ticho (1958), Coit (1967) and Orphanos (1980). Three types of carob trees are distinguished by growers according to Orphanos and Papaconstantinou (1969): *Agria* and *Apostolika* are wild and ungrafted and *'Imera'* are grafted trees. Within grafted types, three cultivars are described: *'Tylliria'*, *'Koundourka'* and *'Koumbota'*.

#### *'Tylliria'*

Origin Cyprus (unknown).  
 Synonyms *'Saradjinica'*, *'Vakles'* or *'Vaklaes'*.  
 Sex female.  
 Tree vigorous and upright habit, reddish twigs and large leaves.  
 Growing area all over the island, is the main cultivar grown in Cyprus.  
 Pods 15-17 cm long, slightly curved, colour reddish brown, width 2-2.5 cm, thickness 1-1.2 cm. The seeds are relatively flat and smooth. Seed content is around 8% (7.6%-10.6%). The flesh contains 51% sugar and the seeds contain 49% gum.

Remarks it is not early cropping; it can be harvested early although the pods remain on the tree after maturity. Its production in Cyprus is mainly for export; excellent quality for milling; it was introduced in some other countries, like Greece, Israel and the USA; several slightly different types have been described (Ticho 1958).

#### *'Koundourka'*

Origin Cyprus (unknown).  
 Growing area Karpass peninsula in Cyprus.  
 Sex female.  
 Tree medium size with weeping habit.  
 Pods dark brown, normally straight and relatively short (about 13 cm). The side towards which the seeds are pointing is thicker than the other side (thickness: 0.97 and 0.73 cm, respectively). The seeds show an angular shape and are thicker than *'Tylliria'* seeds. The seed content is about 14-15%. The flesh contains 50% sugar and the gum content of the seed is 58%.

Remarks early maturing, pods shedding on maturity. Interesting cultivar, as it combines medium tree size, high seed content and self-shedding of the mature pods.

'Koumbota'

Origin Cyprus (unknown).  
Growing area Karpass peninsula in Cyprus.  
Sex female.  
Pods dark brown and long (about 20 cm), and curved towards the narrow side. The side toward which the seeds are pointing is thicker than the other side (1 wide and 0.76 cm thick). The seeds are relatively flat and slightly uneven. The flesh contains about 53% sugar and the seeds yield 53% gum.  
Remarks early maturing.

Italian cultivars

The information given has been reported by Russo (1954), Donno and Panaro (1965), Spina (1986) and Crescimanno *et al.* (1988).

'Gibiliana'

Origin Sicily, Italy.  
Growing areas it is grown mainly in Ragusa and Siracusa districts, Sicily.  
Synonyms 'Latinissima' and 'Cipriana'.  
Sex female.  
Tree vigorous with open growth habit and with lower branches bent towards the ground. Leaflets of medium size.  
Pods dark brown colour with curved shape, rough surface, medium size (16 cm), 2.5 cm wide and 1 cm thick. The pulp has a sugar content of 38-40% and seed yield is about 8-10%.  
Remarks it is a productive cultivar and shows low alternate bearing.

'Amele di Bari'

Origin Bari in Apulia, Italy.  
Growing area district of Apulia, Italy.  
Synonyms 'Amele' and 'Mele'.  
Sex female.  
Tree vigorous with upright growth habit and with dense branching and small leaflets.  
Pods dark brown colour with straight shape and rough surface, medium length (15-19 cm), 2.3 cm wide and 1 cm thick. High pulp content of light brown colour and with high sugar content (53%). Seed yield is low (8%).  
Remarks it is a productive cultivar although it shows alternate bearing. It shows low susceptibility to *Oidium*.

'Racemosa'

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Origin Sicily, Italy.  
Growing area Sicily.  
Synonyms 'Moresca', 'Carruba Spada' and 'Sciabulara'.  
Sex female.  
Tree less vigorous than other Italian cultivars. Long leaves of light green colour.  
Pods dark brown colour of short length (13 cm), 2.3 cm wide and 0.9 cm thick. Seed yield is low (7.5%).

