# Safflower in California

The Paulden F. Knowles personal history of plant exploration and research on evolution, genetics, and breeding

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## The Paulden F. Knowles personal history of plant exploration and research on evolution, genetics, and breeding


*edited by*

**Patrick E. McGuire**
**Ardeshir B. Damania**
**Calvin O. Qualset**

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Text photographs: P.F. Knowles

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# Editors' summary: P.F. Knowles' genetic resources legacy

At the start of Paul Knowles' career, safflower was only incidentally grown in California. By virtue of his work, the crop was introduced and improved and production and distribution became a California industry. Central to this progress was germplasm acquisition, evaluation, conservation, and utilization carried out with Knowles' vision and leadership. His achievements were far reaching. Today, when crop genetic resources are paradoxically both increasingly recognized as highly valuable and yet confronted with ever greater risk of being lost, his story has valuable lessons.

- Accessible, wide-ranging genetic diversity is essential for the genetic improvement of a crop.

  Knowles recognized early on that safflower breeding programs in the US had a narrow genetic base and this lack of germplasm was restricting progress.

- Accessibility of genetic diversity requires international exchange and collaboration.

  Knowles was supported, directly and indirectly, in his efforts by his institution, several US agencies (e.g., USDA, USAID, US Dept. of State), the UN Food and Agriculture Organization, and numerous academic and national researchers and institutions and private growers and sellers in the many countries in which he traveled. He initiated and facilitated exchanges of germplasm, information, and scholars.

- Collection of germplasm should be made across all environments and geographic regions in which the target species or crop grows.

  The mutations he reports and worked with for safflower fatty acid composition arose in very small populations in widely dispersed and unpredictable sites (India, Iran, Israel, Portugal, and Russia) and would never have been found without access to wide-ranging germplasm collections.

- Useful genetic diversity can be found in landraces of the crop from regions where it has a long history of cultivation and in wild species closely related to the crop species.

  He reports useful genes and traits for cultivated safflower from landraces (e.g., the fatty acid composition mutations, flower color variants, growth habit, disease resistances, and male sterility) and from wild species (disease resistances).

- Indigenous germplasm is being rapidly replaced with introductions and newly developed varieties in many regions and environments, it is critical that material continues to be collected for ex situ conservation from these areas.

  He recognized early in his collecting career that safflower landraces that had been grown for centuries in some countries were being replaced by crops and cultivars from developed nations.

- Research on species relationships and distribution, ecology, ethnobotany, cytogenetics, and basic biology are crucial for efficient and directed utilization of landraces and wild species for improvement of related crops.

  Over his career, his graduate students, postdocs, and research colleagues compiled a broad record of research efforts on safflower that encompassed basic agronomy, pathology, cytogenetics, genetics, biochemistry, and biogeography. The productivity of this research effort depended in a large way on the safflower genetic resources collection (the World Collection) to which he was a major contributor. At the same time, these research efforts enhanced the value of the World Collection as the resulting data became part of the information associated with the collection.

- Evaluation and characterization of genetic resources (landraces and breeding lines) under diverse environments and stress conditions are essential for identifying characters useful for crop improvement.

  His work in California with the World Collection and screening for disease resistances and adaptive traits and the work with collaborators in other countries and environments exemplify the value of the evaluation and characterization process for ultimately successful germplasm utilization.

- Novel genetic diversity can lead directly to successful cultivar development.

  Safflower cultivar 'UC-1', released by Knowles in 1968, was essentially the first commercial variety of a new type of safflower oil, a new crop. Its oil properties (high oleic acid) differed in fatty acid composition from that of traditional safflower oil (high linoleic acid) as a result of a mutation discovered in a safflower accession from India. The oil of UC-1 was chemically similar to olive oil. The identification of the novel oil type was made possible only by screening diverse collections of safflower germplasm for variation in fatty acid properties. The Indian accession was crossed in Knowles' breeding program to a Nebraska cultivar (N-10) in 1957 to initiate the incorporation of the novel oil type into an agronomically acceptable background. By 1967, after a backcrossing breeding program, certified seed of the new cultivar was available and it was the foundation for California production for several years and for commercial breeding programs thereafter.

