Promoting the conservation and use of underutilized and neglected crops. 7.

Safflower

Carthamus tinctorius L.

Li Dajue and Hans-Henning Mündel

IPK
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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 volume on safflower attempts to address the needs of plant breeders, geneticists, genetic resources specialists, plant pathologists, crop entomologists and others interested in a practical tool for pursuing their interests in relation to safflower. The authors have attempted to emphasize the globality of safflower research, with special emphasis on collection and evaluation of safflower genetic resources (Chapter 6) from a diversity of regions and in numerous research establishments around the world. Examples are provided of evaluations for characters and germplasm lines of potential direct value to safflower researchers. To facilitate successful exchange of germplasm material, the PI numbers (Plant Introduction numbers of the USDA World Collection) are used wherever possible, as a unifying system across many country collections. The unpublished notes of Knowles, who made several safflower collection expeditions in 1958, 1964-65 and 1975, were available to the second author (Mündel) and have been used extensively.

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.

This series is the result of a joint project between the International Plant Genetic Resources Institute (IPGRI) and the Institute of Plant Genetics and Crop Plant Research (IPK). Financial support provided by the Federal Ministry of Economic Cooperation and Development (BMZ) of Germany through the German Agency for Technical Cooperation (GTZ) is duly acknowledged.

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Dedication

This volume is dedicated to the memory of Dr Paulden F. Knowles, the safflower germplasm collector *extraordinaire*, whose collections have touched and benefited safflower germplasm research and breeding around the world. His collections of cultivated, wild and weedy relatives of safflower from around the world were the product of plant exploration expeditions Dr Knowles undertook in the 1950s, 1960s and 1970s. The widely used USDA World Collection owes most of its safflower lines to Dr Knowles' collecting efforts. This World Collection has resulted in valuable material and indeed provides the core of collections of safflower in many countries and even more institutions.

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Li Dajue and H.-Henning Mündel
22 July 1996

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Introduction

Safflower, *Carthamus tinctorius* L., is a member of the family Compositae or Asteraceae, cultivated mainly for its seed, which is used as edible oil and as bird-seed. Traditionally, the crop was grown for its flowers, used for colouring and flavouring foods and making dyes, especially before cheaper aniline dyes became available, and in medicines.

Safflower is a highly branched, herbaceous, thistle-like annual or winter annual, usually with many long sharp spines on the leaves. Plants are 30-150 cm tall with globular flower heads (capitula) and, commonly, brilliant yellow, orange or red flowers. Achenes are smooth, four-sided and generally lack pappus.

The plant has a strong taproot which enables it to thrive in dry climates. In India the crop has traditionally been grown in the 'rabi' or winter dry season in mixtures with other 'rabi' crops, such as wheat and sorghum. After emergence, the crop maintains a rosette form for some weeks before rapid elongation to mature height. The florets are self-pollinating but seedset can be increased by bees or other insects.

Safflower is one of humanity's oldest crops, but generally it has been grown on small plots for the grower's personal use and it remains a minor crop with world seed production around 800 000 t per year (Gyulai 1996). Oil has been produced commercially and for export for about 50 years, first as an oil source for the paint industry, now for its edible oil for cooking, margarine and salad oil. Over 60 countries grow safflower, but over half is produced in India (mainly for the domestic vegetable oil market). Production in the USA, Mexico, Ethiopia, Argentina and Australia comprises most of the remainder. China has a significant area planted to safflower, but the florets are harvested for use in traditional medicines and the crop is not reported internationally.

This monograph is intended to provide information on potential resources for the safflower scientific community. Some information has not been subjected to the rigorous scrutiny of scientific peer review but may be valuable since safflower has not attracted scientific study until relatively recently and the medicinal uses in China have not been generally acessible to the rest of the world.

1 Names, taxonomy and centres of diversity

1.1 Names

Safflower is most commonly known as 'kusum' (India, Pakistan), derived from the Sanskrit, 'kusumbha' (Chavan 1961), and as 'honghua' (red flower) in China. Its use as a less costly substitute for saffron is indicated by the names false saffron, bastard saffron, thistle saffron and dyer's saffron (Weiss 1983). Common names, with countries and/or languages, are shown in Table 1. Other safflower names recorded include: 'agnisikha', 'asfiore', 'assfore', 'asfrole', 'brarta', 'carthami flos', 'flase', 'ghurtom', 'golzardu', 'hebu', 'kahil', 'kajena-goli', 'kamal lotarra', 'kar', 'karar', 'kazhirak', 'khariah', 'kharkool', 'khartum', 'khasdonah', 'kouchan-gule', 'ma', 'maswarh', 'ostur', 'saffiore', 'snecus', 'su', 'suban', 'zaffrole', 'zaffrone' (Chavan 1961; Smith 1996).

1.2 Species

Knowledge of the cytogenetic and taxonomic relationships among species of *Carthamus* provides a basis for the effective utilization of characteristics in wild and weedy relatives of *Carthamus tinctorius* in future breeding programmes. Kumar (1991) provides an appraisal of past cytogenetic research in safflower, identifying gaps and deficiencies. Information still missing relates to such aspects as the original chromosome number of the genus *Carthamus* and the genetic distance among possible donors in relation to the recipient. A number of wild species, such as *C. persicus (*syn. *C. flavescens), C. lanatus, C. oxyacanthus* and *C. palaestinus,* were identified by Kumar and Agrawal (1989) as good sources of resistance or tolerance to various diseases and pests. Drought-hardiness and resistance to alternaria leaf blight have been partly incorporated into cultivated types through repeated backcrossing and selection.

1.3 Cultivated safflower and its relatives

Cytogenetic studies led Imrie and Knowles (1970) and Khidir and Knowles (1970) to suggest that *Carthamus palaestinus* Eig, a self-compatible wild species restricted to the deserts of southern Israel and western Iraq (Zeven and Zhukovsky 1975), with white and yellow flowered forms, is the progenitor from which derive the weedy species *C. oxyacanthus* Bieb., a mixture of self-compatible and self-incompatible types, and *C. persicus* Willd., a self-incompatible species. These in turn are considered the parental species of the cultivated species *C. tinctorius* L. (Ashri and Knowles 1960). The four species have the genome formula BB and $2n=24$ chromosomes; intercrosses, in all combinations, produce fertile hybrids (Knowles 1959). Pairing of chromosomes is essentially complete in hybrids between these species; this is not the case if the parental species have different chromosome numbers (Ashri and Knowles 1960). Introgression of the weedy and cultivated species may still take place (Zeven and Zhukovsky 1975).

The weedy progenitors of cultivated safflower are widely distributed in the areas where safflower is grown. *Carthamus oxyacanthus* is a very serious common

Table 1. Safflower names around the world.

Country	Common name	Reference	Notes
Afghanistan	Muswar, Maswarah	Knowles 1959	Kabul
	Kajireh	Knowles 1959	Herat
	Kariza	Knowles 1959	Ghazni
Arabia (Iran, Jordan, Syria, Egypt)	Qurtum, Gurtum, Osfur, Asper	Knowles 1959	
	Kurtum, Usfar	Chavan 1961	
Bangladesh	Kusum, Kusumppuli	Chavan 1961	
China	Honghua, Grass safflower, Compositae safflower, Huai safflower, Chuan safflower, Du safflower	Yuan Guobi *et al.* 1989	
Ethiopia	Suff	Smith 1996	
France	Le carthame		
Germany	Saflor, Färberdistel		
India	Jafran	Chavan 1961	(Assamese)
	Kusumba	Knowles 1959	Bihar
	Kusumbo	Chavan 1961	(Gujarathi)
	Kusum Karrah	Chavan 1961	(Hindi)
	Kusuma	Knowles 1959	Hyderabad
	Kusumbe, Kusume	Chavan 1961	(Kanarese)
	Hubulkhurtum (‘seed of safflower’)	Knowles 1959	Kashmir
	Kardai, Kardi	Chavan 1961	(Marathi)
	Kasumba	Chavan 1961	(Punjabi)
	Pavari	Chavan 1961	(Sindhi)
	Sendurakam	Chavan 1961	(Tamil)
	Kushumba	Chavan 1961	(Telugu)
Iran	Golbar aftab	Knowles 1959	Ghom
	Koshe or Kousheh, Kafsha or Kafshe	Knowles 1959	Isfahan
	Kajireh, Golzardu	Knowles 1959	Meshed
	Kajena goli, Khardam	Knowles 1959	Saveh
	Khasdonah, Laba torbak	Knowles 1959	Shiraz
	Zafaran-Golu	Knowles 1959	Tabriz (Turkish)
Italy	Cartama		
Japan	Benibana, Benihana	Smith 1996	
Latin America	Cartamó, Azafrancillo	Smith 1996	
Pakistan	Kusumba	Knowles 1959	
Spain	Alazor, Azafran romí	Knowles 1959	
Turkey	Aspir, Dikken	Knowles 1959	
	Kazhira	Chavan 1961	(Persian)
	Cnicus, Cnecus, Cnikos	Weiss 1971	(early Greek)
	Onicus	Chavan 1961	(Latin)

weed of Pakistan and northwest India, west to Iraq, adapted to habitats associated with people and crop cultivation (Ashri and Knowles 1960), common in disturbed soils along roadsides and growing after crops such as wheat and barley are harvested. It is a branching, very spiny, annual weed. Seeds contain approximately 28% oil and can be used for culinary purposes and as lighting fuel (Weiss 1983). Seeds are mostly small and black with no pappus. *Carthamus persicus* is also a very serious weed, in Syria, Lebanon and Turkey (Knowles 1959, 1965) with light yellow to orange flowers. Outer involucral bracts are narrow and extend beyond the head (Ashri and Knowles 1960). The black seeds have pappus and are rhombic in cross-section.

1.4 Centres of similarity of *C. tinctorius*

Knowles (1969) coined the term 'centres of similarity' for seven regions which are not centres of diversity or origin, but of remarkably similar safflower types (Table 2).

Ashri (1973), after examining 13 morphological features of 2000 safflower accessions from 30 countries, modified Knowles' list and added three more centres of similarity to the list. Using the D2 analysis developed by Mahalanobis, as well as canonical analysis, Patel *et al*. (1989) confirmed the presence of considerable genetic diversity in a population of 56 representative genotypes from India and other countries. Plant height, seed yield, branching height and seed weight accounted for 80% of the diversity. The 14 clusters formed were not associated with geographical regions, confirming that factors aside from geographic isolation contribute to genetic diversity in *C. tinctorius*.

Table 2. Characteristics of safflower from different centres of similarity, listed in order of decreasing frequency.

Centre colour	Height	Branching	Spines	Head size	Flower
Far East	tall	interm.	sp, spls	interm.	r
India-Pakistan	short	many	sp	small, interm.	o, w, r
Middle East	tall	few	spls	interm., large	r, o, y, w
Egypt	interm.	few	sp, spls	large, interm.	o, y, w, r
Sudan	short, interm.	interm.	sp	small, interm.	y, o
Ethiopia	tall	many	sp	small	r
Europe	int.	interm.	sp, spls	interm.	o, r, y, w

Abbreviations: interm.=intermediate; sp=spiny; spls=spineless; r=red; w=white; o=orange; y=yellow (adapted from Knowles 1969).

1.5 Other *Carthamus* species with 12 pairs of chromosomes

Carthamus arborescens L., found in Spain and adjacent northern Africa, has 12 pairs of chromosomes but failed to hybridize with other *Carthamus* species (Ashri and

Knowles 1960). *Carthamus riphaeus* Font Quer is very restricted in occurrence, having been found only in a small area in northern Morocco (Ashri and Knowles 1960). *Carthamus nitidus* Boiss., while classified by Ashri and Knowles (1960) as having 10 pairs of chromosomes, has subsequently been reclassified as having 12 pairs (Kumar 1989; López-González 1989). Nevertheless, this species is sufficiently isolated from the other species to constitute a separate section (López-González 1989).

1.6 *Carthamus* species with 10 pairs of chromosomes

The species having 10 pairs of chromosomes are characterized by a preponderance of purple, blue and pink flowers and include *C. boissier*i Halácsy, *C. dentatus* Vahl (genome formula A_1A_1), *C. glaucus* Bieb. and its various subspecies (genome formulae AA or AA / A_3A_3), *C. leucocaulos* Sm. (genome formula A_2A_2) and *C. tenuis* (Boiss.&Bl.) Bornm. (López-González 1989). The subspecies of *C. glaucus* together cover the area east and north of the Mediterranean Sea: subsp. *glaucus* (I.B.) Schank, in Transcaucasia, Syria, Turkey and Iran; subsp. *anatolicus* (Boiss.) Han. in Israel; subsp. *glandulosus* Han. in Jordan, and subsp. *tenuis* (Boiss. & Bl.) Schank in Israel.

1.7 *Carthamus* species with 11, 22 and 32 pairs of chromosomes

The only species with 11 pairs of chromosomes is *C. divaricatus* (Beg. & Vace.) Pamp., which has a very restricted range in Libya (Knowles 1988). Flowers may be yellow, purple or white with yellow pollen. It is self-incompatible but it will cross with species having 10 pairs of chromosomes and produce partly fertile hybrids. Crosses with *C. tinctorius* are possible, but hybrids are sterile.

Carthamus lanatus L., with 22 pairs of chromosomes and a genome formula of $A_1A_1B_1B_1$, occurs naturally in Portugal, Spain, Morocco, Greece and Turkey. Because its oil content is 16%, and thus suitable for human use (Weiss 1983), it was introduced to Australia where it became a noxious weed. It is considered a progenitor of the two species with $2n$=64: *C. creticus* L. (syn. *C. baeticus* (Boiss. & Reuter) Nyman with a genome formula of $A_1A_1B_1B_1A_2A_2$) and *C. turkestanicus* M. Popov, with a genome formula of $A_1A_1B_1B_1$AA (Khidir and Knowles 1970). *Carthamus leucocaulos* Sibth. & Sm., with $2n$=20 chromosomes and a genome formula of A_2A_2, found on the islands of Greece, is considered another progenitor of *C. creticus* (Khidir and Knowles 1970), and *C. glaucus*, with $2n$=20 and the genome formula AA, is considered the other progenitor of *C. turkestanicus*. *Carthamus lanatus* is self-compatible and has yellow or white flowers, with yellow pollen. *Carthamus creticus* has spread to the eastern Mediterranean, north Africa and Spain; it is self-pollinated, has white pollen, and is a vigorous competitor in nature (Khidir and Knowles 1970). *Carthamus turkestanicus* is found in west Asia, east to Kashmir and in Ethiopia; it has 22 pairs of chromosomes in common (homologues) with *C. creticus*, also has white pollen, and its similarity in appearance to *C. lanatus* in Thrace suggests considerable gene exchange (Khidir and Knowles 1970).

1.8 Alloploids of cultivated safflower with species of different chromosome numbers

Fertile hybrids between *C. tinctorius* (2*n*=24) and *C. tenuis* (2*n*=20), with a high number of bivalents, and with *C. lanatus* (2*n*=44), have been achieved artificially (Ashri and Knowles 1960).

1.9 Genus reclassification

A new classification system, based on anatomical, chorological (biogeographic, related to distribution) and biosystematic information, has been developed and proposed by López-González (1989) working in Madrid, Spain. In this system, the two genera *Carthamus* and *Carduncellus* are replaced by four new genera: *Phonus, Lamottea, Carthamus* and *Carduncellus.* The respective type species are: *Carthamus arborescens* L., *Carthamus caeruleus* L., *Carthamus tinctorius* L., and *Carduncellus monspelienium* All. Species of the three genera *Phonus, Lamottea* and *Carduncellus* are all classified as perennial and have 24 chromosomes in their genomes, whereas the newly circumscribed genus *Carthamus* contains only annual species, and has members of 20, 22, 24, 44 and 64 chromosomes, including several putative allopolyploid species.

The geographical distribution for the four proposed genera is as follows*: Phonus* is found in the Iberian Peninsula (Spain and Portugal) and northern Africa*; Lamottea* is mainly found in the western Mediterranean regions; *Carthamus* is found in west and central Asia as well as in the Mediterranean region; and *Carduncellus* is found in the western European region of the Mediterranean, northern Africa, Egypt and Israel / Palestine.

Only the new genus *Carthamus* is further subdivided into sections, with the species indicated.

Section **Carthamus** has 24 chromosomes and includes the following species: *C. curdicus* Hanelt, *C. gypsicola* Ilj., *C. oxyacanthus* Bieb., *C. palaestinus* Eig, *C. persicus* Willd. and *C. tinctorius* L.

The position of *C. nitidus* Boiss. [2*n* = 24] is questionable. This species seems to be sufficiently isolated from the rest of the genus to form a separate section.

Section **Odonthagnathius** (DC.) Hanelt (incl. Sect. *Lepidopappus* Hanelt) has 20 or 22 chromosomes and includes the following species: *C. boissieri* Halácsy, *C. dentatus* Vahl, *C. divaricatus* Beguinot & Vacc. (with 22 chromosomes), *C. glaucus* Bieb., *C. leucocaulos* Sm. and *C. tenuis* (Boiss. & Bl.) Bornm.

Section **Atractylis** Reichenb., with a presumed *x* number of 11, contains numerous polyploids, including the following species: *C. lanatus* L., *C. creticus* [*C. baeticus* (Boiss. & Reuter) Nyman] and *C. turkestanicus* M. Popov.

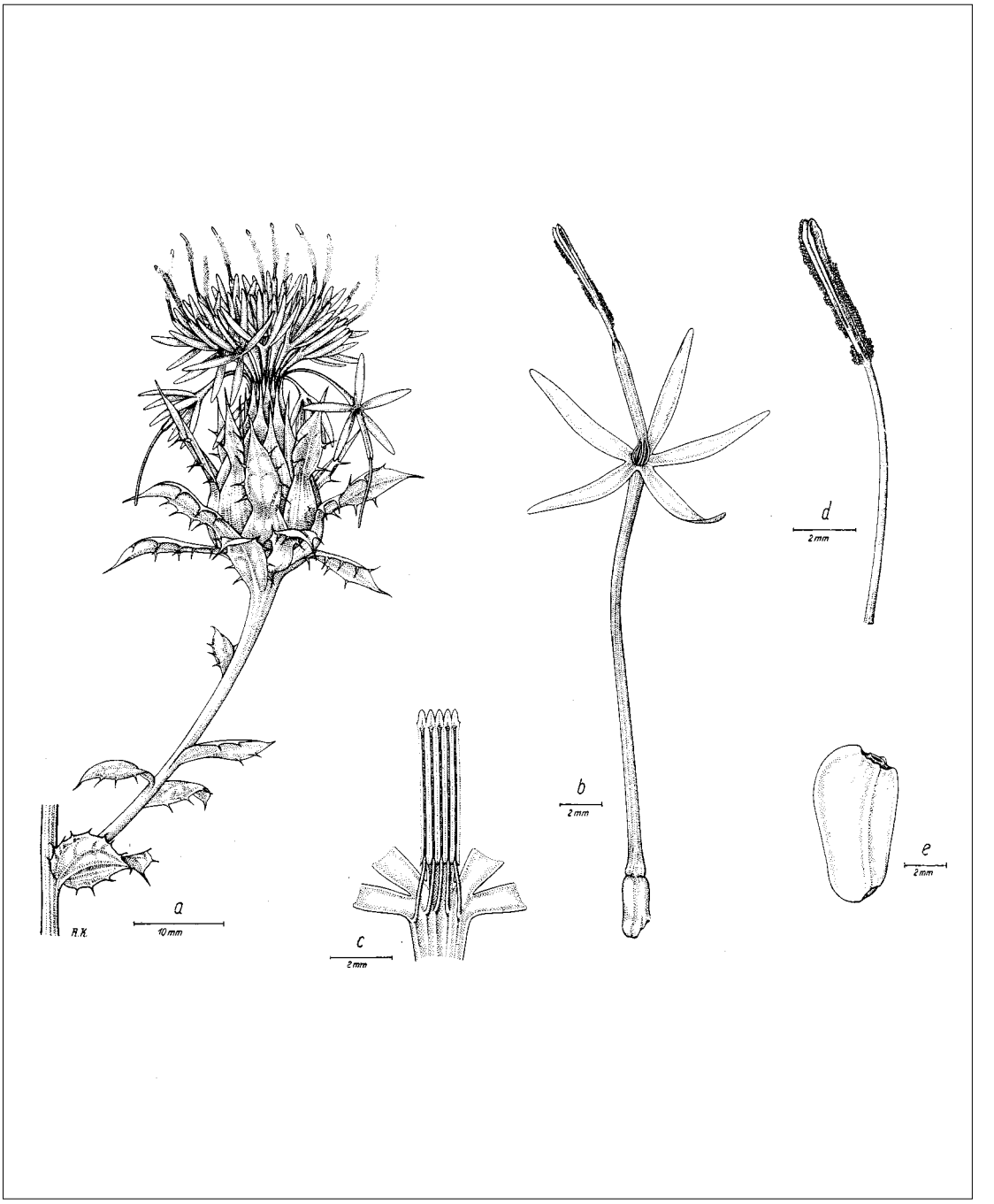

Fig. 1. *Carthamus tinctorius* L. (a) branch with capitulum, (b) disk (tubular) floret, (c) anther tube (slit on one side), (d) stigma, (e) achene (seed) (Drawing by R. Kilian in P. Hanelt (1961) Kulturpflanze 9, p. 120; reprinted with permission of the Akademie Verlag, Berlin).

2 Safflower biology, production and genetics

2.1 Biology

Safflower (*Carthamus tinctorius* L.) a member of the family Compositae or Asteraceae, is a branching, thistle-like herbaceous annual or winter annual plant, with numerous spines on leaves and bracts (Fig. 1), mainly grown in dry hot climates as an oilseed, birdseed or for its flowers, used as dye sources and for medicinal purposes. The typically white achenes, averaging from 0.030 to 0.045 g, are smooth (in some varieties varying amounts of pappus, tufts of hairs may be present on the end adjacent to the plant) and four-sided, with a thick pericarp (Figs. 1, 2). Germination is followed by a slow-growing rosette stage, during which numerous leaves are produced near ground level, strong taproots develop and begin to penetrate deep into the soil, but no long stems form. During this rosette stage, young safflower plants are resistant to cold, even frost, but the crop is very vulnerable to fast-growing weeds. Subsequently, stems elongate quickly and branch extensively (Fig. 3). Branch to stem angles range from 30 to 70º and the degree of branching is genetically and environmentally controlled. Each stem ends in a globular flower capitulum, enclosed by clasping bracts, which are typically spiny (Fig. 4).

Fig. 2. Seeds with pappus (left), white, normal (right) (reprinted with permission from Mündel *et al.* 1992).

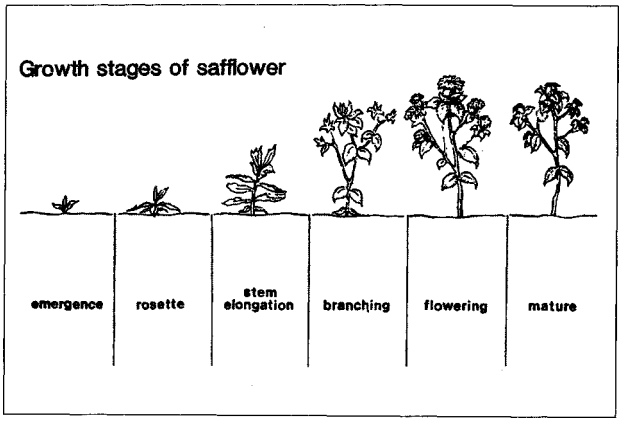

Fig. 3. Schematic sketch of growth stages of safflower (reprinted with permission from Mündel *et al*. 1992).

Fig. 4. Single plant showing primary, secondary and tertiary heads (reprinted with permission from Mündel *et al*. 1992).

In fully developed safflower plants, with soil of adequate depth, the taproots penetrate 2-3 m, with numerous thin horizontal lateral roots. The deep root system enables the plant to draw moisture and nutrients from a considerable depth, conferring on safflower the ability to survive in areas with little surface moisture.