'Saccarata'  
Origin Sicily, Italy.  
Growing area Sicily.  
Synonyms 'Latina', 'Fimminedda' and 'Milara'.  
Sex female.  
Tree vigorous with upright growth and dense foliage. Leaflets of small size.  
Pods light brown colour of medium length (15-16 cm), 2.6 cm wide and 0.8 cm thick. Seed yield is low (9%).

'Tantillo'  
Origin Sicily, Italy.  
Growing areas eastern Sicily.  
Sex hermaphrodite.  
Tree upright habit and medium leaf size  
Pods dark brown colour and mostly straight, length 13-15 cm, width 2 cm. Seed yield is low (6%). Flesh flavour is fair.  
Remarks crops when young; ripening in September-October.

'Bonifacio'  
Origin Sicily, Italy.  
Growing area Agrigento, Sicily.  
Sex hermaphrodite.  
Tree open habit and small leaves.  
Pods dark brown colour, seed yield is medium (12%).

#### Portuguese cultivars

The information provided has been reported by Da Matta (1952), Haselberg (1988) and Tous *et al.* (1996). There are many Portuguese cultivars: 'Mulata', 'Galhosa', 'Canela', 'Costela de Vaca', 'Alfarroba de Burro', 'Castiça', 'Roxa', 'Lisa', 'Parda', 'Da Lapa', 'Brava', 'Bonita', 'Gasparinha' and the recently selected 'AIDA'.

'Mulata'  
Origin Algarve, Portugal.  
Growing areas Algarve region, Portugal.  
Sex female.

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Treevigorous with open growth habit and with big leaflets of dark green colour. Podsdark brown colour with straight shape, rough surface and medium length (14-17 cm), 2 cm wide and 0.9 cm thick. The pulp has a high sugar content and seed yield is medium-high (12-14%). The seeds contain 55.8% gum.

Remarksit is a very productive and early maturing cultivar and well regarded in the Algarve district. It shows low susceptibility to *Oidium*.

#### 'Galhosa'

Origin Algarve, Portugal.

Growing areas Algarve region, Portugal.

Sex female.

Tree vigorous with open growth habit and with leaflets of light green colour.

Podsare reddish to brown colour and 15-17 cm long. Seed yield is high (15-17%).

The seeds contain 58.3% gum.

Remarks late bearing age. Low susceptibility to *Oidium*. Commercially it is an interesting cultivar.

#### Spanish cultivars

The information presented has been compiled from Caja *et al.* (1984), Batlle (1985), Tous (1985), Martinez-Valero *et al.* (1988), Batlle and Tous (1990), Tous and Batlle (1990) and Tous *et al.* (1996). The described cultivars are arranged in order of relative importance.

#### 'Negra'

Origin Spain (unknown).

Growing area Barcelona, Tarragona and north of Castellón.

Synonyms 'Negreta', 'Negral' and 'Del país'.

Sex female.

Treevigorous with spreading growth habit and dense branching. The leaflets are large.

Podsblack and straight, with rough surface, short (13-16 cm), around 2.5 cm wide and 1 cm thick. The pedicel is short. The flesh is white, of good quality with a high sugar content and it has a low seed yield (7-9%).

Remarksit shows alternative bearing mainly if cultural practices are not carried out well. Late maturing. Resistant to fruit shedding and tends to produce small beans. It is susceptible to *Oidium* and *Zeuzera*. Good cultivar for animal feeding. It is the main Spanish cultivar with production of over 24 000 t/year.

#### 'Matalafera'

Origin Spain (unknown).

Growing area mainly Valencia and Alicante.

Synonyms 'Matalafam'.  
Sex female.  
Tree medium vigour with open growth habit. Sparse branching and foliage with smooth and straight branches. Large leaflets. Pods are produced in clusters.  
Pods dark brown colour and slightly curved, smooth surface, 16-18 cm of long, about 2.3 cm wide and 1 cm thick. Flesh content is high and its seed yield is medium (11-12%).  
Remarks productive and shows low alternate bearing, mainly if it is grown on fertile soils. Low susceptibility to *Oidium*. It is interesting for its good commercial features. Around 13 000 t/year of this cultivar are produced.