- Crop introduction is facilitated by agronomic research and outreach and extension to cultivate growers, producers, and markets for production.

  His work in this area early in his career laid the foundation for all his subsequent work. The rising success of safflower as a California crop gave impetus and support for his subsequent breeding, evolution, and geographic interests in the crop and its wild related species.

- Plant 'breeding' in the broadest sense of plant selection, use, and improvement is a story of human curiosity, need, innovation, and persistence.

  On his travels, he didn't interact only with breeders and seed dealers, he sought out farmers, market sellers, and users of the crops in which he was interested. This report on safflower touches on some of the many anecdotal presentations of the ways of growing, harvesting, processing, and using (in art, medicine, industry, and cuisine). The similarities and contrasts that he observed from one country and tradition to another in all these steps with a common plant are enlightening and a testimony to his own sense of curiosity and the apparent value he placed on each person's contribution, testimony, and information.

- Serendipity plays a significant role in revealing the utility of germplasm collections.

  Two examples from Knowles' work illustrate this:

  1. Lettuce is known commonly as a leafy vegetable, and more distantly in time, it was cultivated for its stem, but on both his 1958 and 1964–1965 collection trips, he observed the use of a primitive lettuce

in Egypt as an oil crop in areas where safflower was also cultivated. Its seeds were being collected and pressed, in a manner similar to how safflower oil was obtained. Seed derived from his lettuce collections is still available through USDA National Plant Germplasm System (NPGS), e.g., PI 250020.

2. Among the many other non-*Carthamus* taxa that he collected during his 1958 trip were four 'forage grass' accessions that he labeled '*Agropyron* spp.' in his report (Knowles 1959), but only 'grass' or 'annual grass' in his notebook. These were accessioned by the USDA NPGS and identified to species. Three of them turned out to be *Brachypodium distachyon*: PI 253334 was collected in Morocco and PI 254867 and PI 254868 were collected in Iraq. All three were screened in the last decade as part of a large-scale effort[1] at understanding the geographic, morphological, and genetic diversity in this species in preparation for presenting it as a new model plant system for genomic research. An inbred line (denoted Bd21) derived from Knowles' PI 254867 accession (seed he collected in Iraq as K 1202, '4 km. from Salahudin, 4"-6" tall, ripe', coming from Mosul) became adopted, primarily because it was diploid and because of its facility for transformation, as the 'canonical genotype' for *B. distachyon* serving as the source of DNA and RNA for both the whole genome and EST sequencing projects by the US Dept. of Energy-Joint Genome Institute Community Sequencing Project (DOE-JGI). The full genome sequence for *B. distachyon* from Bd21 was published in 2010.[2] In 1958 Knowles opportunistically collected those seeds and deposited them in the NPGS. Some 40 years later, a testament to NPGS maintenance and regeneration practices, the accessions were thus available for uses and technologies completely unknown in 1958.

Paul Knowles' work finished with the decade of the 1980s. At the time of his death in 1990, work was underway that would culminate with the opening for signature in 1992 of the Convention on Biological Diversity and its subsequent entry into force at the end of 1993. It is an important question whether he could have done his work in the international germplasm access and exchange environment that exists post-CBD. Certainly under the CBD, there is nothing in theory that would prevent his accomplishments, but in practice the many bilateral agreements for exchange of germplasm necessary today and the difficulty in obtaining these (as exemplified by the records of the past 20 years) make it highly unlikely that the current state of safflower knowledge and productivity would have been possible. The International Treaty for Plant Genetic Resources for Food and Agriculture and its Multilateral System for genetic resources access that emerged in the early 2000s would not have helped Knowles' safflower work either. Safflower is not one of the crops covered under the Treaty.