Flowering begins in the primary capitulum, then the secondary capitula and so forth. Within a capitulum, flowering begins in the outer circle of florets and progresses centripetally towards the centre of the capitulum over several days, up to a week. The total bloom stage may last for 4 weeks or more, greatly influenced by growing environment. Shades of orange, yellow and red flowers are most common in early bloom, but post-bloom colours are darker. White flowers occur rarely. The florets are tubular and largely self-pollinating with generally less than 10% outcrossing (Knowles 1969). Pollination occurs as the style and stigma grow through the surrounding anther column at the base of the clasping corolla (Fig. 1). An unpollinated, elongated stigma may remain receptive for several days. Bees, bumblebees and other insects seek out safflower blossoms for both pollen and nectar and can increase levels of outcrossing. Wind-pollination does not contribute to safflower seedset. Developed capitula contain 15-30 or more achenes (Fig. 5), which mature from 4 to 5 weeks after flowering.

Fig. 5. Cross-section of mature safflower head (capitulum), showing seeds enclosed by outer involucral bracts (reprinted with permission from Mündel *et al.* 1992).

A mature achene of common varieties is made up of 33-60% hull and 40-67% kernel. Oil content ranges from 20 to 45% or more of the whole seed. Selection for high oil content in modern cultivars has reduced the pericarp thickness. Seed mass increases rapidly during the first 15 days after flowering. In California, oil content increased 5- to 10-fold during the 10-15 days after flowering (Hill and Knowles 1968). Leininger and Urie (1964) determined that, for their varieties in their growth environment, maximum dry matter accumulation, maximum oil content, maximum germination and minimum hull percentage occurred 28 days after fertilization of a floret, when the seed moisture content was 22-25%.

Leaf size varies greatly among varieties and on an individual plant, and ranges typically from 2.5 to 5 cm wide and 10 to 15 cm long. Leaves are usually deeply serrated on the lower stem, but short and stiff, ovate to obovate around the inflorescence, where they form the involucral bracts. Lower leaves are generally spineless, but further up the stem spines develop in the bud stage and become strong, hard spines by full flowering. Varieties that are almost completely free of spines have been developed for hand harvest of floral parts and of seeds in certain geographic regions (e.g. China, nontraditional areas of India).

2.2 Production issues

Over the past few decades, fact sheets and production guides have been provided for safflower growers in different countries. A sampling of those published in the past 5 years in North America is given in the literature section.

Safflower is generally considered a daylength-neutral, long-day plant. However, the origin of varieties is very important in this connection: summer crop varieties from temperate regions, sown during shortening days as a winter crop in subtropical or tropical regions, have a very long rosette phase (several months), with greatly delayed maturity.

Seeding rates vary greatly around the globe, in part related to variety growth habits, growth environments and cultural methods, particularly row spacing. As long as soil moisture reserves are present, safflower compensates for low plant populations by increased branching and other yield component adjustments (Mündel 1969). Seeding rates for optimum production vary from around 10-15 kg / ha in very drought-prone regions, or those where branching is to be encouraged, up to 40-45 kg / ha or even more for irrigated environments, in regions and with varieties showing minimal branching. Germination of safflower seed occurs at temperatures as low as 2-5º C.

During the rosette stage, the growing point of the young safflower plant is protected from cold by multiple layers of young leaves and leaf primordia, and temperatures as low as –7ºC do not kill the plant (Mündel *et al.* 1992). The first few leaves emerging after a frost may show some injury, but the plant recovers and continues to grow quite normally. However, during the elongation phase, even a light frost can cause substantial damage. At the other end of the plant's development, frost just after flowering (during kernel filling) can dramatically lower yields and oil levels, or kill the seed completely.

During the early stages of growth, especially during the rosette stage, safflower is a poor competitor with weeds. Numerous weed species, left unchecked, can become taller than safflower and effectively shade the crop, competing for sunlight, nutrients and soil moisture. Weeds can cut safflower yields greatly and can cause complete crop losses. Only a limited number of chemical herbicides are registered for use on safflower, mainly because of the high cost of testing required in a number of countries for this minor crop. In Canada the trifluralins and ethalfluralins are registered for pre-plant incorporation to control a variety of grass and broadleaf weeds; a sethoxydim has been registered for post-emergent control of grassy weeds and volunteer cereals (Blackshaw *et al.* 1990). Seeding safflower into a firm moist seedbed not only enhances its emergence and stand, but also improves vigour and allows the crop to compete more effectively with weeds. Mechanical or manual control of weeds emerging prior to safflower emergence is advised.

Safflower, with its deep taproot and xerophytic attribute of spines, has good drought and heat tolerance. The crop may use considerable amounts of soil moisture, but it does not survive standing water for even a few hours in warm weather (air temperatures above 20ºC), partly owing to the rapid spread of soilborne pathogens such as *Phytophthora* (Rubis 1981) and *Pythium*, but also because anaerobic conditions cause plant death very quickly (Mündel *et al.* 1995). Well-drained, deep, fertile, sandy loam soils support maximum safflower yields. In heavy clay soils, crusting may reduce emergence of seedlings and seeding rates that are higher than normal are needed. In general, if moisture has been limiting, one good irrigation just prior to bloom increases yield significantly. Such a system of 'protective irrigation' is used widely in India (A.K. Deshmuk, pers. comm., 1986). Excess rainfall, especially after flowering begins, contributes to a vast array of leaf and head diseases, which reduce yields and even cause crop loss. Kolte (1985) provides a detailed discussion of safflower diseases. Prolonged rainfall during flowering interferes with pollination and seedset, as do high temperatures (i.e. >32ºC) during pollen shedding in the mornings (Mündel *et al.* 1992). Highest yields, with very low disease infection have been achieved with subirrigation, as practised in the Sacramento Valley of California, USA (A.B. Hill, pers. comm., 1968).

Safflower is a long-season crop with a deep taproot that can draw moisture from deep in the subsoil. Thus, it can access and utilize nutrients from below the root zone of cereal crops. Nevertheless, fertilizers tend to increase yields and oil levels, especially in irrigated or higher rainfall areas. Furthermore, in areas afflicted with dryland salinity, safflower uses surplus water from recharge areas, drawing down the moisture with the salts dissolved in it, preventing expansion of saline seeps (Mündel *et al.* 1992).

2.3 Genetics

The outcome of the studies of inheritance of safflower characters is greatly influenced by the selection of parental lines and many sets of parent lines have been used in crosses, especially in diallel crosses. Valid determinations of the heritability,

mode of action and potential for utilization by breeders of genes associated with particular characters will likely require cumulative results from several studies. Only a sampling of studies, on traits discussed in Chapter 6, is presented here, to indicate the types of gene action that have been found in potentially useful characters of safflower. Estimates of heritability for seed yield and oil content generally have been low (e.g. Gupta and Singh 1988).

2.3.1 Seed and oil quality

As the thick pericarp tends to keep the oil content in safflower low, reduction of the pericarp directly increases oil percentages. A number of genes with specific phenotypes have been identified: partial hull (*par par)*, recessive to normal hull, inherited independently of thin hull (*th th)* and striped hull *(stp stp)* (Urie 1981), grey-striped hull (*stp*^{2}) (Abel and Lorance 1975) and reduced hull (*rh rh) (*small dark blotches on the seed*)*. Partial hull plants produce achenes which are predominantly dark owing to a reduction in the outer sclerenchyma layer of the pericarp, resulting in high oil and protein levels; the partial hull character is recessive to reduced hull (Urie 1986). Normal hull is dominant or partly dominant to reduced hull, depending on the normal-hull parent used (Urie and Zimmer 1970a). Thin hull (*th th)* is associated in a pleiotropic effect, by the thickening of endothelial cell walls in the anthers, with a type of structural male sterility, but hybrid seed production was unsuccessful because of the sensitivity of this genotype to environmental effects (Urie and Zimmer 1970b). Striped hull (*stp stp*) is associated with an undesirable colour and odour (Urie and Zimmer 1970b) in oil.

Table 3. Palmitic (C16:0), stearic (C18:0), oleic (C18:1) and linoleic (C18:2) acid content of oil of selected safflower lines and possible genotypes.

		Fatty acid content in safflower oil (%, range)			
		C16:0	C18:0	C18:1	C18:2
Oil type	Genotype	Palmitic	Stearic	Oleic	Linoleic
Very high linoleic	*OlOlliliStSt*	3-5	1-2	5-7	87-89
High linoleic	*OlOlLiLiStSt*	6-8	2-3	16-20	71-75
High oleic	*ololLiLiStSt*	5-6	1-2	75-80	14-18
Intermediate oleic	*ol'ol'LiLiStSt*	5-6	1-2	41-53	39-52
High stearic	*OlOlLiListst*	5-6	4-11	13-15	69-72

Adapted from Knowles (1989).

Interest in a few major fatty acids in the oil of safflower has been high and the genetics of seed content of oleic, linoleic, stearic and palmitic acids were studied by

Futehally (reported by Knowles 1989) (Table 3). The three genes that control production of oleic, linoleic and stearic acids (*ol ol, li li* and *st st*, respectively*)* appear to be major recessive genes at different loci. Increases in stearic acid are accompanied by decreases in the percentage of oleic or linoleic acid or both and, in certain genotypes, it appears that cooler growing temperatures reduce stearic and oleic acids while increasing linoleic acid (Ladd and Knowles 1971). Two alleles have been reported for the *ol* locus, and this locus is linked to trigenic male-female sterility (*S1)* (Carapetian and Knowles 1993).

2.3.2 Plant and developmental characters

Time of flowering was studied by Kotecha (1979), using interspecific crosses of wild and domestic safflower. Time of flowering was identified as a quantitatively inherited trait, influenced by dominance, additive and epistatic gene effects. Based on data from a 10-parent diallel cross, Gupta and Singh (1988b) found partial dominance for days to flowering and overdominance in the F_1 to complete dominance in the F_2 for days to maturity.

Ashri (1971a) found capitula per plant was the most important yield component in safflower. Narkhede and Patil (1987) also reported that this character contributed most to a heterotic effect in 17 crosses of safflower. Number of primary and secondary branches was the next most important contributor to the heterotic effect. Most of the characters studied appeared to be controlled by nonadditive gene action with a degree of overdominance. Correlated responses in various crosses showed that selection for capitula per plant was effective for the improvement of yield (Patil *et al.* 1994). Capitula per plant seemed to be controlled by four groups of genes in a 10-parent incomplete diallel cross (Gupta and Singh 1988a), with mainly nonadditive gene action. However, additive gene action controlled the number of primary branches. In studying yield-related traits over six generations, Narkhede *et al.* (1987) determined that dominance effects were predominant for capitula per plant (and for branches per plant) and duplicate epistasis was evident for all characters studied. These authors recommend reciprocal recurrent selection for the improvement of safflower yields.

Safflower generally lacks seed dormancy and can germinate in the head if rainfall occurs at harvest time. In interspecific crosses of safflower (*C. tinctorius*) with its wild relative, *C. palaestinus*, Kotecha and Zimmerman (1978) observed nonadditive variation for germination time in most crosses. Transgressive segregation for no germination was observed. These workers suggested that genes at a minimum of four loci control germination. When freshly harvested, one line, BJ-26, identified in China by the first author (Li Dajue), required about twice as long as the average of tested lines to germinate, i.e. 112 hours compared with the average of around 60 hours. After 7-8 years in storage, BJ-26 required 66 hours for germination.

In efforts to produce hybrid safflower, Heaton and Knowles (1980) registered two male sterile safflower germplasm lines, UC-148 and UC-149. A single recessive

gene (*ms ms)* conferred complete male sterility. Pollen viability in the heterozygote was normal, as was female fertility of the *ms ms* plants.

Spininess is considered a handicap in introducing safflower to new areas, especially where manual harvest is involved. Narkhede and Deokar (1990) found that spines are basically dominant over spinelessness and concluded that four genes – *Sa, Sb, Sc* and *Sd* – are involved in determining level of spininess. *Sa* is considered the main gene, with any two of the remaining genes acting as complementary duplicates in action.

Studies on the inheritance of pappus (not desirable in commercial cultivars) and seed weight led Kotecha (1979) to conclude that both traits are controlled by at least two loci. Most genetic variance is additive but nonadditive gene effects were detected.

Flower colour is generally considered neutral for seed yield and oil, but when the crop is grown for the florets, colour is important. In India, Narkhede and Deokar (1986) identified four dominant genes: *Y, C, O* and *R*. The gene *C* and combinations *C+O, C+R* and *C+O+R* produced greyish white flowers; *Y+C* produced red flowers; *Y+C+O* and *Y+C+O+R* produced yellowish brown flowers.

2.3.3 Disease resistance

The genetics and mode of inheritance of disease resistance and tolerance, like those for other biotic and abiotic stresses (e.g. insects, parasitic weeds, salinity or alkalinity) are not well defined in most cases. These characteristics can most readily be incorporated into new lines by subjecting germplasm to the relevant stress in the field or laboratory and selecting unaffected plants for breeding programmes. Knowledge of the genetics involved would help breeders in this process; however, there is a great need for rapid, effective and economical screening tools to identify resistant germplasm, preferably at the seedling stage. The only other option is to screen the final products of a breeding programme, advanced lines being evaluated for release as potential varieties; but this does not permit active selection.

Germplasm lines or varieties with identified resistance to some of the major crop diseases have been identified. The genetics have been determined in only a few cases.

Alternaria resistance, to the fungus *Alternaria carthami* (for symptoms see Figs. 6 and 7), together with resistance to the bacterial pathogen *Pseudomonas syringeae*, has been successfully incorporated into several safflower varieties, e.g. Oker, Hartman and Girard produced by the team led by the breeder J.W. Bergman at Sidney, Montana, USA. Beginning in the early 1960s, this group crossed commercial cultivars with mass-selected resistant lines from a disease nursery (Bergman *et al*. 1985, 1987, 1989). In Australia, E.K.S. Harrigan developed Sironaria from a programme of backcrossing to Gila, incorporating resistance to races of *A. carthami* prevalent in Australia (Harrigan 1987a).

Rust resistance against *Puccinia carthami* has been identified, and five improved lines (PCA, PVM-1, PCM-2, PCN and PCOy), each carrying a different dominant

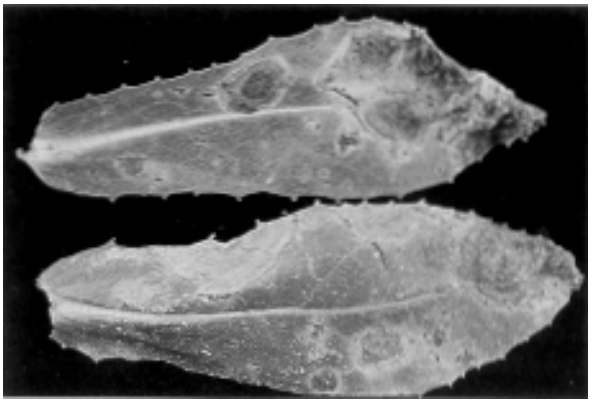

Fig. 6. Disease symptoms of *Alternaria carthami* on safflower leaves (reprinted with permission from Mündel *et al.* 1992).

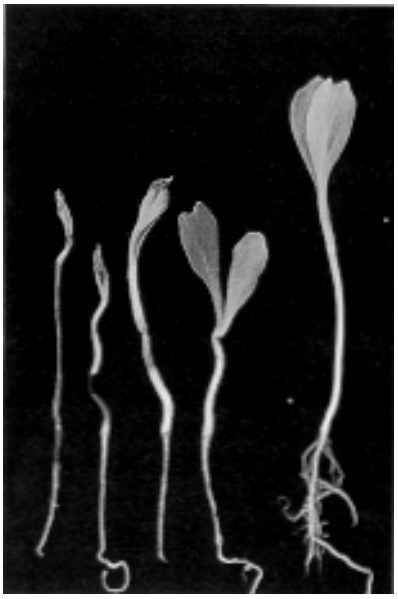

Fig. 7. Healthy seedling with branching roots on right; four diseased seedlings on left: from damping-off pathogens (e.g. seedborne *Alternaria carthami* or soilborne *Pythium ultimum*) (reprinted with permission from Mündel *et al.* 1992).

gene for rust resistance, have been developed (Zimmer and Urie 1970). These lines together provided effective resistance, in both seedling and foliage stages, against all races of rust identified at that time. Lesaf 175, developed by Mündel (1987), incorporates the dominant gene A from PCA into a striped-hull, white-flowering, high-oil line.

Germplasm identified as VFR-1, developed by Thomas (1971) from the breeding line Nebraska 4051, incorporates resistance to verticillium wilt, fusarium wilt and rot, and rhizoctonia root rot, caused by *Verticillium albo-atrum* Reinke & Berth., *Fusarium oxysporum* Schlecht f. sp. *carthami* Klis. & Hous. and *Rhizoctonia solani* Kuhn, respectively. A total of 14 spiny and spineless germplasm lines (GP18 to GP31), resistant to four races of *F. oxysporum* f.sp. *carthami*, were registered by Klisiewicz and Urie (1982). Resistance to all prevalent races of root rot caused by *Phytophthora drechsleri* Tuck was incorporated into the cultivar Dart (Abel and Lorance 1975).

Sclerotinia head rot (caused by *Sclerotinia sclerotiorum* (Lib.) de Bary) (for symptoms see Fig. 8) resistance was incorporated into the first registered Canadian safflower cultivar, the early maturing Saffire, following mass selection and screening in disease nurseries (Mündel *et al.* 1985).

Fig. 8. Infected heads with sclerotia of *Sclerotinia sclerotiorum* in base of heads (reprinted with permission from Mündel *et al*. 1992).

3 Uses and world distribution

3.1 Uses

3.1.1 Historical

In Egypt, dye from safflower was used to colour cotton and silk as well as ceremonial ointment used in religious ceremonies and to anoint mummies prior to binding. Safflower seeds and packets and garlands of florets have been found with 4000-year-old mummies (Weiss 1971). The oil was used as an unguent and for lighting. By the 18th century, Egyptian safflower dye was used in Italy, France and Britain to colour cheese and flavour sausage.

According to Weiss (1971), safflower has been used in the Middle East, India and Africa for purgative and alexipharmic (antidote) effects, as well as in a medicated oil, to promote sweating and cure fevers. Florets were widely used to colour and flavour soups and rice as well as cloth, potions and unguents. Safflower was used as a pot herb and as a laxative (De Materia Medica Dioscorides, cited by Weiss 1983). The 10th century Arab pharmacist, Mesua (cited by Chavan 1961), distinguished the safflower of India from the plant of the same name around Baghdad, which is recognizable from his drawing as *C. tinctorius*. Safflower was retained in the European pharmacopoeia until recently, but seldom prescribed as a specific remedy (Weiss 1983). The Japanese pharmacopoeia details use of safflower (Weiss 1971).

Safflower dyes were particularly important to the carpet-weaving industries of eastern Europe, the Middle East and the Indian subcontinent. Carthamin dye was used extensively to colour cloth until the 19th century, when cheaper aniline dyes became available. Hebrew writings since the 2nd century AD have described the use of tablets of carthamin dye for food colouring, rouge and medicine (Weiss 1983).

3.1.2 Whole plants

A tea made from safflower foliage is used to prevent abortion and infertility by women in Afghanistan and India (Weiss 1983). All parts of the plant are sold by herbalists in India and Pakistan as ‘pansari’ to remedy various ailments and as an aphrodisiac (Knowles 1965).

Young leaves and thinnings are eaten boiled, as a vegetable side dish with curry or rice in India, Pakistan and Burma.

Until this century, soot from charred safflower plants was used to make kohl, the Egyptian cosmetic (Weiss 1983).

Safflower can be grazed or stored as hay or silage. The forage is palatable and its feed value and yields are similar to or better than oats or alfalfa (Smith 1996; Wichman 1996). On the Great Plains of North America, the crop remains green after other crops have matured. Tests in India show that seed production from a ratooned crop is possible. Safflower straw is used similarly to cereal straws. Two or three rows of safflower around a cereal field can help keep free-ranging cattle out of the grain (Chavan 1961).

3.1.3 Flowers

In China, a pleasant-tasting herbal tea is prepared from safflower blossoms (Li Dajue and Han Yuanzhou 1993). Spineless varieties have been used as cut flowers in western Europe, Japan and Latin America.

3.1.3.1 Colouring food and cosmetic

Addition of safflower florets to foods is a widespread and ancient tradition. True saffron is perhaps the world's most costly spice, and safflower is a common adulterant or substitute. Rice, soup, sauces, bread and pickles take on a yellow to bright orange colour from the florets. Health concerns regarding synthetic food colourings may increase demand for safflower-derived food colouring. China produces carthamin dye for use in food, particularly at a large factory in Kunming in Yunnan Province. Cosmetic rouge can be made from carthamin dye mixed with French chalk, and the Japanese cosmetic ('beni') (Weiss 1983) and lipsticks include safflower colouring (Smith 1996).

3.1.3.2 Dyes

Until this century, when cheaper aniline dyes became available, safflower was mainly grown for dye. The water-soluble yellow dye, carthamidin, and a water-insoluble red dye, carthamin, which is readily soluble in alkali, can be obtained from safflower florets (Weiss 1983). Yellow florets contain little or no red dye (Smith 1996). Dye manufacture has virtually ceased in Asia, but dye is still prepared on a small scale for traditional and religious occasions. Flowers are collected in the early morning and dried in the shade. To extract the dye, corollas are washed for 3-4 days in acidulated water in which the dye dissolves. The remaining flower pulp is dried into small cubes and sold locally or treated with sodium carbonate solution to extract the carmine which is then precipitated by dilute acids. Mid-season pickings from the Dacca area of Bangladesh are considered to be of high quality and yields of 70-140 kg / ha are normal. Florets can be collected after the crop ripens, so that dye and oilseed can to be obtained from the same crop (Chavan 1961). Florets contain 0.3-0.6% carthamin. Colouring 1 kg of cotton yarn crimson requires 1 kg of dye, rose pink requires 500 g, and light pink, 250 g (Weiss 1971).

3.1.3.3 Medicines

In China, safflower is grown almost exclusively for its flowers, which are used in treatment of many illnesses as well as in tonic tea. Safflower has a bitter herbal taste, but the Institute of Botany of the Chinese Academy of Sciences in Beijing has developed a nonbitter, sweet-smelling tea which contains amino acids, minerals and vitamins B_1, B_2, B_{12}, C and E. Safflower preparations should be stored in light-resistant containers (Weiss 1971). The main active ingredient in safflower medicines is safflower yellow, which is water-soluble, but alcohol extracts are used in some preparations. Many clinical and laboratory studies support the use of safflower medicines for menstrual problems, cardiovascular disease and pain and swelling associated with

trauma.

Laboratory studies: The pharmacology of safflower includes excitation of smooth muscles. A dose-dependent increase in frequency and amplitude of contraction of uterine tissue of dog, rat, cavy (e.g. guinea pig) and mouse persisted for up to 4 hours. The response could be increased to the point of spasm and was greater in tissue from pregnant animals. Excitation effects on intestinal muscle of the same species were brief. The bronchi smooth muscle of cavy was also affected (Sun Shixi 1955).

Contraction effects of safflower on blood vessels of toad and of dog kidney, with a reduction in kidney volume, have been reported. However, extracts of safflower produce a long-term drop in blood pressure of dogs, cats and hypertensive rats (Liu *et al.* 1992) and the adrenaline-induced reduction of capillary blood flow in rat was inhibited or reversed (Qi Ming *et al.* 1984). Small doses of safflower decoction increased the amplitude and systolic volume of the heartbeat in dog.

A 2-week course of safflower yellow reduced total cholesterol and raised HDL-cholesterol in rabbit without affecting beta-lipoproteins, triglycerides or liver function (Qi Wengxuan *et al.* 1987). In rat, safflower decreased platelet aggregation and blood coagulation *in vivo* and *in vitro* (Li Chengzhu *et al.* 1983). Huang Zhengliang *et al.* (1984, 1987) found that safflower yellow at 220 mg/ml completely inhibited aggregation of rabbit platelets and prevented experimental thrombosis in rat. In mice treated with E-Hong injection liquor, ADP-induced thrombi were smaller and persisted for shorter periods than in control animals (Shen Qingliang *et al.* 1988).