'Duraió'  
Origin Majorca, Spain.  
Growing area is grown mainly on the sunny slopes of the northern range (Sta. María, Consell and Alaro) in Majorca and also in Ibiza, Spain.  
Synonyms 'De Durayo', 'Duraiona' and 'Uraiona', Ibiza.  
Sex female.  
Tree medium vigour, weeping growth habit, dense branching and slow growth. Young branches are smooth and older ones have knots. Leaflets are large, of a faint green colour.  
Pods reddish to brown colour, slightly curved, rough surface, 15-17 cm long, 2 cm wide and less than 1 cm thick. The pedicel is long. Its seed yield is high (15-16%).  
Remarks Productive, sensitive to frost. Shows medium resistance to *Oidium*. It is an interesting cultivar for new orchards (early and regular cropping). Some 9000 t/year are produced.

'Rojal'  
Origin Vilaseca, Salou and Cambrils, Tarragona, Spain.  
Growing area mainly Camp of Tarragona district, Tarragona.  
Synonyms 'Roja'. It is often locally misnamed 'Valencià' or 'Valenciana'.  
Sex female.  
Tree vigorous with upright growth habit and dense branching. Smooth trunk and branches. Foliage is dense and leaflets dark green.  
Pods reddish, curved with smooth surface, 17-20 cm long, around 2 cm wide and about 0.9 cm thick. The flesh content is medium and seed yield is medium (10-11%).

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Remarksproductive and regular bearing, early cropping. Low resistance to fruit shedding. Low susceptibility to *Oidium*. Shows some tolerance to low temperatures because of its dense foliage. An excellent cultivar for its agronomic and commercial characteristics. It is the main cultivar used for new orchards in Tarragona, Spain.

'Mollar'

Origin Murcia, Spain.

Growing area south of Alicante and Murcia.

Synonym 'Melar'.

Sex female.

Tree very high vigour.

Podsbrown colour, 16-22 cm of long. The pulp is faint and with high sugar content. Seed yield is low, 6-7%.

Remarks heavy alternate bearing.

'De la Mel'

Origin Artá, Majorca, Spain.

Growing areas grown in Palma, Puigpunyent, Establiments, San Sardina, Santany, etc.

Synonyms 'Negrillo'.

Sex female.

Tree vigorous spreading growth habit and dense branching and fast growing. Branches have knots. Dense foliage. The leaflets are small and of dark green colour.

Pods dark brown colour, straight and rough surface, medium length (13-18 cm), around 1.75 cm wide and 0.6 cm thick. The flesh has a high sugar content and seed yield is high (13-16%).

Remarks shows alternative bearing, is medium harvesting.

'Banya de Cabra'

Origin Garraf district, Barcelona, Spain.

Growing area mainly Garraf, Barcelona.

Sex female.

Tree vigorous with weeping to open growth habit and intermediate branching. Large leaflet size and long inflorescences (9-11 cm).

Podsbrown colour and twisted with very rough surface, 18-20 cm long, about 2 cm wide and 0.7 cm thick. They have a low pulp content and a high seed yield (13-14%).

Remarksproductive although it shows alternate bearing. Low resistance to fruit abscission. Medium susceptibility to *Oidium*. It is considered more frost tolerant than other Spanish cultivars. Commercially it is an interesting cultivar.

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'Casuda'

Origin probably Valencia, Spain.  
Growing areas Castellón, Valencia and Alicante, Spain.  
Sex female.  
Tree vigorous with upright habit and slender twigs, to leaflets.  
Podsbrown colour, medium length (12 cm) mostly straight. Width is 1.5 cm and valley is 0.5 cm. Smooth surface and distinct creases. The pulp has a high sugar content (51-56%) and fair flavour. The seeds are round.  
Remarks it is a very old cultivar, long grown in Spain. Precocious, good yielding and with ready pod abscission at harvest in September. It was introduced in the USA.