— ***Patrick E. McGuire***, ***Ardeshir B. Damania***, and ***Calvin O. Qualset***
Department of Plant Sciences, University of California, Davis CA USA

1 Vogel JP, DF Garvin, OM Leong, and DM Hayden. 2006. *Agrobacterium*-mediated transformation and inbred line development in the model grass *Brachypodium distachyon*. *Plant Cell, Tissue and Organ Culture* **84**:199–211;
Garvin DF, Y-Q Gu, R Hasterok, SP Hazen, G Jenkins, TC Mockler, LAJ Mur, and JP Vogel. 2008. Development of genetic and genomic research resources for *Brachypodium distachyon*, a new model system for grass crop research. *Crop Sci* **48(S1)**:S69–S84.
2 The International Brachypodium Initiative. 2010. Genome sequencing and analysis of the model grass *Brachypodium distachyon*. *Nature* **463**:763–768.

# Preface

The history of safflower in California is a classic example of the importance of acquisition and use of genetic resources in the adaptation and spread of a crop in an agroecosystem. Paulden F. Knowles (b. April 18, 1919, d. February 7, 1990) played a key role in the establishment of safflower as a California crop. Shortly before his death he began a personal account of that history. He undertook this at the request of the University of California Genetic Resources Conservation Program (GRCP), which intended its publication as number 14 of its numbered report series. Unfortunately, the report was never completed and published before GRCP was closed in 2008.

Because safflower is such a good model for crop development via germplasm acquisition, conservation, and utilization and because Knowles' vision and achievements were so far reaching and productive, we think his story is still valuable even some twenty years later. Accordingly we returned to Paulden Knowles' hand-written first draft and his notes about plans for the report and produced this current document.

The itineraries and results of his collecting trips are even more impressive today, given the policy constraints at both international and national levels and the subsequent changes in accessibility of genetic resources over the past 20 years on the one hand, and the political and armed conflicts and environmental changes in the regions in which he collected on the other. These collections can never be replicated.

His collections were not a one-directional transfer of germplasm and information. Along the way he documented and shared usage and cultural information about the materials he collected. His travels forged the links of a network of researchers involved with safflower. One manifestation of this network were the graduate students from many countries who came through his program at the University of California, Davis. Another was the initiation of international safflower conferences with broad participation by researchers from countries in which safflower is an important crop.

There had been US national safflower conferences beginning in the early 1960s. Dr. Knowles was instrumental in organizing the Third Safflower Research Conference, held in 1969 at the University of California, Davis CA and edited the proceedings of that with M.D. Miller. By the late 1970s, however, the importance of a broader perspective on safflower research and utilization led to planning for a conference on an international scale. The first one was held in Davis CA in 1981, with Dr. Knowles as the organizer and subsequently editor of that proceedings volume. At that conference, he was one of two award recipients; he was recognized for his service as 'scientist, teacher and administrator'. The other was to Carl Claassen as 'innovative oilseed scientist and agribusiness leader'. The second international safflower conference was eight years later in 1989 in India. At this conference, Dr. Knowles was the keynote speaker in recognition of his contributions, being introduced as 'world's renowned scientist and father of safflower'. Since then the conferences have continued on a four-year cycle, moving from India to China, Italy, the US again, Turkey, Australia, and India again, in January of this current year, with the 8th conference.

His work enriched the germplasm holdings of the US National Genetic Resources Program (NGRP), which has been the ultimate repository for his material. In addition to the germplasm, the system has characterization and evaluation data on the accessions from Dr. Knowles' work and that of many other researchers. Safflower was not the only target for Dr. Knowles either: his collection activity and research also dealt with other existing and potential oil crops such as flax, sunflower, soybean, brassicas, crambe, sesame, cuphea, and castor, as well as forage grasses and herbs.

We note two volumes that provide comprehensive information of safflower as a crop and testimony to Dr. Knowles contribution. One is *Oil Crops of the World* (1989, McGraw-Hill Publishing Co., New York NY USA, xviii+551 pages), edited by G. Röbbelen, R.K. Downey, and A. Ashri, to which Dr. Knowles contributed the chapter on safflower and the chapter on genetics and breeding of oil crops. The book was dedicated to Paul Knowles.