Safflower treatment increased uterus weight in ovariectomized mice and increased seminal vesicle weight in castrated mice, but by a smaller amount than treatment with sex hormones did (Jia Hanqing *et al.* 1980).

Strong, long-lasting analgesic effects of safflower yellow have been reported. In mice, the foot-lifting response to formaldehyde, the histamine-mediated increase in capillary blood flow and granulation caused by cotton-ball irritation, were all inhibited. The central nervous system effects of barbitone and chloral hydrate were enhanced by safflower yellow and those of nikethamide (convulsions and some deaths) were reduced (Huang Zhengliang *et al.* 1984).

Clinical use of safflower: Safflower dilates arteries, reduces hypertension and increases blood flow and, hence, oxygenation of tissues. It also inhibits thrombus formation and, over time, dissolves thrombi (Anonymous 1972). Many prescriptions for invigorating blood circulation, especially those for treatment of heart disease, include safflower along with other herbs and have been used in treatment of many diseases (Wang Guishen 1985).

Cardiovascular disease treatment is the main use of safflower because it invigorates the circulation. In 83% of patients with coronary disease, blood cholesterol levels have been reduced after 6 weeks of treatment (Wang Guimiao and Li Yili 1985). Experiments with dogs suggest injections of safflower can reduce the damage done to the heart muscle by an infarction. Heart arrythmia and hypertension

were reduced by safflower treatment three times a day for 4 weeks (Wang Bungzhang *et al*. 1978; Wang Guimiao and Li Yili 1985). A nasal drip of safflower and other herbs speeded blood flow in the medial cranial artery (Duo Zhenshun *et al*. 1992). Injections of safflower extract at Fengfu, Yamen, Fengchi and other acupuncture points every 3 days increased blood flow in the coronary artery (Wang Guimiao and Li Yili 1985).

Treatment of cerebral thrombosis with safflower improved and lowered blood pressure in over 90% of patients (Wang Guimiao and Li Yili 1985; Yu Damao 1987). Herbal decoctions including safflower were also effective in treatment of cerebral embolism (Zhou Zuolin 1992). Lu Zhoucai (1991) treated hemiplegia with a combination of western and Chinese medicine including safflower.

Safflower decoctions have been used successfully for treatment of male sterility (Qin Yuehao 1990) and dead sperm excess disease (Qu Chun 1990). Treatment with safflower resulted in pregnancy in 56 of 77 infertile women who had been infertile for 1.5-10 years (Zhou Wenyu 1986).

Labour can be induced by a preparation of safflower, ideally along with rupture of membranes. According to Liu Yaling (1985), the combination was more effective than western medicine. Safflower boiled in wine along with other flower decoctions is recommended to counter retained afterbirth and retained stillbirth (Wang Guimiao and Li Yili 1985). Safflower, along with Chinese angelica (*Angelica sinensis*) and wine, is used to induce abortion early in pregnancy (Wang Guimiao and Li Yili 1985). For delayed, heavy and painful menstrual periods, safflower soaked in warm white wine or combined with other herbs is advised (Chen Xiuqin 1990; Wang Guimiao and Li Yili 1985; Zhong Xiumei 1992). Safflower combined with peach-kernel (*Prunus persica*), Chinese angelica, chuanxiong (*Ligusticum wallichii*) and peony-root (*Paeonia lactiflora*) is used for some types of amenorrhea (Wang Guimiao and Li Yili 1985). Therapy designed to improve circulation cured pelvic infections in 67% of cases and improved others as well (Wang Chunru 1989).

Recovery from vaso-vagal fainting associated with post-partum haemorrhage has been associated with the steam from a soup of safflower in water (Wang Guimiao and Li Yili 1985).

Chinese medicine recognizes many types of rheumatism. Prescriptions including safflower were successful treatments for sciatica (Wang Guimiao and Li Yili 1985) and thorax rheumatism (Zheng Yukun 1988). Safflower wine is recommended for 62 types of rheumatism.

Safflower prescriptions have been very effective treatments for rheumatoid arthritis (Wang Yue and Wang Luqiu 1990; Wang Zhaoming *et al*. 1985). A preparation of stir-fried earthworm, poisonnut (*Strychnos nuxvomica*) and safflower (10:7:7 by weight) is reported to be highly effective in treating arthritis of the joints (Yau Honghai 1985).

Safflower, along with other herbs, has been used to treat respiratory diseases including pertussis (whooping cough) and chronic bronchitis (Wang Guimiao and Li Yili 1985).

Chronic gastritis and atrophic gastritis, treated with 50 to 120 doses of safflower florets, were cured or improved in over 80% of cases (Chu Hang *et al*. 1985; Ma Shen *et al*. 1989; Wu Lian'en 1992). A safflower decoction cured 70% of patients with ankyloenteron (Dong Jiayun 1988). Constipation caused by medicines for mental illnesses such as schizophrenia has been treated with safflower injections at the Tinggong, Yifeng, Anmian, Fengchi, Naiguan, Chanzohong and other acupuncture points. The injections stimulate menstrual flow, invigorate main and collateral channels and regulate vital energy and blood circulation (Wang Guimiao and Li Yili 1985).

Treatment of epidemic haemorrhagic fever (disseminated intravascular coagulation deficit) in the early stages with safflower-bugleweed (*Lycopus lucidus*) injections prevented further development of the disease (Wang Guimiao and Li Yili 1985).

Chronic nephritis has been improved by safflower treatments (Wang Guimiao and Li Yili 1985; Ye Chuanhui 1986; Zhang Yonghong *et al*. 1989; Zhao Lijun 1990; Zhu Pijiang 1991). Although a seed preparation is suggested for renal calculi (Wang Guimiao and Li Yili 1985), other safflower preparations are used to clear the fever and regulate urethra function as well as the haematuria associated with calculi.

Daily or twice daily doses of safflower with ground beetle in glutinous rice or millet wine helps muscle injuries heal within a week (Wang Guimiao and Li Yili 1985). Wrenched joints were also cured (Lu Jianxin 1989). For wrist tenosynovitis, steaming and wrapping in a towel soaked in a tea of safflower and other herbs is recommended (Qian Zhangquan 1985). A recovery rate of 100% is reported from use of safflower and other herbs for treatment of costochondritis (Wang Wenyuan 1987). Osteochondritis has been cured within 4 days of treatment with compresses of safflower and Chinese angelica (Wang Guimiao and Li Yili 1985). Chronic cartilage strains of the knee were improved with compresses of safflower and dragon's blood (*Daemonoprops draco*) (Xu Zhaoxian 1989). Treatment with safflower and other herbs was effective for chronic suppurative osteomyelitis (Wang Sai 1992) and for cervical spondylosis (Yin Huafu 1988). Bruising can be alleviated by rubbing with an alcoholic safflower preparation (Wang Guimiao and Li Yili 1985). Neonatal cephalo-haematoma was treated successfully with a safflower and chuanxiong injection. Concussion was treated with safflower and peach kernel (Feng Shaoren 1992). Sequelae of concussion have also been treated with safflower and other herbs (Jiang Wei and Kong Fanxue 1992).

In dermatology, safflower has many beneficial effects, including clearing of vitiligo (Bai Pu *et al*. 1992; Tan Dingquan 1989), treatment of erythema nodosum (Si Zaihe 1989) and other skin problems such as pityriasis rosea, polymorphic erythema, acne rosacea, urticaria, psoriasis, pruritis and other dermatitis (Wang Guimiao and Li Yili 1985). Lupus erythematosus has been improved by safflower and other herbs (Wang Zhongying 1989; Wang Guimiao and Li Yili 1985). In cases of nondispersion of macula, for example in measles, the circulatory effects and relief of fever by safflower are beneficial (Wang Guimiao and Li Yili 1985). An alcoholic preparation of safflower and other herbs was completely effective against acne (Liu Yuanxiu 1991). High rates of recovery from alopecia are reported from the use of hair-restoring

preparations including safflower (Chen Shendong 1990; Zhao Zhangguang 1988). Mixed 1:2 with root bark of Chinese wolfberry (*Lycium chinense*) in sesame oil, safflower is an effective poultice for foot callouses (Wang Guimiao and Li Yili 1985).

Spraying the throat with a preparation of safflower and Japanese honeysuckle (*Lonicera japonica*) in water had no side effects and was highly effective in about half of 100 cases of acute laryngitis and pharyngitis and other throat diseases (Wang Shengyun 1985). Safflower treatments, either as topical dust or injections, have been recommended for ear infections (Pan Huanhe 1986; Wang Guimiao and Li Yili 1985).

Safflower eye drops reduce myopia, especially in children (Tao Genyu 1990; Wang Guimiao and Li Yili 1985). Trachoma has been successfully treated with safflower combined with other herbs (Yin Jialou 1986). Invigoration of the blood circulation by safflower has also reduced senile cataracts (Tan Qiuyuan 1992).

Clinical improvements due to safflower treatment have been reported for leukemia (Deng Youan 1988), leucocytopenia (Deng You'an *et al*. 1984), erythrocytosis (Lu Kuijie 1985), allergic purpura, lupus erythematosus (Wang Zhongying 1989; Wang Guimiao and Li Yili 1985), goitre (Liu Shulin 1992), anal fissure (Li Yunshan 1986), jaundice and viral hepatitis (Wang Guimiao and Li Yili 1985) and migraine headaches (Wang Guimiao and Li Yili 1985). Climacteric syrup for reduction of menopausal flushing includes safflower (Chu Qiuping 1989).

Knowles (1965) reported that flowers were soaked overnight and applied wet to reduce allergy rashes in Egypt.

3.1.3.4 Safflower pollen

The pollen is esteemed in China because it is easily collected and contains many nutrients.

3.1.4 Seeds

3.1.4.1 Birdseed

Safflower seeds are commonly used as birdseed, especially for members of the parrot family and pigeons (Canada, USA, France, Egypt, Japan). The birdseed market, which requires bright white seeds, has tripled in the last 5 years to around 25 000 t in 1995 and may double in the next 5-10 years (Gyulai 1996). The seed is mainly purchased for wild birds, although some is used for caged birds and other small pets (Peterson 1996).

3.1.4.2 Foods

In Iran, a paste of seeds is used to hasten cheese curd formation (Knowles 1965). Smith (1996) reported that an experimental substitution of a safflower seed enzyme for rennin produced a pleasant-smelling, soft, white cheese.

In Ethiopia, finely pounded safflower kernels are mixed with water to prepare a drink called 'fitfit', which is used on fast-days or mixed with 'teff' bread and spices to form a porridge (Belayneh and Wolde-Mariam 1991). Crushed dried seeds are

also used to grease the baking plate for the 'teff' flatbread. Roasted seeds, generally mixed with chickpeas, barley or wheat, are eaten as a snack food in Ethiopia and Sudan (Belayneh and Wolde-Mariam 1991). The Egyptians grind the kernels and mix in sesame (Knowles 1965).

3.1.4.3 Medical

In Pakistan, seed decoctions are used to produce heat and dryness in the body and with added sugar, as a laxative (Knowles 1965). For problem menses, at least three daily doses (a 1/2 ounce of seed in 8 ounces of water, boiled until reduced by half) are given, starting on the first day of menstruation, to increase blood flow. A more concentrated dose over a longer period induces abortion. In Kashmir, a decoction of whole or ground seeds is used to flush out the urinary tract, improve the liver and reduce hives (Knowles 1965). In Bangladesh and China, the treatment for urinary calculi is 1/4 ounce of seed mixed with sugar (Knowles 1965; Wang Guimiao and Li Yili 1985). Ground seed mixed with mustard oil is used to reduce rheumatic pains in Bangladesh (Knowles 1965).

3.1.5 Oil

Around the world, safflower is mainly grown for its edible oil for cooking, salad oil and margarine. In affluent countries, research linking health and diet has increased the demand for the oil, which has the highest polyunsaturated/saturated ratios of any oil available. It is nutritionally similar to olive oil, with high levels of linoleic or oleic acid, but much less costly. Polyunsaturated fats are associated with lowering of blood cholesterol. Also, mono-unsaturates such as oleic safflower oil tend to lower blood levels of LDL ('bad' cholesterol) without affecting HDL ('good' cholesterol) (Smith 1996). There is a considerable health food market for safflower oil, especially in North America, Germany (Smith 1996) and Japan.

Safflower oil is stable and its consistency does not change at low temperatures, making it particularly suitable for use in chilled foods. Safflower oil salad dressings have remained stable and satisfactory to –12ºC (Weiss 1971). High oleic safflower oils are very stable on heating, and do not give off smoke or smell during frying (Gyulai 1996). Safflower oil is better suited to hydrogenation for margarine than soy or canola oils, which are unstable in this process (Kleingarten 1993).

The Japanese are the major importers of oil and seed for crushing. Traditionally, safflower oil was mixed with other oils for 'tempura' (Weiss 1983). Now, the biggest use of safflower oil (75-85%) is in gift packs for special occasions (Gyulai 1996), especially during the two gift-giving seasons each year. Safflower oil's share of this market is over 85%, especially as blends of high oleic and high linoleic types, which combine health benefits and salad oil attributes with stable cooking qualities (Smith 1996).

Safflower oil is sprayed on various edible products to prevent them absorbing or losing water, and thus extends their shelf life (Kleingarten 1993). Smith (1996) details many experimental uses of safflower oil in the food industry, but only infant

foods and liquid nutrition formulations have used safflower oil. An oleic oil derivative, methyl-oleate, sprayed on grapes on the vine to accelerate drying reduced the risk of rain and the cost of producing sun-dried raisins (Smith 1996).

Safflower oil is an effective nonallergenic dispersant for injectable medications, but not widely used (Smith 1996). In Iran, the oil is used in treatment of liver and heart ailments (Knowles 1965). The oil is nonallergenic, making it ideal for cosmetics; it is used in Macassar hair oil and Bombay sweet oil (Weiss 1971). Charred safflower oil has been used to treat sores and rheumatism in India (Weiss 1971).

The commercialization of safflower in the 1950s was driven, in part, by the paint and varnish industry. The oil's properties (it has no linolenic acid, high linoleic acid and low colour values, no wax, low free fatty acids and low unsaponifiables), contribute to unsurpassed quality in paints, alkyd resins and coatings (Smith 1996). However, market forces (less costly petroleum products and a shift to water-based paints) have limited this use. Smith (1996) details potential industrial uses that have not developed commercially. The oil has been used to waterproof leather buckets and as axle grease in India (Knowles 1965), where it also is used for lighting and manufacture of soap (Weiss 1971). It is also used to manufacture 'roghan' (used to preserve leather), as glass cement, to hold ornamental tiles in place and, dissolved in turpentine, for making Afridi cloth, a form of batik work. The process for making 'roghan' from safflower differs little from that using 'pohli' oil, described in Section 1.2.8 and the 'roghan' is similar (Weiss 1971).

Industrial uses of safflower oil may expand due to environmental concerns raised by exclusive use of fossil fuels. Biodiesel and fuel additives, as well as uses such as chainsaw-bar oil, may reduce pollutant effects of exhaust gases.

3.1.6 Meal

The meal left after oil extraction is used for animal feed. The residual fat varies with the extraction method, from under 2% to 15%. Crude protein also varies: from 20-25% for undecorticated meal to up to 42% if hulls are removed. Removal of hulls is not generally economical and the meal commonly has 30-40% crude fibre, making it unsuitable for monogastric animals such as swine and poultry. It has been used as range cow cubes and in compounded feeds for cattle and other livestock (Smith 1996).

Although cattle apparently find safflower meal palatable, it has a bitter taste which makes it unacceptable to humans. Protein isolates prepared from debittered meal can be used to fortify bread, pasta and nutritional drinks. An energy bar produced in China includes safflower amino acids, safflower yellow and Chinese crabapple.

3.1.7 Hulls

Markets for hulls have not been found and crushers generally leave the hulls in the meal although removing them would lower the fibre content and raise the feed value of the meal. Hulls were used for presto-logs for fireplaces in the early 1950s (Smith 1996).

Among the potential uses listed by Smith (1996), safflower hulls had no obvious practical disadvantages in the following:

- filler for paper products – produces a dense, hard-surfaced product

- filler for baked bricks and ceramics – produces light, porous bricks
- filler for insulation
- insulation to keep steel ingots from cooling too rapidly
- supporting material for hydroponic culture
- soil diluent for seeding
- metal deburrer, abrasive, cleaner or polisher – hulls are tough and resilient, but not absorbent
- packing material for fragile items
- additive for drilling mud
- low-ash fuel – burns readily, but is bulky
- charcoal briquette manufacture might also yield useful volatile materials.

3.1.8 Use of wild relatives of safflower

Chavan (1961) describes *C. lanatus*, or saffron thistle, a small herb 15-45 cm high found from the Atlantic-Mediterranean coast to Kashmir at altitudes up to 1800 m. It yields an oil similar to that of safflower, but oil content peaks at around 16% before ripening and then diminishes. Saffron thistle is reported to be sudorific (sweat-inducing), fever-reducing and anthelmintic (Chavan 1961).

Carthamus oxyacanthus, wild safflower, is an annual bushy thorny weed in northern India and northern Pakistan known as 'kandiari' or 'pohli'. The fruits are collected for the seeds, which contain about 28% oil, which is similar to safflower oil (Chavan 1961). 'Pohli' oil is used in cooking and for lighting and to prepare 'roghan', soft soap and varnish and, in the Punjab, to dress ulcers and remedy itch. 'Pohli' oil is boiled in an earthen pot for about 12 hours and then poured, still boiling, into cold water, where it forms a gelatinous mass. This 'roghan' is stored in tins and sold locally for making Afridi wax-cloth and as a glass-cement (Chavan 1961).

3.2 World distribution and production

Traditionally, cultivation of safflower has been in a band from the Mediterranean to the Pacific Ocean at latitudes between 20ºS and 40ºN, wherever a hot, dry climate suits the crop. When the crop was widely used for dye, safflower was grown as far north as southern Germany and Alsace in France (Weiss 1971). Today, the crop is grown for local use as an oilseed or a food colourant wherever its heat tolerance and ability to survive on minimal surface moisture provide an agronomic and economic niche for it. World markets, transportation and crushing facilities as well as agronomic factors affect the area seeded to safflower in countries where agriculture is dependent on world trade. As a minor crop, safflower is particularly vulnerable to the vagaries of the market, pests and adverse weather patterns. These have contributed to wide swings in production and seeded area in several countries. Production in some of the major safflower-growing countries is shown in Table 4.

Table 4. Safflower production worldwide and in countries with over 10 000 ha in 5 of 10 years between 1985 and 1994.

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Argentina										
area harvested†	3	4	15	15	50	50	50	15	21	12
production‡	2	10	11	11	33	35	35	16	7	32
Australia										
area harvested	44	30	38	46	33	19	37	32	55	23
production	28	19	25	41	21	10	24	21	23	25
Ethiopia										
area harvested	66	67	67	68	68	69	69	69	70	69
production	32	33	33	34	34	34	35	35	36	35
India										
area harvested	870	911	892	1052	816	842	821	501	707	800
production	497	348	353	462	445	487	327	203	342	430
Mexico										
area harvested	190	204	200	200	150	157	94	91	69	58
production	180	161	219	247	142	159	88	59	59	69
USA										
area harvested	78	132	95	85	82	97	75	120	143	89
production	110	147	155	143	159	139	104	148	227	184
Former USSR										
area harvested	11	11	12	14	11	11	12	32	55	23
production	4	5	4	7	9	6	7	23	43	13
World										
area harvested	1288	1385	1331	1478	1219	1248	1160	1199	1087	1165
production	876	737	811	960	850	873	620	690	737	790

† Area in '000 ha; ‡ production in '000 tons (1 ton = 0.907 tonnes) (adapted from Smith 1996).

India produces about half the world's safflower each year, but very little is exported. In terms of world trade, the USA, together with a very small production from the southern prairies of Canada, produces 180 000-200 000 t per year. Most production from Australia (10 000-20 000 t/year), Argentina (10 000 t/year) and Mexico (80 000-100 000 t/year) is exported, mainly to Japan and Europe with some Mexican oil entering the USA (Gyulai 1996).

Chinese safflower production on 35 000-40 000 ha/year is not included in most crop estimates because it is mainly grown for its florets rather than as an oilseed. It is grown throughout most of the country, but over two-thirds of the area seeded is in Xinjiang Autonomous District. Increasing use of safflower as an oilseed is expanding the area seeded to the crop.

4 Breeding

4.1 Crossing techniques

Safflower is a predominantly self-pollinating crop, with the genetic potential of over 90% for selfing, although environmental conditions may result in outcrossing exceeding 50%. Heterogeneity builds up quickly in safflower populations. Bees of several genera, as well as other insects, are attracted to safflower for pollen and nectar. Wind transportation of pollen is not a major factor in cross-pollination. To enhance their genetic homogeneity, plants selected as parents for genetic studies and breeding purposes are selfed by covering the flowers for one or two successive generations with cloth or paper bags. To ensure planned crossing, flowers are emasculated by removing the anther tubes, along with the upper portion of the corolla tubes and petal lobes, in the late bud stage (Knowles 1980). The next day, when the styles have elongated, the emasculated florets are fertilized with pollen from a preselected flower or head. This quite time-consuming technique is generally followed in breeding programmes.

A mass-emasculation technique developed at the Nimbkar Agricultural Research Institute (NARI) in Phaltan, India, takes less time than emasculation of individual florets and allows more efficient production of crossed seeds (Deshmuk and Ranga Rao 1989). On first flower initiation, 5-10 fully developed capitula from the top 4-5 branches of each plant are covered with low- to medium-density polythene bags. All other branches are pruned off. Temperature and moisture build-up inside the bags prevents dehiscence of anthers. At 50% flowering, in the mornings, bags are removed, flowers are pollinated with the desired pollen source and the bags are closed. To maximize seedset, the procedure is repeated on three successive days. On completion of flowering, polythene bags are replaced with tissue paper bags, to reduce moisture accumulation and disease in the head. One person can bag 105 capitula per hour using this technique, compared with the conventional emasculation rate of 15 florets on each of 12 capitula. Using the mass-emasculation method, a total of 1207 crossed seeds can be produced per person-hour compared with 102 by the conventional method. However, this mass-emasculation technique is only effective at the moderate temperatures of December and early January at Phaltan; at higher temperatures, the pollen is sterilized in the bags.

4.2 Breeding methods

Plant breeders of safflower have generally used variations on the pedigree method for handling segregating generations (Knowles 1989), selecting for highly heritable characters (e.g. early maturity, disease resistance) beginning from single F_2 plants. Uniform F_3 or F_4 lines with superior expression of desired characters can be advanced to small-scale yield tests. Backcrossing has been used to introduce specific characters, especially disease resistance, into otherwise good commercial cultivars.

Mass selection from fields naturally infested with a multitude of diseases has been used to develop cultivars with improved field resistance to several diseases.

Beginning in the early 1960s, this system of initial screening for field resistance to leaf blight caused by *Alternaria carthami* and bacterial blight caused by *Pseudomonas syringae*, followed by crossing to commercial varieties, was used in the development of Oker, Hartman and Girard in Montana, USA (Bergman *et al*. 1985, 1987, 1989). In subsequent crosses, advanced breeding lines with improved oil levels, rather than the original disease-resistant selections, were used.

Recurrent selection programmes also have been used in safflower. In a programme begun in 1970 in Arizona, USA, Rubis (1981) used structural male sterility associated with the thin-hulled gene (*th th*) to enforce outcrossing and produce lines highly resistant to root rot caused by *Phytophthora* spp. This method was developed to create a high selection pressure in order to select new genetic recombinations with high resistance to the fungal pathogen. The thin-hull gene has shown crossability of 98-100%. Flooding, along with high temperatures at flowering time, following moisture stress imposes a very strong selection pressure for resistance to phytophthora root rot. Introduction of the thin-hull gene into the population enforced fertilization of surviving plants by pollen from other surviving plants. Thus, a complete cycle of recurrent selection was achieved in a single year. By following this procedure, the survival rate increased from 14% in the best plots in 1972 to 85% in 1980, while the check variety (Royal) was 100% killed.