'Ramillete'

Origin Murcia, Spain.  
Growing area south of Alicante and Murcia.  
Sex hermaphrodite.  
Tree medium vigour with weeping growth habit and sparse branching.  
Podsbrown colour, curved and rough surface, produced on clusters, 15-20 cm long and around 2.3 cm wide. The flesh and sugar content are high and seed yield is medium-low (8-10%).  
Remarks self-fertile and early cropping, productive although shows alternate bearing and early cropping and easy harvesting. Medium susceptibility to *Oidium*. It is the main cultivar used in new orchards of its traditional growing area.

'Ralladora'

Origin Castellon, Spain.  
Growing area Castellón.  
Sex female.  
Tree vigorous with spreading growth habit and dense branching.  
Podsdark brown colour, 15-16 cm long, around 2.1 cm wide and 1 cm thick. The pulp content is medium and seed yield is medium (11-12%).  
Remarks productive and regular bearing, early cropping. Shows medium resistance to *Oidium*.

'Fina'

Origin Murcia, Spain.  
Growing area South of Alicante and Murcia.  
Synonym 'Mojonera'.  
Sex female.  
Tree medium vigour.

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Podsbrown colour, curved and rough surface, 14-18 cm long. Seed yield is medium (around 10%).

Remarks tends to alternative bearing.

#### Tunisian cultivars

The information gathered is from Crossa-Raynaud (1960), Coit (1967), and Brooks and Olmo (1972). Only one named cultivar, 'Sfax', is reported in Tunisia.

#### 'Sfax'

Origin likely Menzel bon Zelfa or Sfax (Tunisia).

Growing areas several districts in Tunisia.

Sex female.

Tree vigorous with exceptionally spreading (open) habit; twigs very thick and reddish. Large leaflets.

Podsbrownish brown colour, straight or slightly curved, long length (15 cm), 2 cm width, valley 0.6 cm, surface rough. The seeds are elliptic. The sugar content of the flesh is 45-56% and has excellent flavour. Seed yield is medium (10-12%).

Remarks fairly precocious and yield medium heavy, regular. Early ripening and good pod abscission.

#### USA cultivars

The carob tree was likely introduced into the United States from Spain by the US Patent Office in 1854. In the 1950s W. Rittenhouse and J.E.Coit promoted this species in California and introduced budwood of selected cultivars from Cyprus, Israel, Tunisia, Greece, Yugoslavia, Creta, Portugal, Italy and Spain. In addition, seedling trees grown for shade on the streets of cities in Southern California and Arizona were selected for their floral and fruit characteristics for commercial production (Condit 1919; Coit 1949, 1967; Schroeder 1952; Coit and Rittenhouse 1970; Brooks and Olmo 1972). A few of these selections are described.

#### 'Santa Fe'

Origin Santa Fe Springs, California.

Growing area California.

Sex hermaphrodite.

Tree open habit with slender reddish twigs, 8-10 leaflets per leaf.

Pods light brown colour, slightly curved and often twisted, 18-20 cm long; 2 cm wide; smooth surface. The sugar content of the flesh is around 47% and has excellent flavour. Seeds are elliptic. Seed yield is medium (8-10%).

Remarks precocious cultivar and pod abscission is fair. It yields well and regularly. High susceptibility to *Oidium*.

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‘Clifford’  
 Origin Corona, California.  
 Growing area California.  
 Sex hermaphrodite.  
 Tree upright and compact habit, 7-10 leaflets per leaf.  
 Podslight brown colour and slightly curved, short-medium length 13-16 cm, width 2 cm, smooth surface. The flesh has a high sugar content (around 52%) and fair flavour. The seeds are elliptic.  
 Remarks precocious cultivar and heavy and fairly regular bearer.