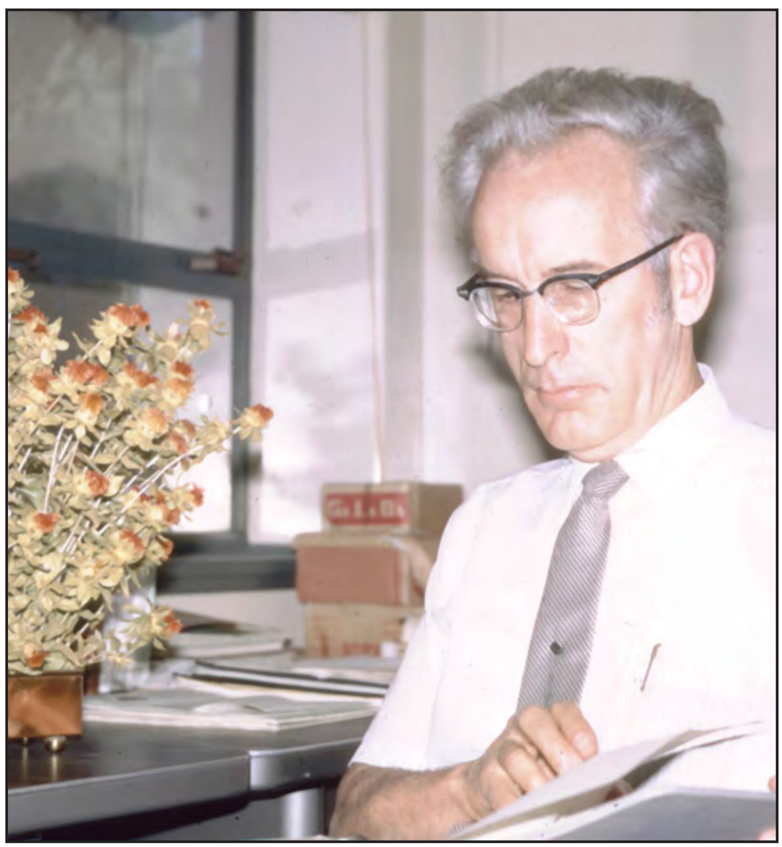
The second is *Safflower* (1996, AOCS Press, Urbana IL USA. xiii+592 pages) by J.R. Smith. This work, from the perspective of Smith's career in the safflower industry, provides a throrough history of safflower as a crop and documentation of Knowles' contributions.

**Note on the text.** The text is based on Dr. Knowles' long-hand manuscript supplemented by notes and his outline of the document. Some updates are provided as footnotes, but no effort has been made to create a review of the advances in safflower research and crop development that have taken place since he drafted the manuscript. The tables in the text and in Appendix 1 were planned by him. Illustrations have been added from his extensive unpublished photograph and slide collection.

In addition, we have compiled in Appendix 2 a bibliography of his published work on oil crops and in Appendix 3 a listing of the accessions associated with Dr. Knowles of safflower and wild *Carthamus*-species relatives maintained at the USDA-ARS-Regional Plant Introduction Station, Pullman WA USA. The actual number of introductions for which Knowles was responsible of safflower and related species in *Carthamus* and other genera related to *Carthamus* is greater than these 1175 accessions. Some accessions of *Carthamus* were no longer viable and maintained at the RPIS by 1995 and thus were not in this listing. In addition, he was responsible for collections of seed from species of other genera related to *Carthamus*, but not listed in Appendix 3 (for example, see Appendix 1 Table 5). As we note in the Editors' Summary, he also collected seed from species of plant families other than Asteraceae and accessions of many of these are maintained in the USDA NGRP.

We acknowledge contributions to Dr. Knowles in 1989 for the preparation of his manuscript by **Amram Ashri** (review), **A. Lee Urie** (summary of USDA activity at Davis), and **Richard C. Johnson** (summary of Knowles accessions in GRIN) and to us in 1995 by **Raymond L. Clark** (information on Knowles accessions in GRIN) for the preparation of this report.