Genic male sterility, identified in safflower by Heaton and Knowles (1982), has been considered for use in hybridization to produce high-yielding cultivars. However, manual removal of male-fertile plants in crossing blocks has generally made this procedure prohibitively expensive where labour costs are high. Carapetian (1994) identified three interacting, unlinked nuclear genes controlling the inheritance of male-female sterility in safflower, using a cross of US-10 (*S1S1s2s2s3s3)* and the geographically distant Indian line 54-147 (*s1s1S2S2S3S3*).

A hybrid safflower breeding programme initiated in 1974 by A.B. Hill uses a cytoplasmic male-sterility system (Hill 1996). The average yield advantage of recent hybrids, compared at several sites in California, Arizona, North Dakota, Canada, Pakistan, Mexico and Spain, was 127% over the best parental lines. Oil levels of the hybrids, which averaged 34% in 1983, increased to 40 and 42% in 1994; levels of 45% and higher are currently being developed.

4.3 Biotechnology

A range of biotechnological methods has been tested on safflower, with varying success. A sampling only is presented here. Anther culture resulted in up to 48% callus formation from the Indian cultivar Manjira, following cold pretreatment of immature flower buds and culturing on MS medium with 2 mg benzyladenine, 0.5 mg NAA / L and 2% sucrose (Prasad *et al*. 1990). Anther-derived calluses showed 47% haploid, 30% diploid and 16% triploid.

A cooperative project between J.W. Bergman in Sidney, Montana, USA and W.E. Dyer of Montana State University, Bozeman, is mapping the DNA of safflower lines as an aid in future identification of lines (Bergman 1996). *Agrobacterium tumefaciens-*

mediated transformations and regenerations of transgenic safflower are also being undertaken, using the cultivar Centennial (Ying *et al.* 1992). Efficient callus formation was achieved from cotyledon, stem and leaf explants. Shoot buds were regenerated from 26% of leaf-derived calluses on callus induction medium. Transformation and stable integration of transgenes was confirmed by the use of GUS assay and DNA hybridization in kanamycin-resistant calluses and GUS assay in regenerated shoots. A protocol was established for the transformation and regeneration of safflower, based on co-cultivation of explants on induction medium, transferral to shoot formation medium containing carbenicilin, followed by transfer to the same medium containing kanamycin (Orlikowska *et al.* 1995). After regeneration of the leafy structures, transfer to elongation medium containing geneticin follows; after elongation, shoots are detached from the original explant tissue and transferred to the same medium, with only transformed shoots remaining healthy and being transferred to rooting medium. Root regeneration, while successful, is still at too low a percentage for this system to be a practical breeding tool (J.W. Bergman, pers. comm., 1996). In India, a protocol for easy and efficient regeneration of plantlets with well-developed root systems was developed using the cultivars A-1 and Manjira (Tejovathi and Anwar 1993). Cotyledons excised from 2- to 3-day-old seedlings and cultured on MS medium supplemented with 0.1 mg NAA +0.5 mg benzylaminopurine / L gave the greatest shoot bud formation, inducing 10-12 shoot buds / explants. Transferring these regenerated shoots to the MS medium containing 1 or 2 mg 2,4,5-trichlorophenoxy propionic acid / L induced rooting.

In Freiburg, Germany, the team of U. Matern and R.E. Kneusel attempted to use genetic engineering techniques for safflower to introduce resistance to leaf blight caused by *Alternaria* spp. (Matern and Kneusel 1993). This group used molecular methods to identify the macrolide, brefeldin A, as the phytotoxin from *A. carthami* which suppresses the plant's defence response and is thus identified as a virulence factor of the fungal pathogen. The phytotoxin is inactivated in a one-step hydrolysis by a strain of *Bacillus subtilis*, and incorporation of the DNA directing manufacture of the enzyme responsible into the safflower genome was proposed as an effective means to protect safflower from alternaria leaf spot disease. The gene was identified, cloned and successful regenerations have been carried out using tester strains of *Agrobacterium tumefaciens*, but efforts at transformations of safflower with the isolated brefeldin A-esterase gene were not successful and the team has disbanded (U. Matern, pers. comm., 1996).

5 Research priorities and constraints

The research priorities expressed by any group reflect the diverse knowledge bases and regional needs and concerns of individuals. We present here the consensus of safflower stakeholders, including those involved in research, extension, industry and production. Several fora have presented opportunities for 'think tanks' on specific concerns. A complete list is impossible, but we have attempted to present all the issues raised, with major emphasis on genetic resources affecting the international safflower research community. The sections of this monograph dealing with the major collections and their evaluations, as well as work by institutions developing varieties (i.e. Chapter 6) should be consulted for progress or lack of progress in relation to a number of the issues (e.g. disease resistances) discussed.

5.1 Safflower workshop, Davis, California, USA, 1981

Following the First International Safflower Conference, at the University of California in Davis, CA, USA, on 17 and 18 July 1981, 26 research, administration and commercial development workers participated in a workshop discussion (Knowles 1981:285-292). The discussion leader for each topic presented the consensus from that section.

5.1.1 Constraints in safflower production and research to remove them

These were presented in descending order of priority, considering the needs of the smallholding farmer and the large fully mechanized operation.

5.1.1.1 Susceptibility to disease and insect pests

Safflower has developed from wild species of desert or arid environment and is very susceptible to foliar diseases favoured by a moist atmosphere; root-rotting organisms, especially those favoured under irrigation; and a large number of insects, especially in those regions where safflower and its related species evolved. Greater resistance to those diseases and insects would allow safflower production over a much larger area than at present.

- Susceptibility to foliar diseases: These have been particularly serious in areas where rainfall occurs between the late bud stage and near maturity. Most serious and widespread is leaf blight caused by *Alternaria carthami*. Other foliar diseases of more localized concern include those caused by *Botrytis cinerea, Cercospora carthami, Pseudomonas syringae, Puccinia carthami* and *Ramularia carthami.*
- Susceptibility to root-rotting organisms: Various species of *Phytophthora* as well as *Fusarium oxysporum* f.sp. *carthami* and *Verticillium dahliae* are serious in many areas.
- Susceptibility to insects: The most serious in limiting safflower distribution has been the safflower fly *(Acanthiophilus helianthi*) which is confined to Africa, Asia and Europe. Aphids are also a major constraint in India and Spain.

  Research to remove these constraints requires joint efforts of plant breeders and

pathologists or entomologists. Accurate tests which quickly measure the resistance of a large number of genotypes are required. An understanding of the inheritance of resistance in the host and of virulence and nonvirulence of different physiological races of pathogens and insects is needed.

5.1.1.2 Developmental pattern

- Early maturity: Development of cultivars that mature several weeks earlier than those commercially grown in the USA would make safflower more competitive with wheat and permit double cropping and production of safflower in currently marginal areas (e.g. Canada).
- Duration of rosette stage: The rosette stage protects the crop from frost, but safflower is frequently overgrown with weeds during this stage, resulting in poor crops.
- Lack of dormancy at maturity: Germination of mature seed in the heads of standing plants following rains lasting more than 24 hours adversely affects quantity and quality of harvested crops in a number of regions of the world. Germplasm screening for dormancy may prove very beneficial.

5.1.1.3 Morphological ideotype

- Angle of branching: Research is needed to evaluate whether appressed types produce denser stands with more heads per hectare and facilitate mechanical and manual harvest.
- Spines: Varieties with reduced or absent spines are needed in regions of nontraditional production, where flowers and seeds are hand-harvested. Generally, such varieties have been lower in yield and oil content than spiny types.
- Seed hull: Well-developed hulls generally result in oil levels below 30%. Reductions in hull thickness, for example by the partial hull gene (*par par*), offer the potential of varieties with more than 50% oil. There is a choice of striped or smooth hulls and hulls without melanin pigment. Research should relate changes in the amounts and character of hull to yield and quality of both oil and protein, and the effects that such changes may have on losses to birds, insects and seed damage during mechanical harvest.

5.1.1.4 Resistance to stress

- Increased resistance to drought: Although safflower is considered drought-resistant, in large part owing to its strong taproot, identification of genotypes which are more efficient in water use would increase production on dryland and where irrigation water is limited.
- Greater resistance to salinity: Safflower has shown considerable tolerance to soil salinity, but greater tolerance is needed. Often safflower is grown in dryland and irrigated areas subject to increasing salinity. More evaluations of germplasm under saline conditions are needed.
- Greater resistance to cold: With greater resistance to cold, true winter saf-

flower types might be developed, to grow alongside winter wheat. Study of genotypes of cultivated safflower and gene recombinations from crosses of cultivated safflower with wild species could define the limits of cold tolerance.

5.1.2 Other research of high priority

5.1.2.1 Increase yield through genetic manipulation

- Change of ideotype: Examine the potential of changes in the morphology of the plant and physiological characteristics to affect yield.
- Heterosis: Develop hybrid cultivars using cytoplasmic male sterility systems.
- Interspecific hybridization and cytogenetics: Explore the potential of interspecific hybridization with and without induction of polyploidy. Encourage changes in chromosome structures.
- Genetic engineering: Evaluate these techniques, particularly when combined with mutagenesis.

5.1.2.2 Production/physiological research

- Cropping systems: Identify niches in cropping systems where safflower can be used, including as a relay or companion crop.
- Water management: Characterize the best use of water for different soil-climate environments, especially as genotypes tolerant to root-rotting organisms are identified or developed.
- Weed control: Study integrated weed control including the use of cropping systems, tillage and herbicides.
- Photoperiod and thermal reactions: Examine responses of various genotypes to daylength under various temperature regimes.
- Allelopathy: Determine whether safflower roots or residue adversely affect the growth of other crops, or vice versa.

5.1.2.3 Product-related research

- Modification of fatty acid composition of the oil: Present market demand is for high linoleic and high oleic oil. The next step will be the development of types with fatty acids not now present in safflower oil for specialty uses, such as those with short-chain saturated fatty acids (potential substitutes for coconut oil).
- Modification of amino acid composition of the meal: Increased levels of lysine and other essential amino acids would enhance the feed value of the meal.
- Elimination of toxic substances in the meal: Germplasm should be evaluated to find lines with lower levels of the two toxic substances – matairesinol monoglucoside and lignan glucoside – found in safflower meal.
- Product markers: Identification of newly developed products by markers such as flower colour, leaf morphology and seed colour would be useful to all phases of the industry.

5.1.2.4 Utilization research

- Oils: Evaluate lines with oils of radically different fatty acids for both edible and industrial uses.
- Toxic substances: Reduce levels of toxic substances in the meal by processing techniques.
- Hulls: Develop better uses for the hulls, possibly as fuel or as raw material for structural applications.
- Fodder: Study the combined use of safflower for grazing and seed production.

5.1.3 Germplasm

Despite considerable work in germplasm collecting and evaluation, the group was strongly of the opinion that germplasm needs had a very high priority. It expressed gratitude to IBPGR for its interest in and support of germplasm collecting, preservation, description and evaluation.

5.1.3.1 Collections

- Additional areas: There was unanimous agreement that collecting should continue, particularly in areas from which collections are scanty. These were identified in descending order of priority as: China, East Africa (including Kenya, Ethiopia and Sudan), South Asia (including northern tribal areas of India and Pakistan, Bangladesh and Burma), Southeast Asia, Japan and Korea.
- Wild species: Wherever possible, wild species should be collected, particularly in the Middle East and islands of the Mediterranean Sea. It was stressed that breeders will draw increasingly on genes in wild species as genetic engineering techniques for safflower are perfected.

5.1.3.2 Conservation

The Conference recommended to IBPGR that the following be designated as global repositories:

- USDA Regional Plant Introduction Station, Washington State University, Pullman, WA 99164, USA. It should receive all collections and serve as a central databank.
- National Bureau of Plant Genetic Resources, Indian Agricultural Research Institute, New Delhi 110 012, India.

5.1.3.3 Descriptors

The group discussed and amended the draft list of descriptors prepared by Dr N.N. Anishetty, Assistant Executive Secretary, IBPGR and Dr R.B. Singh, IBPGR (Singapore). It unanimously recommended that the final version be published by IBPGR.

5.1.3.4 Evaluation and utilization

- Plant introduction and conservation stations: Such stations should have responsibility for initial evaluations and descriptions of collections.

- Evaluations made elsewhere: Such evaluations should be channelled to national plant introduction stations and global repositories.
- Germplasm pools: Interest was expressed in the germplasm pools being developed by Dr D.D. Rubis in Arizona, USA. The hope was expressed that similar pools of germplasm will be developed and made available to safflower researchers.

5.1.3.5 Genetic stocks

- Gene symbols: The increasing numbers of genes that affect morphology, physiology, disease and insect resistance being identified should be standardized and catalogued. Rules may be necessary in proposing symbols.
- Preservation of genetic stocks: The identification of genetic stocks in short-term studies (e.g. by graduate students working on theses) and changes in research personnel make the loss of genetic stocks a real danger. A special agency, probably a plant introduction station, is needed to preserve genetic stocks.
- Chromosome stocks: These need the same attention as genetic stocks.

5.1.4 International needs

5.1.4.1 International trials

It was recommended that, to meet the long-standing need, standardized international safflower trials be developed with the leadership of FAO. Trials should be patterned after trials used successfully for other crops. One such trial, coordinated from the National Agricultural Research Centre in Islamabad, Pakistan, was initiated in 1989, after the Second International Safflower Conference (1989), with the assistance of the International Development Research Centre (IDRC) of Canada in conjunction with the Oilseeds Network and the Sub-Network on 'other oil crops'. Entries were collected, but the IDRC Network disbanded and trial results could not be disseminated.

5.1.4.2 Newsletter

There was strong support for the development of a safflower newsletter, to be published annually; it was hoped that the initial costs could be borne by FAO. After an initial overlap with IDRC's Oil Crops Newsletter, the Sesame and Safflower Newsletter has been published almost every year since 1985. FAO (until 1993 through Dr C. Piñeda) is the clearing house for submissions. Dr Amram Ashri from Rehovot, Israel edited the first volume; since then, Dr José Fernández-Martínez, with the Institute of Sustainable Agriculture, in Córdoba, Spain, has been editor.

5.1.4.3 International safflower research institute

The hope was expressed that an institute could be developed to undertake an international improvement programme on safflower. However, it was recognized that safflower is not deemed important enough as a crop to generate the required support.

5.1.4.4 Future international safflower conferences

A need was expressed for meetings at 4 to 6-year intervals, with some funding support to be sought from FAO, IBPGR and industry. A Safflower International Continuing Committee was set up to organize international safflower meetings with Dr H.-H. Mündel as Chairman. He was succeeded by Chairmen of local organizing committees after the conference hosted by their institution: Dr V. Ranga Rao after the Second International Safflower Conference in Hyderabad, India in January 1989; Prof. Li Dajue after the Third International Safflower Conference in Beijing, China in June 1993; and the Fourth International Safflower Conference is planned for Bari, Italy, 2-7 June 1997 (Chair of the local organizing committee is Prof. A. Corleto).

5.2 Second International Safflower Conference, Hyderabad, AP, India, 1989

At this conference, discussants were asked to provide summaries and recommendations on assigned topics (Ranga Rao and Ramachandran 1991:382-395).

5.2.1 Genetic resources (Discussant: Dr J.M.M. Engels, of IBPGR)

A global Safflower Advisory Committee on Genetic Resources was established with limited membership that covered the major safflower production and diversity regions, germplasm conservation and utilization as well as research. The original committee had to be changed because of deaths and reassignments. As of 1995, the eight members of the International Safflower Germplasm Advisory Committee (ISGAC) were: Dr P.S. Reddy, Chairman, DOR, Hyderabad, India; Dr A. Ashri, Hebrew University, Rehovot, Israel; Dr N.M. Anishetty, FAO, Rome, Italy; Prof. Li Dajue, Botanical Gardens, CAS, Beijing, China; Dr R.C. Johnson, USDA / WSU, Pullman, WA, USA; Dr Chanda Musa, SeedTec (consultant), Obregon, Mexico; Dr V. Ramanatha Rao, IPGRI-Regional Office for Asia, Singapore; and Prof. Zhang Zongwen, IPGRI-Office for East Asia, Beijing, China. The mandate of this committee is to prepare a comprehensive international safflower germplasm catalogue for safflower research workers around the world. Support was requested from FAO, IBPGR and IDRC for the committee operations.

The terms of references for the committee are:

- coordination of safflower germplasm acquisition and setting of priorities
- organization of a network of active and base collections
- establishment of a network of databases; provision of advice on characterization and evaluation, including a revision of the descriptor list (as required)
- establishment of research priorities
- the identification of training needs.

Collecting priorities for cultivated and wild species of Carthamus, in descending order, are: south and northeast China; Nepal; northwest India, Pakistan, Afghanistan and Iran for *C. oxyacanthus*; Sudan.

The countries suggested for inclusion in the base collection network were China,

Ethiopia, India, USA and the former USSR.

Suggested areas of strategic research: seed physiology, regeneration, genetic diversity, maintenance of wild *Carthamus* species, identification of duplicates, core collections.

The conference urged FAO, IBPGR, IDRC and other organizations to provide financial and technical support for conservation and utilization of safflower germplasm activities.

5.2.2 Genetics and breeding (Discussant: Dr P.F. Knowles)

The major research need for safflower was identified as the need to expand the area of adaptation through genetic research and breeding programs.

Germplasm banks containing genotypes with resistance or tolerance to all diseases should be set up. The work of Dr Ken Harrigan and his associates in Australia, developing cultivars resistant to alternaria leaf blight, was given as an example of what is needed for several foliar diseases. Wild species, especially those closely related to cultivated safflower, should also be surveyed for resistance.

A search should be made for genotypes resistant to the more serious insect pests and that resistance should be introduced into cultivars. Black aphid was singled out as a particularly serious pest in many areas.

Good sources of earliness should be sought. These would make safflower more competitive with wheat in higher latitudes and where safflower is grown as a winter crop and is subject to very high temperatures and reduced water supplies as it matures.

Germplasm banks should be rigorously surveyed for superior spineless genotypes. These would facilitate the introduction of safflower to new areas, where harvest is manual, as well as for floral-part needs.

Germplasm, including wild species, should be examined for seed dormancy around seed maturity, as is being done by Prof. Li Dajue in China.

To achieve the superior performance of hybrid cultivars, hybrid breeding efforts, studies in heterosis and identification of simple seedling markers for early detection of male-fertile plants in seed production plots should be encouraged. Hybrids have been produced in India by Maharashtra Hybrid Seeds Company and the Nimbkar Agricultural Research Institute, using genetic male sterility, and in the USA by A.B. Hill of California, based on a cytoplasmic male sterility system, identified by crossing with wild species.

Modification of safflower oils for both edible and industrial purposes will be increasingly important. In recent years, results of nutritional studies with high oleic oils have been promising.

A cultivar network that permits the evaluation of new and improved cultivars over a wide range of environments is needed. This would facilitate transfer of improvements from breeding programmes between countries.

A collaborative international screening and cultivar testing system with broad support (e.g. from IDRC and similar funding agencies) is needed. Although a large

number of breeding materials of practical interest are being generated around the world every year, there is no global system for testing the finished products from the breeding programmes under a wide range of agro-ecological conditions for their adaptability and reaction to biotic and abiotic stresses.

Documentation of available genetic resources in safflower should be undertaken. The Directorate of Oilseeds Research (DOR), Hyderabad, India would facilitate this.

5.2.3 Agroproduction (Discussant: Dr V. Ranga Rao)

Priority areas of research were identified: the economics of safflower compared with other crops, identification of specific niches for safflower culture, the potential for safflower and its agronomy in sequential and intercropping systems, and efficient use of fertilizers.

5.2.4 Agroprotection (Discussant: Dr H.-H. Mündel)

Globally, most safflower is produced under low-input conditions and therefore the major focus in plant protection should be the development of varieties with resistance to the major diseases. International screening nurseries should be established in 'hot spots' to identify and catalogue materials tolerant and resistant to major biotic constraints. The germplasm base should be enhanced through emphasis on wild species. A handbook of safflower diseases and pests with their diagnostic characteristics is needed.

5.2.5 Marketing, processing, utilization, product development, food chemistry and nutrition (Discussant: Dr B. Narsing Rao)

Seeds should be stored whole rather than as decorticated kernels. Mechanical removal of hulls raises oil yields and lowers fibre in meal.

The conditions affecting the extent of aflatoxin as a problem in storage of safflower should be studied. High relative humidities (>70%) favour the development of aflatoxins and reduce oil content.

Debittering seed (with 80% ethanol and isopropanol) can improve feed and food value; a snack food can be made from treated kernels.

The use of carthamin yellow as a vegetable food colour in place of synthetic dyes should be studied. China has taken the lead in this field.

Safflower oil, with high linoleic acid content, can be blended with other vegetable oils to nutritionally upgrade them.

5.2.6 Major constraints, future research and developmental needs (Discussant: Dr P.F. Knowles)

The principal constraints and research and developmental needs of the safflower-growing areas of the world represented at the conference are presented.

5.2.6.1 Constraints

- Low per-hectare yields associated with low harvest index and low seed-oil contents (India, Turkey, Morocco).

- High susceptibility of available commercial cultivars to foliar diseases (*Alternaria, Ramularia, Puccinia*), root rots (*Macrophomina*), wilts (*Fusarium, Verticillium)*; aphids (India), abiotic stresses (drought, salinity, alkalinity), high thermosensitivity and daylength sensitivity, long rosette stage.
- Presence of spines.
- Lack of region-specific agroproduction technologies (e.g. in African countries) to harness the full potential of safflower; absence of information on potential production niches.
- Lack of assured market and price support; absence of demand for safflower seed and oil in nontraditional areas.
- Falling public research support to safflower (major reductions in USA, Australia). The small breeding programme in Canada is also being phased out.
- Absence of processing facilities within reasonable distances of production centres.

5.2.6.2 Priorities and developmental needs

- Intensification of research for the identification of sources resistant to major biotic and abiotic stresses.
- Development of high-yielding varieties and hybrids with high seed-oil content and built-in tolerance to diseases and insect pests.
- Breeding for less thermosensitivity and daylength sensitivity, high-yielding and early maturing varieties.
- Refinement of agroproduction and agroprotection technologies for maximizing yields and returns under diverse agro-ecological situations.
- Breeding for higher yielding spineless varieties suited to nontraditional areas.
- Intensification of research to identify new cropping niches for safflower.
- Development of appropriate seed-processing technologies.
- Search for viable cytoplasmic male sterility systems for the production of hybrids.
- Training of research personnel in breeding techniques, identification and management of diseases.

5.3 North American Safflower Conference, Great Falls, Montana, USA, 1996

This conference was organized by the Alberta Safflower Growers Association (ASGA) to bring together researchers, extension personnel, marketers, processors and growers of safflower. After formal presentations, four round-table discussion groups identified top research areas. The priorities are listed in decreasing rank.

5.3.1 Weed control

Registration of available pesticides; chemistry for post-emergence weed control;

harmonization of regulations / registrations between Canada and USA.

5.3.2 Varietal development

Improved vigour, disease resistance, earlier maturity; improved oleic varieties and dual-purpose birdseed / oleic varieties; expansion of variety selection for value-added uses; development of glyphosate-resistant varieties.

5.3.3 Marketing research

Market intelligence / disclosure, market size (oil / meal / birdseed); bird nutrition; market opportunities; utilization research (additional uses for oil / meal / forage); product promotion; creation of a North American Safflower Association.

5.3.4 Agronomy

Rotation studies specific to production zones; yield models to be developed (growing degree days vs. solar intensity, etc.); fertility; rooting depth.