‘Bolser’  
 Origin Rialto, California.  
 Synonyms ‘Horne’ and ‘Nichols’.  
 Growing areas California.  
 Sex hermaphrodite.  
 Podsshort 12-15 cm, rather plump. The flesh has a medium sugar content (around 42%).  
 Remarks tree bears well and is self-fruitful.

‘Grantham’  
 Origin Bari in Apulia, Italy.  
 Growing areas and synonymswas commonly grown on the Adriatic Coast under different names.  
 Sex male.  
 Remarksmale type selected as pollinator due to its abundance of staminate flowers. It blooms very heavily, but too late to pollinate some early blooming female cultivars in California.

## Appendix II. Centres of research and genebanks

The main institutions and research centres working on carob tree or holding genetic resources are as follows.

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### Institute/Research Centre

### Main research

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#### Australia

International Tree Crops Institute  
 PO Box 929  
 Nedlands 6009  
 Western Australia  
**Expert:** H.W. Esbenshade

Cultivar evaluation,  
 agricultural management  
 and agroforestry

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Loxton Research Centre  
PO Box 411  
Loxton, S.A. 5333  
Tel: +61-85-859100. Fax: +61-85-859190  
**Curator:** F. Hobman

Cultivar collection

**Cyprus**  
Agricultural Research Institute  
PO Box 2016  
1516 Nicosia  
Tel: +357-2-305101. Fax: +357-2-445156  
Email: orphanos@arinet.ari.gov.cy  
**Working team:** P. Orphanos and C. Gregoriou

Plant material and orchard  
management

**Greece**  
Institute of General Botany  
Biology Department  
Athens University  
15784 Athens  
Tel: +30-1-7284653. Fax: +30-1-7234136  
Email: cgspyro@atlas.uoa.gr  
**Working team:** S. Marakis and C.G. Spyropoulos

Cultivar evaluation, pulp  
sugar and CBG quality

**Italy**  
Istituto di Coltivazioni Arboree (ICA)  
Università degli Studi di Palermo  
Viale delle Scienze 11  
90128 Palermo (Sicily)  
Tel: +39-91-423398. Fax: +39-91-6521098  
Email:cmga@cuc.unipa.it  
**Working team:** F.G. Crescimanno  
and R. Di Lorenzo

Cultivar evaluation and  
physiology of reproduction

**Portugal**  
Associação Interprofissional para o  
Desenvolvimento da Produção e Valorização  
da Alfarroba (AIDA)  
Loteamento Industrial de Loulé  
Apartado 302  
8100 Loulé (Algarve)  
Tel: +351-89 415151. Fax: +351-89-415494  
**Working team:** J.M.V. Graça, P. Correia

Cultivar collection  
(Castro Marim-Tavira)  
Cultivar evaluation,  
propagation, agricultural  
techniques (irrigation,  
fertilization, planting  
density, etc.)



and P. Barracosa

Departamento de Biología Vegetal  
Facultade de Ciencias de Lisboa  
Campo Grande Bloco 3 Piso 4  
1700 Lisboa  
Tel: +351-1-7573141. Fax: +351-1-75800048  
Email: bmloucao@bio.fc.ul.pt  
**Working team:** M.A. Martins-Loução,  
F. Catarino and C. Cruz

Plant crop physiology,  
biological studies  
and fertilization

### Spain

Institut de Recerca i Tecnologia Agroalim  
entàries (IRTA)  
Departament d'Arboricultura Mediterrània  
Centre Mas Bové  
Apartat 415, 43280 Reus (Tarragona)  
Tel: +34-77-343252. Fax: +34-77-344055  
Email: ignasi@masbove.irta.es  
Email: tous@masbove.irta.es  
Germplasm bank (Reus and Tortosa)  
**Working team:** J. Tous, I. Batlle, A. Romero,  
J. Plana, M. Rovira and N. Aletà

Cultivar characterization  
and evaluation, germplasm  
collection, clonal selection,  
physiology of reproduction,  
vegetative propagation,  
and gum (CBG) quality  
orchard management