— ***Patrick E. McGuire***, ***Ardeshir B. Damania***, and ***Calvin O. Qualset***
Department of Plant Sciences, University of California, Davis CA USA



**Paul Knowles** at his desk at the University of California, Davis. UC Dept. of Plant Sciences Collection.

# Foreword

The story of Paulden F. Knowles and safflower in California exemplifies the trials and tribulations and hopes involved in the introduction of a new crop far from its original habitat. It shows the many vital interactions between farmers, processors, and research and extension workers which are crucial to success of the crop. Knowles has shown the way through the development of safflower in California, which can serve as a model case study on the future development of new crops, a topic which is of great significance these days in both the developed, but gene-poor countries of the north, as well as the developing, but gene-rich countries of the south.

Knowles was immensely successful in introducing a balanced research program which involved the collaboration of the USDA, the private industry with commercial interests, and the University of California's efforts. This he could do because of his scientific stature, motivation, ability to foresee long-term needs of the industry, and personal attributes, as was the case with his collection of germplasm, evaluation, wild species research, and genetic manipulations of oil quality.

Last but not the least, Knowles was a research leader, a scholar, an educator who attracted, taught, and inspired many of his students from all parts of the world. Today several of his students are carrying on the traditions of dedicated research and education imparted to them by the personal example of Knowles.

— ***Amram Ashri***, 1991
Hebrew University of Jerusalem, Israel

# Dedication

This report is dedicated to my graduate students who worked on safflower. Without their enthusiasm, dedication to research, and imagination, this report would not be possible. I salute them. Their names and present locations[1] are given below.

— ***Paulden F. Knowles***, 1989

1 Editors' note: At time of Knowles' draft, 1989.

**Amram Ashri**, Israel
**Yousef Attieh**, Jordan
**Sheldon Bartholomew**, deceased
**Harold E. Bockelman**, Idaho USA
**Jirair Carapetian**, Iran
**John Dillé**, South Carolina USA
**Ali Estilai**, California USA
**Wesley W. Ebert**[2], California USA
**José Fernández Martínez**, Spain
**Shama Futehally**, Pakistan
**August Hartman**, California USA
**Bryan Harvey**, Canada
**Arthur B. Hill**, California USA
**Thomas C. Heaton**, California USA
**Bruce Imrie**, Australia
**M. Osman Khidir**, Iraq
**Sheldon Ladd**[2], Oregon USA
**Ricardo León**, Mexico
**Osman Mutwakil**, Sudan
**G.V. Ramanamurthy**, India
**El Saeed El Saeed**, Sudan
**Stanley S. Schank**[2], Florida USA
**Steven R. Temple**, California USA
**Demetrius Yermanos**, deceased

2 Editor's note: Deceased.

# Introduction

In October of 1947 I joined the staff of what was then called the Division of Agronomy of the University of California. My assignment was oilseed crops, primarily flax, which at that time was grown commercially in the Imperial Valley, the Westside of the San Joaquin Valley, and San Mateo County. While flax was given emphasis, an effort was made to assemble seeds of other oilseed crops.

A fruitful source of seeds was the Chemurgy Project at the University of Nebraska at Lincoln. From Dr. C.E. Claassen, in charge of evaluations of several oil crops, seed was obtained of cultivars of safflower, castor, and sesame. Safflower (*Carthamus tinctorius* L.) was sown in late January, 1948, and other crops in the spring. Most promising of those crops was safflower, where in test plots Nebraska materials yielded 3011 lbs/ac (3372 kg/ha).

In subsequent years safflower became the primary crop in my research program. This is an account of my involvement with that crop up to and beyond retirement in 1983. I am grateful both to graduate students, who did much of the work, and to members of other departments. Emphasis has been given to germplasm collection and evaluation. The account also includes results of research that developed from studies of introduced germplasm.

# Early history in California

The University of California's evaluations of safflower germplasm began about the turn of the 20th century. For trials at the several UC field stations in the period 1899-1901, Shinn (1903) summarizes:

> Foothill Station (near Jackson): The well-known safflower, *Carthamus tinctorius* (No. 1345 of the Inventory), was grown in this region years ago, and occasionally appears in old gardens. Since tested on the substation, it proves very easy of growth on both soils, very drought-enduring. Does not compare with the Russian sunflowers as a yielder of seeds for oil or chicken feed.
>
> Southern Coast Range Station (near Paso Robles): Safflower.—No. 1343, sown December 4th, grew three feet high, bloomed May 30th, and kept green until autumn.
>
> Southern California Station (Chino Valley): Seeds of this well-known dye and oil plant (*Carthamus tinctorius*), No. 1345 of the Inventory, were sown on both tracts. On the dry land (home tract) it grew 3 feet high and produced

> some seed; on the moist land the crop was very large, the plants being 4 feet high. It produced seeds at the rate of 5,500 pounds per acre. The drought resistance of this plant appeared considerably greater at Paso Robles than at this substation. It thrives over a large part of California, and is of very easy culture.