6 Collecting and evaluations

6.1 Germplasm collecting

Crop-collecting priority regions change over the years. Those for safflower – both cultivated and wild *Carthamus* species – were most recently amended at the Second International Safflower Conference in Hyderabad, India, in January 1989 as follows:

- Priority 1, south and northwest China
- Priority 2, Nepal
- Priority 3, northwest India, Pakistan, Afghanistan and Iran for *C. oxyacanthus*
- Priority 4, Sudan (Engels 1991).

In addition, centres in China, Ethiopia, India, Russia and the USA have been included in a network of base collections. The same conference subcommittee (Engels 1991) suggested strategic research on safflower seed physiology, regeneration, genetic diversity, maintenance of wild *Carthamus* species, identification of duplicates in germplasm collections and establishment of a core collection. Despite shrinking public national and multilateral support and political turmoil, among a multitude of problems that have prevented comprehensive collecting in several of the areas identified, a potentially very useful start has been made. This section refers to major collecting expeditions, both before and since the 1989 conference, as a guide to global germplasm resources.

Safflower seed is an 'orthodox' seed in terms of its storage behaviour, viability of seed is maintained best by storing well-dried seed at low humidity and at low temperatures. In dry environments, safflower seed equilibrates at around 6-7% moisture. Based on the IBPGR guidelines established, 'medium-term storage' can be accomplished by storage at 4ºC and 30% relative humidity; 'long-term' storage can be effected at –20ºC. To the extent possible, with the financial resources provided, centres storing the collections outlined below use those or similar sets of conditions. Unfortunately, however, a number of collections are stored at ambient temperature and humidities. This results in a great potential loss of viability and accumulation of mutations as viability is reduced. The major collections have and are being stored *ex situ* at germplasm centres. It is possible, however, to conserve germplasm *in situ*, on-farm, to maintain genetic diversity, especially of local landraces adapted to local environmental stresses. A farmer-curator scheme called Seeds of Survival (SOS) has been piloted mainly for cereal crops, in Ethiopia, by the Plant Genetic Resources Centre / Ethiopia (recently renamed the Biodiversity Institute).

6.1.1 International

6.1.1.1 FAO

The FAO has been concerned with germplasm collecting, exchange and use since 1947 (Anishetty and Esquinas-Alcazar 1991). The FAO programme on plant genetic resources has given priority to providing technical assistance for and promoting and stimulating activities on species and regions that are not adequately covered by

other international organizations. Involvement in safflower includes, among other things, the provision of a clearing-house for articles to the annual Sesame and Safflower Newsletter published by Dr José Fernández-Martínez in Córdoba, Spain and supporting international conferences.

6.1.1.2 IBPGR/IPGRI

Soon after its formation in 1974, the International Board for Plant Genetic Resources (IBPGR) established crop and regional priorities for collecting of germplasm. Since then, IBPGR has encouraged, and at times assisted, national programmes to develop local collecting priorities. In consultation with Dr A. Ashri of the Hebrew University in Rehovot, Israel, IBPGR has developed a descriptor list for safflower to assist in the documentation of collected germplasm (Engels and Arora 1991). This list was finalized by a subcommittee headed by N.M. Anishetty during the First International Safflower Conference at Davis, California in 1981. Documentation data were divided into three categories:

- Passport (accession identifiers and information recorded by collectors);
- Characterization (characters which are highly heritable, can be seen easily and are expressed in all environments);
- Preliminary Evaluation (estimates for a limited number of traits thought desirable by users of a particular crop).

Descriptors and descriptor states must be properly coded or numbered, to facilitate use of the documentation. For safflower, the Passport data are divided into 10 'accession data' and 15 'collection data' groups; the Characterization and Preliminary Evaluation data are categorized into 5 site data and 25 plant (i.e. vegetative, flower/fruit, seed) data groups. The complete descriptor list for safflower is available from IBPGR's successor organization, the International Plant Genetic Resources Institute (IPGRI).

In 1986, the Consultative Group on International Agricultural Research (CGIAR), of which IPGRI is a member, extended the former IBPGR's mandate as follows: "To further the study, collection, preservation, documentation, evaluation and utilization of the genetic diversity of useful plants for the benefit of people throughout the world. IBPGR shall act as a catalyst both within and outside the CGIAR system in stimulating the action needed to sustain a viable network of institutions for the conservation of genetic resources for these plants" (Engels and Arora 1991).

From 1978 to 1989, IBPGR supported 15 collecting missions which, among a diversity of crops, acquired 82 safflower accessions from Algeria, China, Egypt, Ethiopia, Libya, Nepal, Oman, Pakistan, Sudan, Syria and Yemen (Rao and Zhou 1993).

6.1.2 Major national collections

6.1.2.1 China

The Safflower Research Group of the Beijing Botanical Garden of the Chinese Academy of Sciences, headed by Prof. Li Dajue, has collected, evaluated and documented safflower accessions with the support of IBPGR since 1989, with China having been

designated as a top priority for collecting by the First International Safflower Conference in 1981 (Knowles 1981). The total of 2051 accessions includes the Dr Paulden F. Knowles' World Collection of 1545 samples from 49 countries, and 465 specimens from within China. The Plant Information and Quantitative Analysis Research Group of the Institute of Botany, Chinese Academy of Sciences, has developed a safflower information system, including a Chinese-English database dictionary based on the information collected. Extensive evaluations, based on complete grow-outs of the germplasm at Beijing, have been reported in English (Li Dajue *et al.* 1993). Similar evaluations at Urumqi, in western China, where safflower germplasm collecting and evaluation began in 1980, have been reported in Chinese (Wang Zhaomu and Fan Lin 1991; Wang Zhaomu *et al.* 1993).

The National Crop Gene Bank, Institute of Crop Germplasm Resources, Chinese Academy of Sciences in Beijing, set up a safflower germplasm bank during the early 1990s and collected 261 accessions. The Eighth Five-year Plan (1996-2001) includes collecting of an additional 1100 accessions (Li, Zhou and Rao 1993). The Botanical Institute in Beijing, in part with assistance from IBPGR / IPGRI, has taken the lead in collecting and evaluation.

6.1.2.2 Ethiopia

From 1979 to 1985, 116 safflower accessions were collected by staff of the Plant Genetic Resources Centre / Ethiopia (PGRC / E) in cooperation with the breeder at the Melkawerer Research Centre, which is part of the Institute of Agricultural Research. The collections were made in nine administrative regions, mainly in the lower and mid-highlands, from subhumid to semi-arid regions, and the genetic diversity of this material is reported by Urage and Weyessa (1991).

6.1.2.3 India

Safflower research in India is coordinated from Solapur, in Maharashtra State, where the Germplasm Management Unit (GMU) is the major repository for world safflower germplasm in India, with 6115 accessions assembled from 38 countries (Mehtre *et al.* 1995). The GMU in cooperation with the Project Coordination Unit (Safflower) at the Mahatma Phule Agricultural University and the Directorate of Oilseeds Research (DOR) in Hyderabad, has coordinated the systematic collecting, maintenance, evaluation, documentation and cataloguing of safflower germplasm since the early 1980s when characterization of indigenous and exotic collections and elimination of duplicate entries reduced the original 9000 accessions to 1196 (Rao *et al.* 1991).

6.1.2.4 USA

Dr Paulden F. Knowles, of the University of California at Davis, with financial support from the US Department of Agriculture, collected samples of cultivated safflower mainly from research stations and bazaars in 14 countries from India, westward through the Middle East, North Africa and southern Europe in 1958 (Knowles

1959). In 1964-65, Knowles spent a sabbatical year in nine countries from India westward, Egypt, Sudan and Spain, collecting cultivated and wild and weedy safflower species and studying its culture and utilization (Knowles 1965). In 1975, he visited southern Lebanon, western Turkey and western Iran (Knowles 1991). Collections from these expeditions form one of the major sources of safflower germplasm available to researchers worldwide (via the Regional Plant Introduction Station in Pullman, Washington, USA).

6.2 Evaluations

This section attempts to highlight evaluations of safflower germplasm around the world. Where expression of the major character(s) evaluated is affected by environmental factors such as daylength and temperature, the location is described geographically. The reader is referred to the complete evaluations. The list of evaluations is incomplete, but the aim has been to present information that will enable safflower workers to access germplasm that is useful in their programmes. In general, selected entries expressing potentially useful characteristics are sorted by country of origin in the tables below. A word of caution is needed here. Partly owing to the ease of crossing among safflower lines, especially in landraces and old varieties, and partly to potential mechanical mixtures, over time, considerable heterogeneity has accumulated in much of the germplasm in the international collections. While heterogeneity itself may in fact buffer a line from a diversity of environmental stresses, single plant selections, followed by selfing, may be required to ensure that specific, simply inherited characters can be identified and used for future specific crossing purposes.

6.2.1 Australia

The morphological characters of 1424 introductions were recorded and elite lines from these were screened for resistance to *Alternaria carthami* (leaf spot, blight) and *Phytophthora cryptogea* (root rot) at Griffith, New South Wales (Harrigan *et al.* 1985). For each disease, five lines showed resistance and three entries showed resistance to both diseases: A504 (Turkey), A948 (Poland) and A949 (Poland).

6.2.2 China

The Beijing Botanical Garden of the Chinese Academy of Sciences, in part with assistance from IBPGR, has taken the lead in collecting and evaluation safflower germplasm. All accessions from China and overseas (largely, the Knowles' World Collection) were grown in the field and evaluated at this site (39º33'N; 116º16'E). Detailed evaluations of 33 characters are documented by Li Dajue *et al*. (1993). Only a few examples of potentially useful characters are presented here. Wherever possible, as well as the Beijing accession number (BJ), the USDA plant introduction (PI) numbers have been used, as these are most widely used.

Yield/plant, determined for 2021 accessions, averaged 17.2 g / plant, with 86.8% of all accessions yielding less than 30 g. The 16 lines with yields above 70 g / plant, and their countries of origin, are listed in Table 5.

Table 5. Safflower germplasm with seed yields above 70 g/plant (Beijing evaluations).

Accession number			
BJ[†]	PI[‡]	Yield (g/plant)	Country of origin
1965	426,187	86	Afghanistan (*Carthamus* spp.)
1981	367,833	77	Argentina
2030	401,477	87	Bangladesh
1351	279,054	82	India
1398	283,771	78	India
1568	205,215	77	India
1656	306,857	77	India
1675	306,883	84	India
1681	306,890	78	India
1796	307,014	89	India
1847	307,066	87	India
1866	307,085	87	India
1913	307,132	83	India
2117	406,020	78	Iran
1926	340,072	82	Turkey
1589	305,536	74	USSR (former)
1984	369,844	76	USSR (former)

Adapted from Li Dajue *et al.* 1993.
[†] BJ = Beijing accession numbers; [‡] PI = USDA Plant Introduction numbers.

Oil, the major marketable component of safflower around the world, was assessed in 2021 accessions at Beijing. Oil levels ranged from 11.5 to 47.5% with a mean of 28.3% and exceeded 40% in 21 lines (Table 6). BJ-33 had the highest oil content, 47.5%.

Heads (capitula) per plant is greatly influenced by field management (row widths, stand) and environment, but is very strongly linked to yield in safflower. The average among 2039 accessions evaluated at Beijing was 20 capitula / plant. More than 50 capitula / plant were produced by 33 accessions from 13 countries, and BJ 1965 (PI 426,187) from Afghanistan produced 90 heads / plant (Table 7).

Seed dormancy. Lack of seed dormancy results in germination in the head, if rain or heavy dew occur around harvest-time. Most commercial safflower varieties lack such seed dormancy. At Beijing, 1973 accessions from over 50 countries were grown out and freshly harvested seed was subjected to germination tests at 20ºC. The average time to achieve at least 60% germination was 60 hours, but 21 accessions, mainly from China and Turkey, required more than 120 hours (Table 8).

Table 6. Safflower germplasm with seed oil content above 40 % (Beijing evaluations).

Accession number			
BJ†	PI‡ or locality	Oil content (%)	Country of origin
147	Fubei, Xinjiang	40.1	China
148	Fubei, Xinjiang	42.4	China
430	Ta Cheng	44.8	China
2174	–	41.9	China
2255	Xinjiang	41.0	China
2451	–	40.2	Ethiopia
1134	251,910	43.4	Turkey
7	–	42.1	USA
29	–	41.8	USA
30	–	43.8	USA
31	–	40.8	USA
32	–	44.0	USA
33	–	47.5	USA
35	–	44.4	USA
38	–	43.0	USA
42	–	44.0	USA
401	–	46.0	USA
402	–	45.2	USA
403	–	42.4	USA
404	–	43.3	USA
547	–	44.3	USA

† BJ = Beijing accession numbers; ‡ PI = USDA Plant Introduction numbers (adapted from Li Dajue *et al.* 1993).

Salt tolerance. In many regions of the world, salinity in soils endangers productive crop cultivation. Safflower is known as a crop of moderate salt tolerance (just slightly below barley). However, although the more advanced plant can withstand considerable salt stress, most varieties are highly susceptible to salt during germination and emergence. Thus, varieties of safflower which can tolerate higher levels of salt during germination offer a distinct advantage. At Beijing, 2229 accessions from 50 countries were assessed for salt tolerance during germination (Zhang and Li 1993). Seeds were washed twice daily with 1.5% NaCl solution or (checks) with distilled water. The time (hours) to germination of saline-treated seeds as a percentage of that of the checks was recorded. On the 9-point scale recommended by IBPGR, in which 1 is the most salt-tolerant (germination time in salt solution within 20% of that in distilled water) and 9 the least salt-tolerant (germination time over 260% of that in distilled water), 72 of the entries scored 1 (Table 9).

Table 7. Safflower germplasm producing more than 50 capitula/plant (Beijing evaluations).

Accession number			
BJ[†]	PI[‡] or region	Capitula/plant	Country of origin
1510	304,596	51	Afghanistan
1965	426,187	90	Afghanistan (*Carthamus* sp.)
769	209,282	62	Australia
2025	401,472	53	Bangladesh
2253	Xinjiang	66	China
682	195,925	60	Ethiopia
693	198,844	82	France
713	199,890	59	India
730	199,907	52	India
763	199,952	66	India
893	248,801	78	India
933	248,841	56	India
935	248,843	53	India
1401	283,774	55	India
1548	305,191	61	India
1645	306,846	51	India
1649	306,850	53	India
1656	306,857	51	India
1666	306,873	80	India
1678	306,887	53	India
1679	306,888	66	India
1857	307,076	54	India
1869	307,088	56	India
2048	401,589	51	India
1477	304,467	73	Iran
2071	405,974	51	Iran
2077	405,980	52	Iran
1616	306,684	53	Israel
1003	250,196	53	Pakistan
1583	305,530	70	Sudan
1930	340,076	63	Turkey
1589	305,536	54	USSR (former)
1923	314,650	53	USSR (former)

[†] BJ = Beijing accession numbers; [‡]PI = USDA Plant Introduction numbers (adapted from Li Dajue *et al.* 1993).

Table 8. Safflower germplasm requiring over 120 hours to germinate when freshly harvested (Beijing evaluations).

Accession number			
BJ[†]	PI[‡] or region	Time for germination (hours)	Country of origin
192	Fujian, Xia Pu	134	China
195	Zhe Jiang, Shao Xing	127	China
244	Hebei, Da Ning	123	China
334	Hebei, Meng Cum	122	China
335	Jiang Su, Sui Ning	142	China
341	Hebei, Xian Xian	123	China
349	Zhe Jiang, Jian De	139	China
2286	–	126	China
2288	–	121	China
2290	–	126	China
1449	304,438	127	Iran
1958	343,777	122	Iran
1274	259,996	132	Pakistan
1275	259,997	153	Pakistan
1260	258,416	123	Portugal
1134	251,910	165	Turkey
1135	251,997	175	Turkey
1138	251,980	164	Turkey
1139	251,981	168	Turkey
1140	251,982	170	Turkey
1949	340,095	121	Turkey

Adapted from Li Dajue *et al.* 1993.
[†] BJ = Beijing accession numbers; [‡] PI = USDA Plant Introduction numbers.

Table 9. Safflower accessions with salt tolerance scores of 1 (Beijing evaluations).

Accession numbers		Country of origin
BJ[†]	PI[‡]	
1239	253,916	Afghanistan
1336	268,374	Afghanistan
2258		Albania
109	Gao Qing	China
199	Tong hua (Ji Li)	China
2173	–	China
2245	Wo Yang (An Hui)	China
2254	–	China
2255	–	China
2594	269,879	China
2685	250,009	China
1072	250,611	Egypt
1604	306,603	Egypt
1611	306,610	Egypt
2694	250,611	Egypt
798	226,546	Ethiopia
2213	*C. lanatus*	Germany
698	199,875	India
747	199,924	India
791	212,886	India
918	248,826	India
934	248,842	India
936	248,844	India
962	248,870	India
1062	250,600	India
1243	254,365	India
1288	260,628	India
1351	279,054	India
1390	283,763	India
1514	305,151	India
1518	305,155	India
1679	306,888	India
1708	306,922	India
1732	306,947	India
1775	306,993	India
1820	307,039	India
1855	307,074	India
217	–	Korea
1080	250,715	Iran
1082	250,717	Iran
1111	250,840	Iran
1112	250,841	Iran
1118	250,925	Iran
1119	250,926	Iran
1132	251,398	Iran
1250	255,579	Iran
1463	304,453	Iran
1476	304,466	Iran
1478	304,468	Iran
2074	405,977	Iran
2102	406,005	Iran
2494	250,840	Iran
2496	250,841	Iran
2579	250,715	Iran
2695	250,717	Iran
1212	253,758	Iraq
1618	306,686	Israel
1274	259,996	Pakistan
1275	259,997	Pakistan
1265	258,421	Portugal
774	209,287	Romania
1923	314,650	Russia
788	210,460	Turkey
805	237,539	Turkey
1135	251,997	Turkey
1138	251,980	Turkey
1139	251,981	Turkey
1140	251,982	Turkey
1936	340,082	Turkey
2139	407,624	Turkey
2634	340,082	Turkey
–	2	USA

[†] BJ = Beijing accession numbers; [‡] PI = Plant Introduction numbers from USDA (adapted from Li Dajue *et al.* 1993).

The tables of the Chinese evaluations, presented above, identify germplasm with combinations of desirable characters. For example, among the salt-tolerant lines, the Chinese BJ 2255 has high oil; the Indian BJ 1351 (PI 279,054) has high yield / plant and the Pakistani BJ 1679 (PI 306,888) has many heads / plant; BJ 1274 (PI 259,996) and BJ 1275 (PI 259,997) both require more than 120 hours to germinate; the Russian (former USSR) BJ 1923 (PI 314,650) has many heads / plant; the Turkish, BJ 1135 (PI 251,997), BJ 1138 (PI 251,980), BJ 1139 (PI 251,981) and BJ 1140 (PI 251,982) all have long germination times right after maturity (164-175 hours).

Evaluations as comprehensive as those at Beijing were carried out on the same collection at Urumqi under the guidance of Prof. Wang Zhaomu at the Institute of Economic Crops, Xinjiang Academy of Agricultural Sciences, in Urumqi in far western China (Wang and Jia 1993). Among other evaluations, 2491 safflower accessions from 52 countries were assessed for protein and amino acid composition, with protein ranging from 10.0% (Iran) to 26.1% (India and Turkey) and averaging 17.5%. High environmental temperatures tended to raise protein levels, but a strong genetic component was evident.

Duration of rosette stage, evaluated under several temperature and photoperiod regimes by growing out 695 accessions from world and Chinese collections at Kunming (25º01'N), Yuanmo (25º44'N) and Urumqi (43º34'N) in China (Yang 1993), had ranges of 32-78, 18-44 and 26-49 days, respectively. The majority of entries were daylength-neutral (photo-insensitive), with only 23 responding to daylength. A total of 175 were sensitive to temperature, including about a third of the Indian and Chinese accessions; 49 were insensitive to both daylength and temperature; 138 were sensitive to both. The daylength- and temperature-insensitive entries have good potential for wide geographic adaptation and are shown in Table 10 (Yang 1993).

Table 10. Photoperiod- and temperature-insensitive safflower lines identified at Kunming, Yuanmo, and Urumqi, China.

Country of origin	PI number or name
China	Changnin, Midu, Weishan, Wuhu, Xiapu, Yangbi, Yunnan
India	183,741; 279,052; 305,210; 306,822; 306,961; 395,166
Iran	388,907; 405,983
Mexico	Mexican dwarf
Portugal	253,566; 253,561; 258,413; 258,414; 258,415; 258,417
South Africa	262,437
Spain	253,388; 262,443
Switzerland	253,561
Syria	386,173
Turkey	304,502; 340,074; 340,075

Adapted from Yang (1993).

Fatty acid analyses of 1787 accessions from 47 countries and 18 provinces in China, grown at Beijing (39º33'N; 116º16'E) were carried out at Yunnan. This group had 81 entries originating from 13 different countries containing more than 82% linoleic acid; 21 of these exceeded 84%. PI 306829 from India had 85.6% linoleic acid, and three Chinese entries exceeded 86% (Changshu from Jiangsu, Wuzhong from Ningxia and Woyang Spineless from Anhui Province). In general, cooler climates, associated with higher latitudes and increasing altitudes, plus strong day and night temperature fluctuations, were associated with high linoleic acid. Nine entries from India, Pakistan, Bangladesh and the USA had oleic acid contents from 72 to 80.3% (Yang *et al*. 1993). Palmitic and stearic acid were also analyzed.

6.2.3 Ethiopia

At Melkawerer (9º15'N, 40º9'E; 750 m above mean sea level; with an annual rainfall of 500 mm; average temperatures of 30ºC), 33 parameters were assessed in 133 landraces in irrigated field plots from 1983 to 1986, planting in November and harvesting in April. Height, number of seeds per plant, location of branches, seed size and seed yield were recorded. All had white seeds, most had conical seeds and most had a bushy growth habit. Flower colour ranged from reddish orange and yellow to white. Other parameters measured varied widely (Urage and Weyessa 1991). Higher yields were observed in lines with bushy growth and red to yellow flowers than in more erect and white-flowered lines. The highest-yielding lines were PGRC/E numbers 205060, 205064, 205072, 205075 and 205092 (Belayneh and Wolde-Mariam 1991).

6.2.4 India

6.2.4.1 Solapur evaluations

A few of the many evaluations performed over the years by the Germplasm Management Unit at Solapur are highlighted here. The location is 17º14'N; 75º56'E; altitude 484 m.

Between 1987 and 1994, from 936 to 1223 Indian and foreign accessions, including 965 from China (in 1993-94), were grown in field plots under protective irrigation during the 'rabi' or dry seasons and evaluated in terms of 56 characters (Rao *et al*. 1990; Patil *et al*. 1990a; Shende *et al*. 1990; Rao *et al*. 1992; Mehtre *et al*. 1995). An annual comprehensive catalogue detailing these evaluations is circulated to Indian safflower workers and potentially useful lines are reported in the Sesame and Safflower Newsletter. Among the 1990-91 evaluations, 37 early maturing accessions (<108 days), 15 appressed growth habit types, 4 entries with 20 or more primary branches/plant, 5 entries with 80 or more capitula/plant, 4 lines with bold capitula (3.0 cm and above), 9 entries with high seed yield/plant, 4 partial-hull types, 13 stripe-hull types, 1 thin-hull type and 9 entries with high oil (>35%) were identified (Rao *et al*. 1992). Fifteen promising entries were selected

from the Chinese material on the basis of yield and yield-contributing characters compared with A-1 and Bhima as checks.

The 1196 accessions resulting from the organization of the Indian safflower germplasm were grown out and evaluated for 53 descriptors under various biotic (insect, diseases) and abiotic (salinity, alkalinity) stresses (Rao *et al*. 1991).