Conselleria d'Agricultura del Govern Balear  
Pasaje Torrella 1  
07012 Palma de Majorca  
Tel. +34-71-176100. Fax: +34-71-176156  
**Curator:** J. Rallo

Cultivar collection (Finca  
Experimental 'Sa Granja')

Private farm:  
Partida 'El Paraiso' 40  
03570 Villajoyosa (Alicante)  
Tel: +34-6-891190  
**Curator:** J. Lloret

Cultivar collection

### Tunisia

Institut National de la Recherche  
Agronomique (INRAT)  
Laboratoire d'Arboriculture Fruitière  
Avenue de l'Indépendance  
2049 Ariana  
Tel: +216-1-231985. Fax: +216-1-752897

Cultivar collection

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**Curator:** B. Jraidi

INEC (Institut Europeen des Industries  
de la Gomme de Caroube)  
Secretariat General  
Institut of Food Science  
Department of Food Science  
Swiss Federal Institute of Technology  
Zürich, ETH Zentrum, LFO F18  
Schmelzbergstrasse 9  
8092 Zürich, Switzerland  
Tel: +41-1-6325368. Fax: +41-1-2620994  
Email: puhan@ilw.agrl.ethz.ch  
**General Secretary:** Z. Puhan

Appendix III. Basic descriptor list for carob (*Ceratonia  
siliqua* L.) cultivars

Characteristic†	Category and rank
<b>1 Tree</b>	
Sex	male, female or hermaphrodite
Vigour	very high, high, medium
Growth habit	upright, open, weeping
Foliage density	most dense, dense, less dense
Branching	dense, intermediate, sparse
<b>2 Leaf</b>	
Rachis length (cm)	
Number of leaflets	
Leaflet shape	elliptic, oval, round
Leaflet area (cm <sup>2</sup> )	small ( ), medium ( ), big ( )
Length/width relation (L/W)	short, long, narrow
Leaf colour	light green, green, dark green
<b>3 Inflorescence</b>	
Length (cm)	short (<8), medium (8-10), long (>10)
Flowers per inflorescence (<15)	many (>30), medium (15-30), few
Colour	green, yellow, red
Nodosity insertion	yes, no

#### 4 Fruit pod or bean

Shape	straight, curved, twisting
Surface	smooth, rough, very rough
Colour	black, brown, reddish
Length (cm)	short (<14), medium (14-18), long (>18)
Width (cm)	small ( ), medium ( ), big ( )
Valley (cm)	
Groove (cm)	
Pod thickness	thin ( ), medium ( ), thick ( )
Pedicle length	short ( ), medium ( ), long ( )
Pod weight (g)	
Number of seeds per pod	
Seed yield (%)	low (<9.5), medium (9.5-13), high (>13)
Sugar content (%)	low (<40), medium (40-50), high (>50)
Fibre content (%)	

#### 5 Seed or kernel

Shape	round, oval, elliptic
Surface	smooth, rough, very rough
Colour	red-brown, brown, black-brown
Length (L) (cm)	short ( ), medium ( ), long ( )
Width (W) (cm)	narrow ( ), medium ( ), wide ( )
Thickness (T) (cm)	thin ( ), medium ( ), thick ( )
L/W, L/T, W/T relations	
Volume of 100 seed (cc)	
Seed weight (g, average 100 seeds)	small (< 0.17), medium ( 0.17- 0.2), high(>0.2)
Gum content (% dry wt. of endosperm)	low (< 48), medium (48-2), high (>52)

#### 6 Agronomic

Yield; regularity of production; precocity; sensitivity to frost, wind; pest and disease susceptibility; ripening season; ease of harvesting, etc.

#### 7 Commercial

Uses of carob pods (animal feed or human food); tannin content; sugar, etc.; quality of CBG (viscosity and gel strength); germ content, etc.

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† Passport, management, and environmental and site descriptors are omitted.  
Source: modified from Tous *et al.* (1996).

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