The first introductions of safflower to California were probably made much earlier when immigrants from the Mediterranean area brought with them seed for planting in their gardens. In the countries of origin of these immigrants, safflower had been grown for centuries for the red flowers which were used to color foods. They were a substitute for saffron, though they have a bland taste.

The first large-scale testing program in the US was directed by Frank Rabak of the US Department of Agriculture (Rabak 1935). This led to small commercial plantings in the northern Great Plains and California. The low yields and low oil contents of introductions at that time, most of them from India, discouraged interest by oilseed processing companies.

# Commercial establishment in California

The success of the initial nursery plantings in 1947–48 led to larger planting in 1948–49. The average yield of eight varieties and selections developed by the University of Nebraska was 2753 lb/ac (3083 kg/ha) (Knowles 1949b). Such yields and the good performance of safflower in small semi-commercial plantings totalling less than 100 acres provided the information that led to extensive commercial plantings of over 25,000 acres in 1949–50. Another stimulating factor was mandatory cutbacks in California's cotton acreage, which led also to commercial plantings of castor.

Two companies contracted acreages in the 1949–50 season, Pacific Vegetable Oil Corporation in San Francisco and Oilseed Products Company in Fresno. If average yields are considered, the crop was a disaster. The reasons were (Knowles and Davis 1951):

- "A few growers put safflower on poor ground thinking that safflower would perform better than other crops under such circumstances.
- "The variety N-852 proved to be very susceptible to root rot, and the disease was aggravated by untimely irrigations.
- "Many disappointments with safflower were a consequence of late dates of seeding.
- "A few plantings made early in the fall suffered from frost damage.
- "Some loss from shattering occurred when the crop was allowed to stand for some time after it was ripe.
- "Weeds and volunteer grain in some cases seriously reduced yields."

On the other hand, there were some excellent yields, one field on the west side of Fresno County gave over 4800 lb/ac (5380 kg/ha). A field near Meridian in the Sacramento Valley gave about 3700 lb/ac (4140 kg/ha). The few successes outweighed the disasters. Several farmers elected to grow safflower in 1950–51, with only Pacific Vegetable Oil Company contracting acreages.

Other factors were involved in the successful establishment of safflower, the most important being:

1. An expansion in the information base: As expected, farmers learned quickly from their successes and failures and experience of their neighbors. The University of California at Davis and at the West Side Field Station, the Agricultural Extension Service through several farm advisors in the Central Valley, Imperial Valley, and Palo Verde Valley, and the USDA at the Cotton Research Station near Shafter, together provided a great deal of information (Knowles and Davis 1951). In addition, the Pacific Vegetable Oil Corporation conducted several nursery trials.
2. Contracted acreages: The Pacific Vegetable Oil Corporation established contracts with growers which guaranteed both a market for the crop and a price tied to the selling price of the oil and meal but not below a stated minimum price.
3. An advisory service provided by the Corporation which farmers could contact at any time before, during, and after planting.

4. Promotion: The Pacific Vegetable Oil Corporation held many meetings both in fields and indoors during the winter. At such meetings University of California personnel contributed information from their research on safflower.

From this point on, there was annual safflower production in California. The fluctuations in acreage were strongly influenced by the relative market prices of safflower and wheat.

A major factor in the early years that adversely affected the commercial development of safflower was disposal of the meal. While the oil was moving in the marketplace, the meal was not. The Pacific Vegetable Oil Corporation provided funds to enable the University of California to evaluate the meal as feed for poultry and for livestock. With good data on comparisons of safflower meal with other oilseed meals, large accumulations of the meals were no longer a problem.