A total of 3465 germplasm accessions were categorized by hull type and analyzed by NMR for oil content (Patil *et al*. 1990). Among the entries exceeding 35% oil content: 30 intermediate-hull types contained up to 43.7% oil, 6 of the 92 brown-striped hull types had up to 37.6% oil, 5 of the 16 reduced-hull types contained up to 39.5% oil; 10 of the 17 partial-hull types contained up to 46.8% oil, and the 5 thin-hull types had 39.1-41.1% oil. The entry with the highest oil content was the partial-hulled EC 159676, with 46.8% oil. The low oil content in the majority of accessions is thought to be in part due to partial or complete nondehiscence of anthers, resulting in the development of empty seeds in hull-reduced entries (Patil *et al*. 1990). Figure 9 a-c shows reduced-hull, partial-hull and striped-hull types.

Among 17 Indian safflower varieties screened for resistance to leaf blight caused by *Alternaria carthami* in field and glasshouse trials in 1989 to 1991, one variety, Makavya Kusum (HUS-305), showed resistance under both field and glasshouse conditions and three were moderately resistant – A-1, Sagaramutyalu (APRR-3) and HUS-304 (Deokar *et al*. 1992). In earlier preliminary screening of 3145 germplasm lines in earthen pots, none were rated as resistant and 29 showed tolerance to alternaria leaf blight (Deokar *et al*. 1991).

Screening 75 germplasm lines for resistance to rhizoctonia root rot did not identify any entries as resistant but 10 were rated as tolerant (partial wilting within 10-15 days and complete wilting within 25-30 days) (Deokar *et al*. 1991a).

6.2.4.2 Other safflower evaluations in India

The USDA World Collection of Safflower was first imported and evaluated in India through the Nimbkar Agricultural Research Institute in Phaltan, Maharashtra (now included in the All India Coordinated Safflower Research Programme; Singh *et al*. 1995), where a PL480 grant from the US Department of Agriculture (Grant No. FG-In-519; Res. Proj. No. A7CR 23) was used for extensive evaluations in a project called 'Resistance of safflower to insects and diseases', commencing in 1974 (Karve 1980). From 1975 to 1980, with a research grant from the Indian Council of Agricultural Research, the USDA World Collection of safflower, locally collected lines and lines from other breeding programmes in India were evaluated (Anonymous 1985). A total of 1200 entries were planted in the field in single rows for 3 years; and half each in the 4th and 5th years. The germplasm was divided into two main physiologically adapted types, the winter crop (tropical), represented best by the Indian ecotype (relatively early in maturity, short, profusely branching and of bushy growth habit, with a lack of resistance to many fungal diseases – associated with evolving under dry, cool climatic conditions); and the summer crop (subtropical to temperate, responding to long daylength), representing the

a

b

c

Fig. 9. Hull character of seeds: Reduced - *rh rh* gene expression (a); partial - *par par* gene expression (b); striped - *stp stp* gene expression (c) (reprinted with permission from Mündel *et al.* 1992).

exotic varieties of great variability, requiring warm weather conditions and having a long rosette stage. Accessions with expressions of potentially useful / desirable characters are presented in the publication, giving local numbers to entries of Indian origin and PI numbers for those entries imported as part of the World Collection. The entries with PI numbers given which showed high degrees of resistance to some of the major biotic stresses (diseases and insect pests) are listed in Table 11.

Table 11. Safflower germplasm with high degree of resistance to selected biotic stresses (Phaltan evaluations).

PI number	Country of origin	PI number	Country of origin
Fungal pathogen (leaf blight): *Alternaria carthami*			
170,080D		240,409	Egypt
170,274B		248,362	India
199,935C	India	248,362B	India
209,281A	Israel	288,837A	
209,287	Romania		
Fungal pathogen (leaf spot): *Ramularia carthami*			
181,866A	Syria	240,409	Egypt
183,689A		248,362A	India
199936A	India	248,383	India
209,281	Israel	248,620A	Pakistan
Fungal pathogen (leaf spot): *Cercospora carthami*			
173,883A	India	199,828	
173,885A	India	199,892A	India
175,624D	Turkey	199,925	India
Insect pest (safflower fly): *Acanthiophilus helianthi*			
199,935C	India	248,806	India

Adapted from Anonymous (1985).

Note: where different types of plants with different observed resistances were detected in an accession screened, suffixes were assigned to the selected plant number (A,B).

In 1990, evaluation of 103 safflower germplasm lines for resistance to leaf spot caused by *Cercospora carthami* did not identify any immune or resistant lines (<10% of plants infected) at the Dryland Agricultural Research Station, Mulegaon, Solapur. However, Bhima and 14 introduced lines were rated as moderately resistant (25-50% plants infected) (Shinde *et al.* 1992).

A breeding programme initiated in 1980 for the nontraditional safflower regions in Madhya Pradesh emphasizes the development of spineless varieties to facilitate manual harvesting. This programme was supported for several years by the Canada-based International Development Research Centre (IDRC) and in 1990, JSI-7, based on spineless x spineless crosses, was released as the first Indian spineless variety (Sawant and Deshpande 1993).

6.2.5 Israel

Dr Amram Ashri and his team, with the help of a PL480 grant from the US government, assessed the world germplasm of safflower, including introduced and endemic wild *Carthamus* species, in terms of 56 characters at Rehovot (31º32'N; 34º29'E) and Bet Dagan (32º00'N; 34º30'E) for five seasons from 1966 to 1970 (Ashri 1973). In 1966 and 1967, about 1400 lines were planted; in 1968 and 1969, about 2000; in 1970, only about 100. The detailed evaluations included analysis of 20 morphological features to assess the variability in safflower originating from different countries. Sources of earliness, lateness, tallness and shortness were identified. Correlations among characters were estimated and heads per plant was identified as the most important yield component. Accessions of *C. persicus* and *C. palaestinus* were free of the safflower fly (*Acanthophilus helianthi* Ross), but only three cultivated lines had fewer than 25 flies / 100 heads (Ashri 1971b). Ten lines were free from rust, 17 free from ramularia leaf spot and 22 were free from cercospora leaf spot (Ashri 1971a). Sources of resistance to rust, *Ramularia* and powdery mildew were identified in *C. persicus*, *C. oxyacanthus* and in other more distantly related wild safflower species.

6.2.6 Pakistan

In Islamabad, Pakistan, at the National Agricultural Research Centre, 1294 lines of the USDA World Collection have been evaluated for yield, plant height, spininess, days to flowering and numbers of flowers per plant (Aslam and Hazara 1993).

Screening of the entire USDA World Collection of 1982 entries, with the aid of a PL480 grant from the US Department of Agriculture (Grant No. FG-Pa-395; Res. Proj. No. PK-ARS-226) was carried out from 1985 to 1987 in a project called 'Evaluation and culture of sunflower and safflower in dobari lands of Sind', commencing in 1985 (Chaudhry 1986, 1987, 1988) under the guidance of Dr Altaf Hussain Chaudhry, at the Agricultural Research Institute at Tandojam, Sind province in the very hot south of the country using irrigation. Screenings were also carried out at Shikarpur and Matli in the 'dobari' system of growing a crop on residual moisture after harvest of a paddy rice crop. Initial screening, to study the reaction of different disease and insect pests in single-row field plots, was followed by intensive evaluations of 162 selections which showed desirable agronomic traits. None of the entries was free from ramularia leaf spot. A total of 160 entries were free from the safflower fly. All entries at Tandojam had some rust. Just traces of infection with leaf spot caused by *Alternaria carthami* were found on five entries (Table 12). The majority of spineless entries showed safflower fly infection levels of 31-40%; but the majority of spiny entries showed only 11-20% infections and five spineless entries with 10% or less infection by the safflower fly (*Acanthiophilus helianthi)* were identified (Table 12). Another major pest is the black aphid (*Macrosiphum solidaginnis*) (Chaudhry *et al.* 1991). Dr Chaudhry is no longer active in his breeding programme, but he developed the spineless Thori-78 and the early maturing, high-yielding selection no. 28 from Thori-78.

Table 12. Safflower germplasm with high degree of resistance to alternaria leaf spot and safflower fly (Sind, Pakistan evaluations).

PI number	Country of origin	PI number	Country of origin
Fungal pathogen (leaf blight, 'Trace'): *Alternaria carthami*			
251,284	Jordan	262,419	Australia
253,518	Austria	306,614	Egypt
253,519	Austria		
Insect pest (safflower fly, =<10%): *Acanthiophilus helianthi*			
199,874	India	253,894	Pakistan
250,077	Egypt	Thori-78	Pakistan
251,284	Jordan		

Adapted from Chaudhry (1988).

6.2.7 Spain

In 1985, the USDA World Collection of safflower was multiplied in Córdoba and 188 entries from 32 countries were evaluated, along with 12 commercial Spanish varieties, at Sevilla, for protein, oil and hull content. Oil and protein content of the achene were negatively correlated, but there was no correlation between oil and protein content of the kernel (Rojas *et al.* 1993).

Among 199 entries of the world collection from 37 countries, multiplied and evaluated for weight of seed, oil content and fatty acid composition at Córdoba (37º32'N; 4º28'W), seed weight and oil content showed a normal distribution, with seed weight averaging 42.1 mg and ranging from 19.2 to 65.5 mg; while oil averaged 28.1% (Table 13) (de Haro *et al.* 1991). The oleic acid levels were higher than those observed by Futehally (cited in Knowles 1989:Table 4), suggesting that environmental as well as genetic factors control oleic acid levels.

Table 13. Seed weight, oil content and major fatty acids of 199 safflower lines (Córdoba evaluations).

Character	Mean	Range	Country of origin of lines with highest levels
Seed weight (mg)	42.1	19.2 - 65.8	India
Oil content (%)	28.1	–	India, Iraq, Pakistan
Palmitic acid (% oil)	7.1	4.6-9.6	
Stearic acid (% oil)	3.2	1.3-7.6	Afghanistan
Oleic acid (% oil)	21.5	9.5-84.2	Jordan, Kenya
Linoleic acid (% oil)	67.4	11.4-80.0	Portugal

Adapted from De Haro *et al.* (1991).

In 1984 and 1985, 1400 entries of the World Collection were screened for resistance to the parasitic weed broomrape (*Orobanche crenata* Forsk) at Córdoba and Sevilla (Osuna) using natural field infection (heavy at Córdoba and light at Sevilla). Using absolute lack of emergence of the parasite from any of the plants of the safflower entry as the criterion for selection as a potential source of resistance to broomrape, 11 lines were selected (Melero-Vara *et al*. 1989). Among 417 rust-resistant lines, field and controlled environment testing identified another 12 entries with resistance to broomrape (Table 14).

Table 14. Rust-resistant safflower accessions selected for resistance to *Orobanche crenata* (broomrape) in Spain (identified by PI numbers from USDA World Collection) (country of origin in parentheses).

From two-location test	From two rust-screening tests
199,909 (India)	209,282 (Australia)
199,911 (India)	210,460 (Turkey)
248,630 (Pakistan)	239,041 (Morocco)
253,385 (Israel)	250,608 (Egypt)
253,894 (Israel)	251,264 (Jordan)
253,907 (Afghanistan)	251,266 (Jordan)
262,442 (Spain)	251,285 (Jordan)
283,748 (India)	253,515 (Germany)
306,602 (Egypt)	262,439 (Ethiopia)
312,275 (Hungary)	407,620 (Turkey)
343,930 (Ethiopia)	407,622 (Turkey)
407,624 (Turkey)	

Adapted from Melero-Vara *et al.* (1989)

6.2.8 USA

At the Regional Plant Introduction Station in Pullman, Washington (46º28'N; 117º05'W), the collections from Knowles' expeditions (1958, 1964-65 and 1975) have been grown out, described and are being maintained (Knowles 1985). In recent years, a core collection of 210 entries which maintains a high proportion of the genetic diversity in the whole collection has been established (Johnson *et al*. 1993). This core has been established to facilitate initial evaluations which may otherwise be prohibitive because of complexity or cost. Descriptor data and Random Amplified Polymorphic DNAs (RAPDs) for this core collection are being compiled and evaluated (Dr R.C. Johnson, pers. comm., 1996).

At Sydney, in eastern Montana (47º25'N; 104º06'E), Dr J. Bergman is evaluating fatty acid contents and other seed-quality characteristics among 1000 accessions received from the USDA World Collection.

6.3 Institutions holding safflower collections

To exchange germplasm, it is essential that the requester provide all the necessary documentation to meet requirements for import permits and phytosanitary certificates and deal with any costs associated with obtaining samples (importing and exporting seed). Although IPGRI (formerly IBPGR) supports the free exchange of germplasm and a number of countries and organizations adhere to the basic principles espoused by IBPGR in 1974, recent and likely changes in intellectual property laws can result in charges for germplasm. In some countries, the agencies entrusted with admitting crop germplasm (seeds) also charge for that service.

The accompanying listing of safflower germplasm collections of >75 accessions is a combination of an FAO-World Information Warning System on PGR (Germplasm Conserved in Genebanks) of 13 December 1995 and personal information available to the authors. In some cases the major centre(s) for safflower germplasm are indicated without reference to the major national genebank. It is anticipated that the appropriate contacts can help provide the necessary information to facilitate an exchange of seeds. Unless otherwise indicated, samples are freely available.

6.3.1 Australia

Queensland Department of Primary Industries, PO Box 46, Brisbane, Queensland 4001, Australia. Samples stored in medium-term storage. Restricted availability of samples.

6.3.2 China

Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences (Academia Sinica), 20 Nan Xin Cun, Xiangshan, Haidian District, Beijing 1000093, China. Tel.: +86-10-6259 0833 ext. 2029/2019; Fax: +86-10-6259 2686; E-mail: lidj@botany.ihep.ac.cn. In-charge, Prof. Li Dajue. Centre for Chinese safflower germplasm collections. Small quantity of collections is in short-term storage.

Seed of safflower collections is stored in medium- and long-term storage, at the **National Crop Gene Bank, Institute of Crop Germplasm Resources, Chinese Academy of Agricultural Sciences, No. 30, Bai Shi Qiao Road, Beijing 100081, China. Tel.: +86-10-6217 4433; Fax: +86-10-6217 4142.**

6.3.3 Ethiopia

Ethiopia Biodiversity Institute, PO Box 30726, Addis Ababa, Ethiopia. Tel.: +251-1-180 381 / 612 244; Fax: +251-1-613 722. Dr Seyfu Ketema, Director. This is the former Plant Genetic Resources Centre/Ethiopia (PGRC/E), established with the assistance of GTZ, Germany in 1976, following IBPGR's identification of Ethiopia as a top priority area for collecting and preservation of germplasm of a wide variety of crops. Safflower is in medium- and long-term storage. This institute has been instrumental in initiating farmer-curator preserving of germplasm of local landraces of crops through a scheme called Seeds of Survival (SoS).

6.3.4 Germany

The recently reunited Germany now has two major genebanks a short distance apart.

Institute of Crop Sciences, Federal Research Centre for Agriculture (Bundes-Forschungsanstalt für Landwirtschaft - FAL, Institut für Pflanzenbau), Bundesallee 50, 38116 Braunschweig, Germany. Tel.: +49-531-596-617; Fax: +49-531-596-365. Dr Lothar Frese, in charge. The safflower collection includes wild and weedy species, landraces, cultivars and breeding lines. Safflower germplasm is stored in both medium- and long-term storage.

Genebank, Institute for Plant Genetics and Crop Plant Research (Institut für Pflanzengenetik und Kulturpflanzenforschung - IPK), Corrensstraße 3, 06466 Gatersleben, Germany. Tel.: +49-39482-5280; Fax: +49-39482-5155; E-mail: hammer@ipk-gatersleben.de. Head: Prof. Dr Karl Hammer. Collection includes 74 accessions of different *Carthamus* species. Storage is in closed glass containers, with silica gel, for both medium- (0ºC) and long-term (–15ºC) storage.

6.3.5 India

Storage and availability conditions have not been identified.

National Bureau of Plant Genetic Resources, Pusa Campus, New Delhi, 11012, India. Contact possible via IPGRI Tel.: +91-11-5786 112; Fax: +91-11-5731 845.

Directorate of Oilseeds Research, Indian Council for Agricultural Research (ICAR), Rajendranagar, Hyderabad 500 030 A.P., India. Tel./FAX: 91-40-245 222. Dr P.S. Reddy, Project Director and Chairman International Safflower Germplasm Advisory Committee (ISGAC) is the contact for all germplasm resources and breeding programmes in India, irrespective of where they are stored.

6.3.6 Mexico

Instituto Nacional de Investigaciones Agricolas, Estacion de Iguala, Iguala, Mexico. Seed is stored in medium-term storage.

Program de Oleaginosas (Oilseed Breeding Programme), CIANO/SARH Calle Norman E. Borlaug Km 12, Apdo. Postal 515, Cd. Obregón, Sonora State, Mexico 8500. Storage and availability conditions are not specified.

Instituto Nacional de Investigacio nes Forestales y Agropecuarias, Col. San Rafael, Serapio Rendon, 83-C.P. 06470, Mexico. Availability is not specified; storage conditions are medium- and long-term.

6.3.7 Russia

N.I. Vavilov All-Russian Research Institute of Plant Industry, Bolshaya Morskaya Street 44, 190 000 St.Petersburg, Russia. Tel: +7-812-311-99-01 or -314-22-34; Fax: +7-812-311-87-62; E-mail: vir@glas.aps.org. Dr Victor Dragavtsev, Director. Sofia N. Kutsova, Acting Head, Industrial Crops Department (including safflower). The world collection of safflower has been evaluated *inter alia* for the fatty acid composition of its oil. Availability of germplasm is not specified (although free exchange has taken place with second author, Mündel); storage conditions are medium and long term.

6.3.8 United States of America

Agricultural Research Service/US Department of Agriculture, Western Regional Plant Introduction Station, 59 Johnson Hall, Pullman, WA 99164-6402, USA. Tel. +1-509-335-1502; Fax: +1-509-335-6654; E-mail: W6RJ@ARS.GRIN.GOV. Curator/Res. Agronomist for safflower: Dr Richard C. Johnson. Centre for distribution of USDA World Collection of safflower, including P.F. Knowles' collections from expeditions in 1958, 1964-65 and 1975; domesticated safflower, wild and weedy species. Total safflower collection consists of 2042 entries; with a core collection of 210, representing 10% of the total collection and all 53 countries from which safflower germplasm originated (Johnson *et al.* 1993). Data are catalogued by the Genetic Resources Information Network (GRIN) system. Storage conditions are for medium term at 4ºC and 30% relative humidity; with long-term storage (–20ºC) of duplicates of the samples stored at the National Seed Storage Laboratory in Fort Collins, Colorado. On retirement of Dr Dave Rubis, 139 accessions deemed the most valuable of his collection/genetic stocks, emphasizing high oleic lines, phytophthora root rot resistance, different hull types and seed dormancy, were deposited at Pullman. On retirement of Dr Knowles, 220 entries in his special collections were also forwarded to Pullman. Prof. Li Dajue has sent samples of his collections in China to be included in the World Collection of Safflower at Pullman. Countries which have received all or most of this USDA World Collection (over 1700 entries) in the past 5 years include Canada and Syria. Countries within which either one institution or a combination of organizations received at least 100 entries over the past decade (1987-96) include Algeria, Argentina, China, India, Israel, Italy, Pakistan and Romania (R.C. Johnson and D. Stout, pers. comm., 1996).

6.4 Safflower research: centres/individuals and examples of varieties produced

6.4.1 Australia

At present, there is no active plant breeder developing safflower varieties in this country, but over several decades, Dr E.K.S. Harrigan, of CSIRO, at Griffith, New South Wales, has done some outstanding work. In 1974, he initiated a disease resistance breeding programme at the Division of Irrigation Research (Harrigan *et al.* 1985). Shortly before his retirement he released two new varieties: Sironaria, which has good field resistance to Australian strains of *Alternaria carthami*, as well as good resistance to phytophthora root rot (Harrigan 1987a), and Sirothora, which has good resistance to root rot caused by *Phytophthora cryptogea* and outyields the old standard variety, Gila (Harrigan 1987b).

6.4.2 Canada

Dr Hans-Henning Mündel, Agriculture and Agri-Food Canada, Research Centre, PO Box 3000 Main, Lethbridge, Alberta, Canada. Tel.: +1-403-327-4591 ext. 448; FAX: +1-403-382-3156; E-mail: MUENDEL@EM.AGR.CA. Operates a small saf-

flower breeding and development programme for early maturity and sclerotinia head rot resistant varieties (Mündel *et al*. 1985). Varieties registered in Canada from this programme include Saffire (1985), AC Stirling (1991) and AC Sunset (1995).

6.4.3 China

Prof. Li Dajue, Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences (Academia Sinica), 20 Nan Xin Cun, Xiangshan, Haidian District, Beijing 1000093, China. Tel.: +86-10-6259 1431 ext. 6071 (office), 6340 (res.); Fax: +86-10-6259 0384 or 2686; E-mail: lidj@botany.ihep.ac.cn. Prof. Li Dajue is in charge of safflower and sweet sorghum breeding programmes; actively involved in germplasm collecting and evaluation in China (supported by IBPGR) and organized the Third International Safflower Conference (1993). Safflower cultivars developed are characteristically early, spineless, with red flowers and appressed branching or seed dormancy. The varieties include the FO-series: e.g. FO-2 is a cross of Ruicheng from Shaanxi Province and VFstp-1 (Urie *et al*. 1976); FO-3, a spineless, striped-hull, red-flowered variety, from FO-2 x 23M-8-2 (Xi'an Safflower x Mexican Dwarf); FO-4 is a cross of FO-2 x UC-26, spineless, with red flowers and narrow branching; FO-8 (Tacheng x AC-1) x 23M-8-2, is also spineless, with red flowers, striped hull seed and early maturity.

Prof. Wang Zhaomu, Institute of Economic Crops, Xinjiang Academy of Agricultural Sciences, Urumqi, Xinjiang 830000, China. Tel.: +86-991-452 1547 (office), 452 0693 (res.). Operates safflower and brassica breeding programmes for western China.

6.4.4 Ethiopia

Drs Elias Urage and Bulcha Weyessa, Institute of Agricultural Research, Melkawerer Research Centre, PO Box 2003, Addis Ababa, Ethiopia. Safflower varieties developed in Ethiopia include Aklilu which gives high yields in the mid-highlands; Bako-red and Bako-white selections; Kulumsa Thornless; Bozinan.

6.4.5 India

Dr P.S. Reddy, Project Director and Chairman International Safflower Germplasm Advisory Committee (ISGAC), Directorate of Oilseeds Research, Indian Council of Agricultural Research, Rajendranagar, Hyderabad 500 030 A.P., India. Tel.: +91-40-245 222 / 245 331; Fax: +91-40-245 222; Telex: 0425 6856 DOR IN. Contact for germplasm resources and breeding programmes in India. Major breeding objectives include earliness, high seed yield and oil content, resistance / tolerance to alternaria leaf spot, wilt and root rot, resistance / tolerance to aphids and responsiveness to fertilizers. Examples of varieties developed by public programmes in India include Annigeri-1, Annigeri-300, Bhima (S-4), CO-1, JSI-7 (spineless), K-1, Malavya Kusum (HUS-305), Manjira, Niphad 62-8, Nira (NRS-209), S-144 (Reddy and Therumalachar 1976), Sagaramutyalu (APRR-3), Sweta (JSF-1), Tara and T-65.

Project Coordinating Unit (Safflower), 91, Bhavani Peth, MPKV, Solapur-413 002, Maharashtra State, India. The Germplasm Management Unit (GMU) coordinates germplasm collecting throughout the country.

Nimbkar Agricultural Research Institute Phaltan 415-523, Maharashtra State, India. Tel.: +91-2166 22396; Fax: +91-2166 22338. Dr Nandini Nimbkar, Director. Safflower breeding and development have been carried out here since 1967. The variety Nira (NS-209) was released in 1987.

6.4.6 Mexico

Program de Oleaginosas (Oilseed Breeding Programme), CIANO/SARH. Calle Norman E. Borlaug Km 12, Apdo. Postal 515, Cd. Obregón, Sonora State, Mexico 8500, Tel./Fax: +52-64 12 16 18. Objectives of this safflower breeding programme include high yield, oil levels higher than 38%, linoleic and oleic acid lines, resistance to alternaria leaf spot and rust, intermediate to early maturity and wide adaptation. Recent varieties from Mexico include Quiriego 88, Sahuaripia 88 and San José 89, which, on average, yield 15% higher than Gila (Musa 1993; Musa and Muñoz 1990).

6.4.7 Spain

Safflower has had some ups and many downs in Spain (prices, broomrape, safflower fly, etc.). Dr José Fernández-Martínez, in cooperation with Dr J. Domínguez-Giminez, formerly of the Centre for Agrarian Research and Development (CIDA) and then of the Institute of Sustainable Agriculture (IAS), CSIC, Apartado 4084, Córdoba, Spain, has developed a number of varieties: the high linoleic acid varieties Tomejil, Rancho, Merced; and the high oleic acid varieties Alameda and Rinconada (Fernández-Martínez and Domínguez-Giminez 1987). Dr Fernández-Martínez is also editor of the annual Sesame and Safflower Newsletter**.**

6.4.8 USA

Dr Jerald W. Bergman, Eastern Agricultural Research Centre, MSU, PO Box 1350, Sidney, Montana 59270, USA Tel.: +1-406-482-2208; Fax: +1-406-482-7336, E-mail: aaxjb@gemini.oscs.montana.edu. The major 'public' safflower breeding programme in the USA, emphasizing high oil, high oleic acid, alternaria resistance and industrial uses. Recent varieties include: the early maturing Erlin (released in 1996), Centennial (released in 1991; protected under Plant Variety Protection Act), Girard (released in 1986), Oker (released in 1985) – all regular 'linoleic' varieties; and Montola 2000 (released in 1991; protected under Plant Variety Protection Act), a high oleic acid (>80%) variety, followed by Montola 2001; and the high linolenic variety, Morlin.

Arthur B. (Barney) Hill, Director, Safflower Research, c/o Mycogen Plant Sciences, **20212 County Road 103, Woodland, CA 95776 USA. Tel.: +1-916-666-5338, Fax: +1916-666 7993, E-mail: agrimad!mycomad!hill@uunet.uu.net.** A private hybrid safflower breeding programme, called SAFFTECH, emphasizing high yield and oil.

This was for more than two decades the Cargill safflower breeding programme, then part of Agrigenetics, then part of Mycogen.

Arthur Weisker, Seedtec International, PO Box 2210, Woodland, California 95696, USA. Tel.: +1-916-666-7871; Fax: +1-916-662-9125. Runs a safflower breeding programme emphasizing improved yield and particular fatty acid profiles (high oleic; low saturates). Varieties developed by Seedtec include the previously very popular S-208 (1967), then S-541 (1978; high oil), S-317 (their first high oleic) and, more recently, S-555 (1988) (high yield and *Fusarium* tolerance) and S-518 (1991) (high oleic acid, >80%).

Two safflower breeders deserve recognition: Canadian-born Dr P.F. Knowles, working at the University of California at Davis, mentioned a number of times in this book in connection with his plant-exploration trips that led to the collecting of the largest part of the world collection of safflower germplasm. Together with his students, he identified many of the taxonomic relationships among the *Carthamus* species, developed the first high oleic safflower variety (UC-1) and was instrumental in assisting diverse country programmes to use the collections. Dr Dave Rubis, working at the University of Arizona, is the author of most genetic descriptions, identifications of genetic stocks and symbols in safflower. In 1958, he developed the variety Gila, which became popular in many countries outside the USA (Mexico, Australia, Argentina, etc.) for much of the next three decades.

7 Literature guides

7.1 Handbooks, monographs, safflower descriptor list

Chavan, V.M. 1961. Niger and Safflower. Indian Central Oilseeds Committee Publ., Hyderabad. Pp. 57-150.

Hanelt, P. 1963. Monographische Übersicht der Gattung *Carthamus* L. (Compositae). Zeit. Feddes Repert. 67:41-180.

IBPGR Secretariat. 1983. Descriptors for Safflower. AGPG:IBPGR/81/93, Rome, Italy, May. 22 p.

Knowles, P.F. 1989. Safflower. Pp. 363-374 *in* Oil Crops of the World (G. Röbbelen, R.K. Downey and A. Ashri, eds.). McGraw-Hill, New York. [Brief overview of distribution, systematics, breeding and utilization.]

Knowles, P.F. (ed.) 1981. Proceedings First International Safflower Conference, Univ. of Calif., Davis, California, USA, July 12-16. 299 p.

Kolte, S.J. 1985. Diseases of Annual Edible Oilseed Crops, III. Sunflower, Safflower and Nigerseed Diseases. CRC Press, Boca Raton, Florida, USA. Pp. 97-136.

Li Dajue. 1993. Abstracts on Safflower. Beijing Botanical Garden, Pub., Beijing, China. 784 p. [More than 2500 abstracts from important papers, journals, and books worldwide; copies may be purchased by sending a certified cheque or money order for US$60, payable to the Academy, to Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences, Beijing 1000093, China.]

Li Dajue, Zhou Mingde and V. Ramanatha Rao. 1993. Characterization and Evaluation of Safflower Germplasm. Geological Pub. House, Beijing, China. 260 text and 16 colour p. [Outline of origin, distribution, biology of safflower, collecting and conservation strategy, characterization resulting from evaluations of germplasm of safflower, including world collection grown in China; copies may be purchased by sending a certified cheque or money order for US$45, payable to the academy, to Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences, Beijing 1000093, China.]

Li Dajue and Han Yuanzhou (eds). 1993. Proceedings Third International Safflower Conference, Beijing, China, 14-18 June 1993. Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences. [Copies may be purchased by sending a certified cheque or money order for US$75, payable to the Academy, to Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences, Beijing 1000093, China.]

López, González, G. 1989. Acerca de la clasificación natural del género *Carthamus* L., s.l. Anales del Jardín Bot. de Madrid 47(1):11-34.

Ranga Rao, V. and M. Ramachandran (eds). 1991. Proceedings Second International Safflower Conference, Hyderabad, India, Jan. 9-13, 1989. Indian Soc. of Oilseeds Research, Pub., Hyderabad, India. 419 text and 11 colour p.

Smith, J.R. 1996. Safflower. AOCS Press, Champaign, IL, USA. 624 pp. [Emphasis is on origin of safflower production, marketing, and research in the USA. Country-by-country developments are presented.]

Weiss, E.A. 1983. Oilseed Crops. Chapter 6. Safflower. Longman Group Limited, Longman House, London, UK. Pp. 216-281.

Weiss, E.A. 1971. Castor, Sesame, and Safflower. Barnes and Noble, Inc., New York. Pp. 529-744.

7.2 Recent production guides

Helm, J.L., A.A. Schneiter, N. Riveland, and J. Bergman. 1991. Safflower production. North Dakota State University, Fargo, ND 58105, USA, A-870 (revised), 14 AGR-6, 4 p.

Mündel, H.-H., R.J. Morrison, R.E. Blackshaw and B. Roth (eds). 1992. Safflower Production on the Canadian Prairies. Agric. Can. Res. Station, Lethbridge / Alberta Saffl. Growers Assoc., with funding by Farming for the Future Project No. 87-0016, Alberta Agric. Research Institute. [35 p., incl. 4 color p. of varieties, seed types, diseases and insect pests. Available from Alberta Safflower Growers Assoc. Box 822, Lethbridge, Alberta T1J 3Z8, Canada.]

Smith, H.A., C. Rust, D. Baldridge, J. Bergman and J. Caprio. n.d. Safflower: a Montana Specialty Crop. Montana State University, Extension Service, Bozeman, Montana 59717, USA. 4 p.

Smith, J.R. 1996. Safflower. Appendix C: Recommended Cropping Practices. AOCS Press, Champaign, IL, USA. Pp. 530-552.

8 References

Abel, G.H. and D.G. Lorance. 1975. Registration of Dart safflower. Crop Sci. 15:100.

Anishetty, N.M. and J.T. Esquinas-Alcazar. 1991. FAO's role in conservation and utilization of plant genetic resources. Page 107 *in* Proceedings Second International Safflower Conference, Hyderabad, India, 9-13 Jan. 1989 (V. Ranga Rao and M. Ramachandran, eds.). Indian Society of Oilseeds Research, Directorate of Oilseeds Research, Hyderabad.

Anonymous. 1972. Study of coronary heart disease prescription No. 2 on dilating blood artery and relieving smooth muscle plasma [in Chinese]. Research Association of Coronary Heart Disease in Beijing, China.

Anonymous. 1985. Safflower improvement. Thirteenth Research Report, Nimbkar Agricultural Research Institute, Phaltan, Dist. Satara, Maharashtra, India. 69 p.

Ashri, A. 1971a. Evaluation of the world collection of safflower, *Carthamus tinctorius* L. I. Reaction to several diseases and associations with morphological characters in Israel. Crop Sci. 11:253-257.

Ashri, A. 1971b. Evaluation of the world collection of safflower, *Carthamus tinctorius* L. II. Resistance to the safflower fly, *Acanthophilus helianthi* R. Euphytica 20:410-415.

Ashri, A. 1973. Divergence and evolution in the safflower genus, *Carthamus* L. Final Research Report, P.L. 480, Washington, DC, USA. Project No. A10-CR-18, Grant No. FG-Is-234, 180 p.

Ashri, A. and P.F. Knowles. 1960. Cytogenetics of safflower (*Carthamus* L.*)* species and their hybrids. Agron. J. 52:11-17.

Aslam, M. and G.R. Hazara. 1993. Evaluation of the world collection of safflower *(Carthamus tinctorius)* for yield and other agronomic characters. Page 238 *in* Proceedings of the Third International Safflower Conference, Beijing, China, 9-13 June 1993 (Li Dajue and Han Yunzhou, eds.). Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences.

Bai Pu, Cao Linlin, Ma Kuanyu, Li Zhilao and Wang Xinghai. 1992. Qi Bao Qu Bai Pill was used for treatment on vitiligo of 369 cases [in Chinese]. J. Shanxi Traditional Chinese Medical Sci. 13(6):254.

Belayneh, H. and Y. Wolde-Mariam. 1991. Safflower production, utilization and research in Ethiopia. Pp. 43-55 *in* Proceedings Second International Safflower Conference, Hyderabad, India, 9-13 Jan. 1989 (V. Ranga Rao and M. Ramachandran, eds.). Indian Society of Oilseeds Research, Directorate of Oilseeds Research, Hyderabad, India.

Bergman, J.W. 1996. American varietal development and agronomy. Page 5 *in* North American Safflower Conference, Great Falls, Montana, USA, 17-18 Jan. (H.-H. Mündel, J. Braun and C. Daniels, eds.). Lethbridge, AB, Canada.

Bergman, J.W., D.E. Baldridge, P.L. Brown, A.L. Dubbs, G.D. Kushnak and N.R. Riveland. 1987. Registration of 'Hartman' safflower. Crop Sci. 27:1090-1091.

Bergman, J.W., G. Carlson, G. Kushnak, N.R. Riveland and G. Stallknecht. 1985. Registration of 'Oker' safflower. Crop Sci. 25:1127-1128.

Bergman, J.W., G. Carlson, G. Kushnak, N.R. Riveland, G. Stallknecht, L.E. Welty and D. Wichman. 1989. Registration of 'Girard' safflower. Crop Sci. 29:828-829.

Blackshaw, R.E., D.A. Derksen and H.-H. Mündel. 1990. Herbicides for weed control in safflower (*Carthamus tinctorius*). Can. J. Plant Sci. 70:237-245.

Carapetian, J. 1994. Effects of safflower sterility genes on the inflorescence and pollen grains. Aust. J. Botany 42:325-332.

Carapetian, J. and P.F. Knowles. 1993. Genetic linkage between the trigenic male-female sterility and oil quality alleles in safflower. Crop Sci. 33:239-242.

Chaudhry, A.H. 1986. Evaluation and culture of sunflower and safflower in dobari lands

of Sind. 1st Annual Report, PL480 Program of USAID, Project No. PK-ARS-226, Grant No. FG.PA 395, 25 p.

Chaudhry, A.H. 1987. Evaluation and culture of sunflower and safflower in dobari lands of Sind. 2nd Annual Report, PL480 Program of USAID, Project No. PK-ARS-226, Grant No. FG.PA 395, 59 p.

Chaudhry, A.H. 1988. Evaluation and culture of sunflower and safflower in dobari lands of Sind. 3rd Annual Report, PL480 Program of USAID, Project No. PK-ARS-226, Grant No. FG.PA 395. 102 p.

Chaudhry, A.H., B.R. Oad and M.H. Memon. 1991. Research and production of safflower *(Carthamus tinctorius)* in southern Pakistan. Pp. 57-66 *in* Proceedings Second International Safflower Conference, Hyderabad, India, 9-13 Jan. 1989 (V. Ranga Rao and M. Ramachandran, eds.). Indian Society of Oilseeds Research, Directorate of Oilseeds Research, Hyderabad, India.

Chavan, V.M. 1961. Niger and Safflower. Indian Central Oilseeds Committee Publ., Hyderabad, India. Pp. 57-150.

Chen Shengdong. 1990. Observations on the curative effects of hair-generated agent for treatment on *Alopecia areata* of 123 cases [in Chinese]. Henan Traditional Chinese Medical Sci. 10(3):23-24.

Chen Xiuqin. 1990. The treatment on uterine bleeding of 890 cases by Metrorrhagia-healed Remedy [in Chinese]. Shandong Traditional Chinese Medial Sci. J. 9(1):24.

Chu Hang, Zhang Dunyi, Xia Jinglian, Chen Shuzhen and Hou Shuying. 1985. Yi Qi Hua Yu Prescription was used for treatment on chronic gastritis of 106 cases [in Chinese]. J. Combination of Traditional Chinese and Western Medicine 5(5):267-268.

Chu Qiuping. 1989. The Treatment on Women's Climacteric Syndrome of 52 cases by Climacteric syrup [in Chinese]. Shanghai Traditional Chinese Medicine J. 1:24-25.

De Haro, A., M. del Rio, J.C. López, M.A. García, M.J. Palomares and J. Fernández-Martínez. 1991. Evaluation of a world collection of safflower (*Carthamus tinctorius* L.) for oil quality and other seed characters. Sesame and Safflower Newsl. 6:94-99.

Deng You'an. 1988. Observation on the recent curative effect of the traditional chinese medicine invigorating the circulation of blood plus anticarcinogen for treatment of acute leukemia [in Chinese]. J. Combination of Traditional Chinese and Western Medicine 8(11):683.

Deng You'an *et al*. 1984. The treatment of leucocyptopenia of 23 cases with prescription for invigorating blood circulation and reducing stasis [in Chinese]. J. Combination of Traditional Chinese and Western Medicine 4(12):717-719.

Deokar, A.B., B.S. Manke, B.N. Narkhede, P.S. Patil, S.M. Nikam and M.S. Munde. 1984. 'Bhima' – a new safflower variety. J. Maharashtra Agric. Univ. 9(3):351-352.

Deokar, C.D., P.B. Shinde and V.B. Akashe. 1991a. Screening of safflower germplasms against rhizoctonia root rot under laboratory conditions. Sesame and Safflower Newsl. 6:80-81.

Deokar, C.D., D.M. Veer, R.C. Patil and V.G. Akashe. 1991b. Preliminary screening of safflower germplasm against alternaria leaf blight under artificial conditions in glass-house. Sesame and Safflower Newsl. 6:77-78.

Deokar, C.D., D.M. Veer, R.C. Patil and V.G. Akashe. 1992. Varietal resistance of safflower (*Carthamus tinctorius*) to Alternaria leaf blight. Sesame and Safflower Newsl. 7:72-75.

Deshmuk, A.K. and V. Ranga Rao. 1989. A new and efficient method to achieve mass hybridization in safflower without emasculation: a re-appraisal of currently followed emasculation techniques. Pp. 157-161 *in* Proceedings Second International Safflower Conference, Hyderabad, India, 9-13 Jan. 1989 (V. Ranga Rao and M. Ramachandran, eds.). Indian Society of Oilseeds Research, Directorate of Oilseeds Research,

Hyderabad, India.
Dong Jiayun. 1988. Huo Xue Hua Yu decoction was used for treatment on ankyloenteron of 50 cases [in Chinese]. J. Combination of Chinese Traditional and Western Medicine 8(4):237.
Duo Zhenshun, Sun Xiping and Zhang Fang. 1992. The effects of Chinese medicine Shu-Jing Drip on cerebral artery blood flow of atherosclerosis of 30 cases [in Chinese]. J. Shanxi Traditional Chinese Medicine 8(2):12-13.
Engels, J.M.M. 1991. Summary proceedings and recommendations: genetic resources. Page 383 *in* Proceedings Second International Safflower Conference, Hyderabad, India, 9-13 Jan. 1989 (V. Ranga Rao and M. Ramachandran, eds.). Indian Society of Oilseeds Research, Directorate of Oilseeds Research, Hyderabad, India.
Engels, J.M.M. and R.K. Arora. 1991. IBPGR's activities in safflower germplasm conservation. Pp. 111-115 *in* Proceedings Second International Safflower Conference, Hyderabad, India, 9-13 Jan. 1989 (V. Ranga Rao and M. Ramachandran, eds.). Indian Society of Oilseeds Research, Directorate of Oilseeds Research, Hyderabad.
Feng Shaoren. 1992. The treatment of syndrome caused by cerebral trauma of 47 cases with the prescription for invigorating blood circulation [in Chinese]. J. Combination of Practical Chinese and Western Medicine 15(3):140-141.
Fernández-Martínez, J. and J. Domínguez-Gimenez. 1987. Release of five new safflower varieties. Sesame and Safflower Newsl. 2:89-90.
Gyulai, J. 1996. Market outlook for safflower. P. 15 in Proceedings of North American Safflower Conference, Great Falls, Montana, January 17-18 (H.-H. Mündel, J. Braun and C. Daniels, eds.). Lethbridge, AB, Canada.
Gupta, R.K. and S.B. Singh. 1988a. Diallel analysis for seed yield, oil content and other economic traits in safflower *(Carthamus tinctorius* L.). Genetika-Yugoslavia 20:161-173.
Gupta, R.K. and S.B. Singh. 1988b. Genetic analysis for earliness in safflower (*Carthamus tinctorius* L.). Genetika-Yugoslavia 20:219-227.
Harrigan, E.K.S. 1987a. Safflower registration of cv. Sironaria. Sesame and Safflower Newsl. 3:47-49.
Harrigan, E.K.S. 1987b. Safflower registration of cv. Sirothora. Sesame and Safflower Newsl. 3:49-50.
Harrigan, E.K.S., C.F. McRae and A.D. Heritage. 1985. Sources of resistance to *Phytophthora cryptogea* and *Alternaria carthami* for safflower breeding in Australia. Sesame and Safflower Newsl. 1:45-47.
Heaton, T.C. and P.F. Knowles. 1980. Registration of UC-148 and UC-149 male-sterile safflower germplasm. Crop Sci. 20:554.
Heaton, T.C. and P.F. Knowles. 1982. Inheritance of male sterility in safflower. Crop Sci. 22:520-522.
Hill, A.B. 1996. Hybrid safflower development. Pp. 5-6 *in* North American Safflower Conference, Great Falls, Montana, USA., 17-18 Jan. (H.-H. Mündel, J. Braun and C. Daniels, eds.). Lethbridge, AB, Canada.
Hill, A.B. and P.F. Knowles. 1968. Fatty acid composition of the oil of developing seeds of different varieties of safflower. Crop Sci. 8:275-277.
Huang Zhengliang, Gao Qiming and Cui Zhumei. 1984. Studies on Pharmacology of the yellow pigment of safflower (*Carthamus tinctorius* L.) [in Chinese]. Traditional Chinese Medicine 15(8):12-14.
Huang Zhengliang, Cui Zhumei and Ren Yuan. 1987. Studies on the resistant effect of safflower yellow pigment on blood coagulation [in Chinese]. Traditional Chinese Medicine 18(4):22-25.
Imrie, B.C. and P.F. Knowles 1970. Inheritance studies in interspecific hybrids between

Carthamus flavescens and *C. tinctorius*. Crop Sci. 10:349-352.
Johnson, R.C., D.M. Stout and V.I. Bradley. 1993. The U.S. collection: a rich source of safflower germplasm. Pp. 202-208 *in* Proceedings of the Third International Safflower Conference, Beijing, China, 9-13 June 1993 (Li Dajue and Han Yunzhou, eds.). Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences.
Jia Hanqing, Chen Meilin and Ma Shuren. 1980. Observation of the effect of safflower as sex hormone [in Chinese]. J. Jiamusi Coll. of Medical Sci. 2:18-20.
Jiang Wei and Kong Fanxue. 1992. Application of Hua-Yu-Rong-Nao decoction for treatment on sequelae of cerebral trauma of 67 cases [in Chinese]. Shandong Traditional Chinese Medicine 11(1):23.
Karve, A.D. 1980. Resistance of safflower (*C. tinctorius* L.) to insects and diseases. A final technical report. Nimbkar Agricultural Research Institute, Phaltan, India.
Khidir, O.M. and P.F. Knowles. 1970. Cytogenetic studies of *Carthamus* species (Compositae) with 32 pairs of chromosomes. II. Intersectional hybridization. Can. J. Genet. Cytol. 12:90-99.
Kleingarten, L. 1993. Page 5 *in* Notes Safflower Conference, Billings, Montana, 18 February 1993. (H.-H. Mündel and J. Braun, eds.). Lethbridge, AB, Canada.
Klisiewicz, J.M. and A.L. Urie. 1982. Registration of Fusarium resistant safflower germplasm. Crop Sci. 22:165.
Knowles, P.F. 1959. Plant Exploration Report for Safflower and Miscellaneous Oilseeds: Near East and Mediterranean Countries, March-October 1958. Dept. of Agronomy, University of California, Davis, CA, in collaboration with USDA-ARS Crop Research Division, CR-43-5. [42 text p. plus photos.]
Knowles, P.F. 1965. Report of Sabbatic Leave, August 1, 1964-August 1, 1965. Report for University of California, Davis, CA. [48 text pp. plus numerous photos.]
Knowles, P.F. 1968. Registration of UC-1 Safflower. Crop Sci. 5:641.
Knowles, P.F. 1969. Centers of plant diversity and conservation of crop germplasm: Safflower. Econ. Botany. 23:324-329.
Knowles, P.F. 1980. Safflower. Pp. 535-547 *in* Hybridization of Crop Plants (W.R. Fehr and H.H. Hadley, eds.). Am. Soc. Agron., Madison, Wisconsin, USA.
Knowles, P.F. (ed.). 1981. Proceedings of First International Safflower Conference. University of California, Davis, CA, USA. July 12-16. 299 pp.
Knowles, P.F. 1985. Oilseed crop breeding: past and future. Pp. 199-209 *in* Oil Crops: Sesame and Safflower (A. Omran, ed.). Manuscript Report, IDRC-MR105e.
Knowles, P.F. 1988. *Carthamus* species relationships. A lecture in Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences, Beijing, China.
Knowles, P.F. 1989. Safflower. Pp. 363-374 *in* Oil Crops of the World (G. Röbbelen, R.K. Downey and A. Ashri, eds.). McGraw-Hill, New York.
Knowles, P.F. 1991. Global perspectives of safflower. Pp. 13-16 *in* Proceedings Second International Safflower Conference, Hyderabad, India, 9-13 Jan. 1989 (V. Ranga Rao and M. Ramachandran, eds.). Indian Society of Oilseeds Research, Directorate of Oilseeds Research, Hyderabad, India.
Kolte, S.J. 1985. Diseases of Annual Edible Oilseed Crops, III. Sunflower, Safflower and Nigerseed Diseases. CRC Press, Boca Raton, Florida, USA. Pp. 97-136.
Kotecha, A. 1979. Inheritance and association of six traits in safflower. Crop Sci. 19:523-527.
Kotecha, A. and L.H. Zimmerman. 1978. Genetics of seed dormancy and its association with other traits in safflower. Crop Sci. 18:1003-1007.
Kumar, H. 1991. Cytogenetics of safflower. Pp. 251-277 *in* Chromosome engineering in plants: Genetics, Breeding, Evolution, Part B., Developments in Plant Genetics and Breeding, 2B (T. Tsuchiya and P.K. Gupta, eds.). Elsevier, Amsterdam.
Kumar, H. and R.K. Agrawal 1989. 'HUS 305' a high-yielding safflower variety. Indian

Farming 39(5):17-18.
Ladd, S.L. and P.F. Knowles. 1971. Inheritance of alleles at two loci regulating fatty acid composition of the seed oil of safflower (*Carthamus tinctorius* L.). Crop Sci. 11:681-684.
Leininger, L.N. and A.L. Urie. 1964. Development of safflower seed from flowering to maturity. Crop Sci. 4:83-87.
Li Chengzhu, Yan Shichun, Zhao Fengdi and Yan Diequn. 1983. Effects of safflower on blood coagulation function of big rat [in Chinese]. Traditional Chinese Medicine 14 (7):27-28.
Li Dajue and Han Yuanzhou. 1993. The development and exploitation of safflower tea. Pp. 837-843 *in* Proceedings of the Third International Safflower Conference, Beijing, China, 9-13 June 1993 (Li Dajue and Han Yunzhou, eds.). Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences.
Li Dajue, Zhou Mingde and V. Ramanatha Rao (eds.). 1993. Characterization and evaluation of safflower germplasm. Geological Publishing House, Beijing, China. 260 pp.
Li Xinwen, Fu Chong and Jiao Meijun. 1993. Development of poly-amino acids safflower nutrient. Pp. 844-849 *in* Proceedings of the Third International Safflower Conference, Beijing, China, 9-13 June 1993 (Li Dajue and Han Yunzhou, eds.). Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences.
Li Yunshan. 1986. The treatment on anal fissure of 85 cases by sit-washing on washing-fissure decoction [in Chinese]. Henan Traditional Chinese Medicine 6:34.
Liu, F., X.Z. Yang, F.G. Li, J. Hu and R.F. Cheng. 1992. Hypotensive effects of safflower yellow in spontaneously hypertensive rats and influence on plasma renin activity and angiotensin II level [in Chinese]. Acta Pharmaceutica Sinica 27(10):785-787.
Liu Shulin. 1992. Treated of goitre with goitre-resolved therapy [in Chinese]. Sichuan Traditional Chinese Medical Sci. 10(5):47.
Liu Yaling. 1985. The application of Chinese Herbal Medicine in inducing labor for women in later gestation [in Chinese]. Beijing Medical Sci. 7(1):44.
Liu Yuanxiu. 1991. The treatment of pigment flecks of acne with fleck-eliminating smearing medicinal liquid [in Chinese]. J. Jilin Traditional Chinese Medicine 6:23.
López González, G. 1989. Acerca de la clasificación natural del género *Carthamus* L., s.l. Anales del Jardín Bot. de Madrid 47(1):11-34.
Lu Jianxin. 1989. The treatment on joint wrench of 458 cases by Chinese medicine ointment for external application [in Chinese]. J. PLA Medicine 14(3):228.
Lu Kuijie. 1985. The prescription for invigorating blood circulation was used for treatment on erythrocytosis [in Chinese]. Beijing Traditional Chinese Medical Sci. 2:21-22.
Lu Zhoucai. 1991. The treatment on hemiplegia of 288 cases by traditional Chinese and western medicine combination [in Chinese]. Shanxi Traditional Chinese Medical Sci. 12(10):444.
Ma Shan, Liang Fangxing, Wang Shangrui, Dong Shuping, Yin Shengguang, Xue Changlian and Lin Zongli. 1989. The curative effect of Wei-You for treatment on atrophic gastritis of 910 cases [in Chinese]. J. Traditional Chinese Medicine 30(9):32-33.
Matern, U. and R.E. Kneusel. 1993. The use of recombinant DNA techniques to confer resistance to the *Alternaria* leaf spot disease of safflower. Pp. 807-815 *in* Proceedings of the Third International Safflower Conference, Beijing, China, 9-13 June 1993 (Li Dajue and Han Yunzhou, eds.). Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences.
Mehtre, S.P., V.B. Akashe, B.D. Koli, D.M. Veer and M.W. Patil. 1995. Evaluation of exotic safflower germplasm collected in China for agromorphological characters. Sesame and Safflower Newsl. 10:79-84.
Melero-Vara, J.M., C. Garcia Baudín, J. Domínguez and J. Fernández-Martínez. 1989. Evaluation on the resistance of a safflower world collection against broomrape.

Sesame and Safflower Newsl. 4:83-85.
Mündel, H.-H. 1969. Effect of rainfed and irrigated conditions on yield of indigenous and exotic varieties of safflower (*Carthamus tinctorius* L.). Madras Agric. J. 56:772-777.
Mündel, H.-H. 1987. Registration of Lesaf 175 safflower germplasm line. Crop Sci. 27:369-370.
Mündel, H.-H., H.C. Huang and G.C. Kozub. 1985. Sclerotinia head rot in safflower: assessment of resistance and effects on yield and oil content. Can. J. Plant Sci. 65:259-265.
Mündel, H.-H., H.C. Huang, G.C. Kozub and D.J.S. Barr. 1995. Effect of soil moisture and temperature on seedling emergence and incidence of *Pythium* damping-off in safflower (*Carthamus tinctorius* L.). Can. J. Plant Sci. 75:505-509.
Mündel, H.-H., R.J. Morrison, R.E. Blackshaw and B. Roth (eds). 1992. Safflower Production on the Canadian Prairies. Agric. Canada Res. Station, Lethbridge / Alberta Safflower Growers Association with funding by Farming for the Future Project No. 87-0016, Alberta Agric. Research Institute. 35 p.
Musa, G.L.C. 1993. Safflower production and research in Mexico. Sesame and Safflower Newsl. 8:109-112.
Musa, G.L.C. and V.S. Muñoz. 1990. Registration of 'Quiriego 88' safflower. Crop Sci. 30:961-962.
Narkhede, B.N. and A.B. Deokar. 1986. Inheritance of corolla color in safflower. J. Maharashtra Agric. Univ. 11:278-281.
Narkhede, B.N. and A.B. Deokar. 1990. Inheritance of spineness and pericarp types in safflower. J. Maharashtra Agric. Univ. 15:279-281.
Narkhede, B.N. and A.M. Patil. 1987. Heterosis and inbreeding depression in safflower. J. Maharashtra Agric. Univ. 12 (3):337-340.
Narkhede, B.N., A.M. Patil and A.B. Deokar. 1987. Gene action of some characters in safflower. J. Maharashtra Agric. Univ. 17(1):4-6.
Orlikowska, T.K., H.J. Cranston and W.E. Dyer. 1995. Factors influencing *Agrobacterium tumefaciens*-mediated transformation and regeneration of the safflower cultivar 'Centennial'. Plant Cell, Tissue and Organ Culture 40:85-91.
Pan Huanhe. 1986. The treatment on suddenly occurred deafness of 34 cases with ventilating and vital energy-nourished decoction [in Chinese]. Jiangsu Traditional Chinese Medical Sci. J. 7(7):21.
Patel, M.Z., M.V. Reddi, B.S. Rana and B.J. Reddy. 1989. Genetic divergence in safflower *(Carthamus tinctorius* L.). Indian J. Genetics and Plant Breeding 49 (1):113-117.
Patil, R.C., V. Ranga Rao, V.D. Shende and K.P. Deolankar. 1990a. Evaluation of exotic and Indian germplasm accessions of safflower-II. Sesame and Safflower Newsl. 5:97.
Patil, R.C., V. Ranga Rao, V.D. Shende, K.P. Deolankar and Mev Singh. 1990b. Isolation of high oil types in safflower. Sesame and Safflower Newsl. 5:91-93.
Patil, V.D., M.V.S. Reddy and Y.S. Nerkar. 1994. Efficiency of early generation selections for yield and related characters in safflower *(Carthamus tinctorius* L.). Theor. Appl. Genet. 89:293-296.
Peterson, R. 1996. Birdseed market outlook. P. 15 *in* Proceedings of North American Safflower Conference, Great Falls, Montana, 17-18 January (H.-H. Mündel, J. Braun and C. Daniels, eds.). Lethbridge, AB, Canada.
Prasad, B.R., M.A.Khadeer, P. Seeta and S.Y. Anwar. 1990. Influence of genotype and cold pre-treatment on anther culture response in safflower, *Carthamus tinctorius* L. Indian J. Exp. Biol. 28:924-927.
Qi Ming, Li Chunmei, Lu Heqi and Liu Wenfu. 1984. Effects of some herbs on microcirculation of blood of rat's mesentery [in Chinese]. J. Chinese Traditional Medicine 25(12):65-67.

Qi Wenxuan, Zheng Yunxia, Wei Daowu, Zhang Yanying and Yang Jianying. 1987. Effects of safflower yellow pigment on the blood fat and liver function of rabbits [in Chinese]. J. Lanzhou Coll. of Medical Sci. 3:57-60.

Qian Zhangquan. 1985. Treatment of wrist muscle tenosynovitis by washing method with decoction [in Chinese]. Sichuan Traditional Chinese Medical Sci. 3(11):46.

Qin Yuehao. 1990. An analysis on the clinical treatment of male sterility of 300 cases by kidney-benefited and invigorating blood-circulation decoction [in Chinese]. Jiangxi Traditional Chinese Medicine 21(3):21-22.

Qu Chun. 1990. Clinical observation on dead sperm excess disease of 182 cases [in Chinese]. Shanghai Traditional Chinese Medicine J. 5:28-29.

Rao, R. and Zhou Mingde. 1993. Safflower genetic resources - IBPGR activities. Pp. 287-292 *in* Proceedings of the Third International Safflower Conference, Beijing, China, 9-13 June 1993 (Li Dajue and Han Yunzhou, eds.). Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences.

Rao, V.R. and M. Ramachandram. 1991. Proceedings of Second International Safflower Conference, Hyderabad, India, 9-13 January 1989. 419 p.

Rao, V.R., R.C. Patil, V.D. Shende and K.P. Deolankar. 1990. Evaluation of exotic germplasm accessions of safflower-I. Sesame and Safflower Newsl. 5:95-96.

Rao, V.R., R.C. Patil, V.D. Shende and K.P. Deolankar. 1992. Evaluation of exotic and indigenous germplasm accessions of safflower-IV. Sesame and Safflower Newsl. 7:88-89.

Rao, V.R., M. Ramachandran and R.C. Patil. 1991. Current status of safflower genetic resources in India. Page 109 in Proceedings Second International Safflower Conference, Hyderabad, India, 9-13 Jan. 1989 (V. Ranga Rao and M. Ramachandran, eds.). Indian Society of Oilseeds Research, Directorate of Oilseeds Research.

Reddy, B.S. and D.K. Therumalachar. 1976. S-144, a high yielding variety of safflower. Current Research 5:185-186.

Rojas, R., J. Ruso, J. Osorio, A. de Haro and J. Fernández-Martínez. 1993. Variability in protein and hull content of the seed of a world collection of safflower. Sesame and Safflower Newsl. 8:122-126.

Rubis, D.D. 1981. Development of a root rot resistance in safflower by introgressive hybridization and thin-hull facilitated recurrent selection. Pp. 205-209 *in* Proceedings First International Safflower Conference, Univ. of Calif., Davis, California, USA, 12-16 July (P.F. Knowles, ed.).

Sawant, A.R. and S.L. Deshpande. 1993. Current status of improvement of spineless safflower and future strategy. Pp. 306-315 *in* Proceedings of the Third International Safflower Conference, Beijing, China, 9-13 June 1993 (Li Dajue and Han Yunzhou, eds.). Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences.

Shen Qingliang, Chen Nengquan, Shang Daoxi and Bai Yunguang. 1988. Experimental studies on the antithrombus effect of E-Hong Injection liquor [in Chinese]. Chinese Traditional Medicine Bull. 13(6):46-47.

Shende, V.D., V.R. Rao, R.C. Patil and K.P. Deolankar. 1990. Evaluation of exotic and indigenous germplasm accessions of safflower-III. Sesame and Safflower Newsl. 5:98-99.

Shinde, P.B., D.S. Ghorpade and S.I. Tambe. 1992. Screening of safflower against Cercospora leaf spot. Sesame and Safflower Newsl. 7:89-91.

Si Zaihe. 1989. The treatment of erythema tuberosum with blood circulation-invigorated and dampness-benefited decoction [in Chinese]. Zhejian Traditional Chinese Medicine J. 24(3):112.

Singh, V., M.B. Deshpande, D.B. Yadav, S.V. Choudhary and N. Nimbkar. 1995. An appraisal of 25 years of safflower research under irrigated conditions at NARI India:

1968-1993. Sesame and Safflower Newsl. 10:69-78.
Smith, J.R. 1996. Safflower. AOCS Press, Champaign, IL, USA. 624 p.
Sun Shixi. 1955. Studies on pharmacology of safflower and saffron crocus [in Chinese]. J. Chinese Medical Sci. 5:443-448.
Tan Dingquan. 1989. Qu Bai Xiao Ban Decoction was used for treatment on vitiligo of 200 cases [in Chinese]. J. Hunan Traditional Chinese Medical Sci. 5(5):41.
Tan Qiuyuan. 1992. Observations on the curative effects of invigorating blood circulation and eliminating cataract decoction for treatment of the senile cataract of 200 cases [in Chinese]. Hunan Traditional Chinese Medical Science J. 8(4):15-16.
Tao Genyu. 1990. Observation on the curative effect of Traditional Chinese Medicine myopic agent mixed with boiled water for treatment of false-nature myopia of youngsters [in Chinese]. Bull. Shanxi Coll. of Traditional Chinese Medicine. 13(2):46-48.
Tejovathi, G. and S.Y. Anwar. 1993. 2,4,5-Trichloro phenoxy propionic acid induced rhizogenesis in *Carthamus tinctorius* L. *in* Proceedings of the Indian National Science Academy, Part B, Biological Sciences 59:633-636.
Thomas, C.A. 1971. Registration of VFR-1 Safflower germplasm. Crop Sci. 11:606.
Urage, E. and B. Weyessa. 1991. Genetic diversity of Ethiopian safflower collections. Pp. 175-178 *in* Proceedings Second International Safflower Conference, Hyderabad, India, 9-13 Jan., 1989 (V. Ranga Rao and M. Ramachandran, eds.). Indian Society of Oilseeds Research, Directorate of Oilseeds Research.
Urie, A.L. 1981. Continued studies on inheritance of partial hull in safflower (*Carthamus tinctorius* L.). Pp. 264-271 *in* Proceedings First International Safflower Conference. University of California, Davis, California USA, 12-16 July (P.F. Knowles, ed.).
Urie, A.L. 1986. Inheritance of partial hull in safflower. Crop Sci. 26:493-498.
Urie, A.L. and D. E. Zimmer. 1970a. Registration of reduced-hull safflower lines, reduced-hull -1, -2, -3, -4. Crop Sci. 10:732.
Urie, A.L. and D. E. Zimmer. 1970b. Registration of thin-hulled, structurally male-sterile safflower lines, th-5 and th-10. Crop Sci. 10:463-646.
Urie, A.L., L.H. Zimmerman, C.A. Thomas, W.F. Peterson and P.F. Knowles. 1976. Registration of VFstp-1 safflower germplasm. Crop Sci. 16:888.
Wang Bingzhang, Yang Minggang, Pang Lei and Yu Zhanjiu. 1978. The effects of safflower (*Carthamus tinctorius)* liquor on ischemic degree of cardiac muscle in different infarct regions of experimental myocardial infarction dog [in Chinese]. Acta Pharmaceutica Sinica 14(8):474-478.
Wang Chunru. 1989. The treatment on pelvic infection of 102 cases with invigorating the circulation of blood and stasis-reduced therapy [in Chinese]. Jilin Traditional Chinese Medicine 6:21.
Wang Guimiao and Li Yili. 1985. Clinical application of safflower (*Carthamus tinctorius)* [in Chinese]. Zhejiang Traditional Chinese Medical Science J. 1:42-43, 1985.
Wang Guishen. 1985. Clinical application of safflower [in Chinese]. Zhejiang Traditional Chinese Medical Science J. 20(1):42-43.
Wang Sai. 1992. A report on the treatment of chronic suppurative osteomyelitis of 520 cases [in Chinese]. Tianjin Traditional Chinese Medical Science 2:6-7.
Wang Shengyun. 1985. Sanhua atomizing agent used for treatment of 100 cases of acute throat diseases [in Chinese]. J. Heilongjiang Traditional Chinese Medicine 6:23-24.
Wang Yue and Wang Luqiu. 1990. A clinical observation on the effect of rheumatic prescription for treatment of rheumatoid arthritis of 50 cases [in Chinese]. J. Jiangsu Traditional Chinese Medicine 11(2):1-3.
Wang Zhaoming, Chang Jiyun, Jiang Lianhong, Zhang Huiying and Yu Hexuan. 1985. Rheumatism tablet was used for treatment on rheumatoid arthritis of 310 cases [in Chinese]. J. Combination of Traditional Chinese and Western Medicine 5(5):284-285.

Wang Zhaomu and Fan Lin. 1991. Ecology and variety of safflower in Xinjiang. Pp. 179-183 *in* Second International Safflower Conference, Hyderabad, India, 9-13 Jan. 1989 (V. Ranga Rao and M. Ramachandran, eds.). Indian Society of Oilseeds Research, Directorate of Oilseeds Research.

Wang Zhaomu (ed.) 1993. The evaluation and utilization of world collection of safflower germplasm [in Chinese]. Chinese Science and Technology Press. 484 pp.

Wang Zhaomu and Jia Zuocheng. 1993. The protein contents of world safflower resources and their affecting factors. Pp. 337-345 *in* Proceedings of the Third International Safflower Conference, Beijing, China, 9-13 June 1993 (Li Dajue and Han Yunzhou, eds.). Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences.

Wang Zhongying. 1989. Lupus pill was used for treatment on lupus erythematosus [in Chinese]. J. Combination of Traditional Chinese and Western Medicine 9(8):465-468.

Weiss, E.A. 1971. Castor, Sesame and Safflower. Barnes and Noble, Inc., New York. Pp. 529-744.

Weiss, E.A. 1983. Oilseed crops. Chapter 6. Safflower. Longman Group Limited, Longman House, London, UK. Pp. 216-281.

Wichman, D. 1996. Safflower for forage. Page 11 *in* Proceedings of North American Safflower Conference, Great Falls, Montana, 17-18 January (H.-H. Mündel, J. Braun and C. Daniels, eds.). Lethbridge, AB, Canada.

Wu Lian'en. 1992. Yi Qi Huo Xue Prescription used for treatment of gastritis [in Chinese]. J. Jiangsu Traditional Chinese Medical Science 13 (1):35-37.

Xu Zhaoxian. 1989. Treatment on chronic knee-joint cartilage tissue strain of 52 cases with self-made cartilage tissue-treated ointment No. 1 [in Chinese]. Shanghai Traditional Chinese Medicine J. 11:10.

Yang Jianguo. 1993. The reaction of light and temperature on the development of safflower and its ecotype. Pp. 351-357 *in* Proceedings of the Third International Safflower Conference, Beijing, China, 9-13 June 1993 (Li Dajue and Han Yunzhou, eds.). Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences.

Yang Jinguo, Jiang Yuzhong, Liu Xuyun and Zhao Yongkang. 1993. The research on the germplasm resources of safflower with different contents of fatty acids. Pp. 358-365 *in* Proceedings of the Third International Safflower Conference, Beijing, China, 9-13 June 1993 (Li Dajue and Han Yunzhou, eds.). Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences.

Yao Honghai. 1985. Treatment on bone arthritis with Shenjindan (muscle stretching powder) of 126 cases [in Chinese]. Shandong Traditional Chinese Medical Sci. J. 1:21-25.

Ye Chuanhui. 1986. The prepared Chinese herbal medicine Colon Pouring-into Liquor was applied for treatment on acute renal function exhaustion [in Chinese]. J. Traditional Chinese Medicine 27(11):25-26.

Yin Huafu. 1988. An analysis on the curative effect of cervical vertebra sickness cured No. 2 for treatment of cervical vertebra sickness [in Chinese]. J. Combination of Traditional Chinese and Western Medicine 8(5):292.

Yin Jialou. 1986. Observations on the recent effects about the internal and external treatments of trachoma of 550 cases [in Chinese]. Anhui Coll. of Traditional Chinese Medicine Bull. 5(2):35-36.

Ying, M.C., W.E. Dyer and J.W. Bergman. 1992. *Agrobacterium tumefaciens*-mediated transformation of safflower (*Carthamus tinctorius* L.) cv. 'Centennial'. Plant Cell Reports 11:581-585.

Yuan Guobi, Han Yunzhou, and Li Dajue. 1989. Safflower germplasm and its exploitation and utilization. Science Press. 344 pp.

Yu Damao. 1987. Application of Xiao Shuan Decoction for treatment on cerebral thrombosis of 68 cases [in Chinese]. J. Zhejiang Traditional Chinese Medicine 22(10):441.

Zeven, A.C. and P.M. Zhukovsky. 1975. Dictionary of Cultivated Plants and their Centres of Diversity. Centre for Agric. Publ. and Document. (Pudoc), Wageningen, Netherlands. 219 p.

Zhang Li and Li Dajue. 1993. Evaluation of safflower (*Carthamus tinctorius* L.) germplasm: salt tolerance of indigenous and exotic safflower. Pp. 366-373 *in* Proceedings of the Third International Safflower Conference, Beijing, China, 9-13 June 1993 (Li Dajue and Han Yunzhou, eds.). Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences.

Zhang Yonghong, Zou Yuanqin, Gong Lijuan, Yu Chenghui, Guo Huifang, Jiang Jianlong, Sun Wei and Zhou Jialin. 1989. Traditional Chinese Medicine: the treatment of chronic nephritis in 540 cases based on the analysis of the symptoms in traditional Chinese medicine [in Chinese]. Bull. Nanjing Coll. of Traditional Chinese Medicine 2:5-8.

Zhao Lijun. 1990. Bu Yang Huan Wu Decoction was applied for treatment on chronic nephritis of 108 cases [in Chinese]. J. Practical External Medicine of Traditional Chinese Medical Sci. 4(3):27-28.

Zhao Zhangguang. 1988. Observations on the curative effects of Hair-regenerated Essence-101 for treatment of alopecia areata of 8324 cases [in Chinese]. Traditional Chinese Medical Sci. J. 29(9):53-54.

Zheng Yukun. 1988. The treatment of thorax rheumatism of 800 cases with milkvetch-peach-safflower, etc. decoction [in Chinese]. Liaoning Traditional Chinese Medical Sci. J. 12(9):19-20.

Zhong Xiumei. 1992. Clinical observation on the effect of Taohongsiwu decoction plus other herbs for treatment of vaginal bleeding of 128 cases [in Chinese]. Zhejiang Traditional Chinese Medical Sci. J. 27(7):300.

Zhou Wenyu. 1986. Tian Ying's prescription was used for treatment on sterility of 77 cases [in Chinese]. J. Traditional Chinese Medicine 27(12):31-32.

Zhou Zuolin. 1992. The curative effects of Tao-Hong-Si-Wu Decoction for treatment on cerebral embolism of 32 cases [in Chinese]. Correspondence of Traditional Chinese Medicine 11(3):44-45.

Zhu Pijiang. 1991. Hu Shen Hua Yu Decoction was used for treatment on renal function imperfection of 61 cases [in Chinese]. J. Combination of Traditional Chinese and Western Medicine 11(12):750-752.

Zimmer, D.E. and A.L. Urie. 1970. Registration of rust resistant safflower breeding lines PCA, PCM-1, PCM-2, PCN, and PCOy. Crop Sci. 10:463.