# Expanding the germplasm base

It was not many years after the commercial establishment of safflower that it became apparent that breeding programs were increasingly restricted by lack of germplasm, most of which stemmed back to materials from the University of Nebraska. It was also known that many countries in the Old World were substituting crops and varieties from developed nations for those that had been grown for hundreds of years.

### Collection trip in 1958

The University of California and the USDA agreed to fund a joint collection trip, whereby the University paid my salary and the USDA paid all expenses. My journey began on March 5, 1958, and terminated in early November (see Table 1 for itinerary). Most of the travel was by air and railroad, with local travel by rented vehicles or vehicles loaned or charged to me by the US Agency for International Development (USAID) or research stations. Wherever I went I was hospitably received and generously treated. A detailed report of the collection trip was filed with the Department of Agronomy, UC Davis and the New Crops Research Branch, Crops Research Division, ARS, USDA (Knowles 1959). A total of 420 accessions of cultivated safflower (Appendix 1 Table 1), 431 accessions of wild *Carthamus* species (Appendix 1 Table 2), and 29 accessions of species of other wild genera related to *Carthamnus* were collected.

**Table 1.** Itinerary of 1958 collection trip.

| Date | Location |
|---|---|
| April 4–24, May 21 | **India** (Delhi, Pusa, Hyderabad, Poona, Amritsar) |
| April 25–May 20, 22–24 | **Pakistan** (Lahore, Lyallpur, Rawalpindi, Peshawar, Karachi) |
| May 25–29 | **Afghanistan** (Kandahar, Lashkar Gah—southern areas) |
| May 30–June 4 | **Iran** (Tehran, Abadan, Ahvaz, Dezful—southern areas) |
| June 5–10 | **Iraq** (Baghdad, Hilla, desert west of Ramadi—southern areas) |
| June 11–20 | **Egypt** (Cairo, Alexandria, Kena, Luxor, Sohag, Assiut) |
| June 21–24 | **Jordan** (Amman, Deir Alla Station, Nablus, Jerusalem) |
| June 25–28 | **Syria** (Damascus, Aleppo) |
| June 29–July 9 | **Iraq** (Mosul, Salahudin, Sirsank, Kirkuk, Sulaimaniya—northern areas) |
| July 10 31 | **Iran** (Tehran, Isfahan, Tabriz, Mashad) |
| August 1–10 | **Afghanistan** (Kabul, Ghazni, Dasht-I-Nawar, Charikar—central areas) |
| August 11 | **Iran** (Tehran) |
| August 12–24 | **Turkey** (Ankara, Gokhoyuk, Amasya, Tokat, Yozgat, Eskişehir, Bursa, Balikesir, Izmir, Istanbul) |
| August 25–31 | **Israel** (Tel Aviv, Jerusalem, Beersheba, Tiberias, Nazareth, Safad, Acre, Haifa) |
| September 1 | **France** (Paris) |
| September 2–9 | **Morocco** (Rabat, Oujda, Melilla, Casablanca, Tadla, Bine el Quidane, Meknes) |
| September 10–20, 25–26 | **Spain** (Madrid, Cuenca, Teruel, Albacete, Alicante, Elche, Murcia, Granada, Malaga, Seville, Trujillo) |
| September 21–24 | **Portugal** (Lisbon, Sacavém, Oeiras) |

**Herbaria.** As plans were made for the collection trip it was soon apparent that there was very little information on where to collect. To remedy this situation I examined herbarium specimens of *Carthamus* at the University of California in Berkeley; Stanford University; the California Academy of Sciences, Golden Gate Park, San Francisco; the State Department of Agriculture, Sacramento; and the Rancho Santa Ana Botanic Garden, Claremont, California. In addition, en route to the collection areas, herbaria in several countries were also visited (Table 2).

**Table 2.** Herbaria visited en route in 1958.

| Date | Herbarium/location |
|---|---|
| March 6–7 | US National Herbarium, Smithsonian Institution, Washington DC USA |
| March 10 | New York Botanical Garden, Bronx Park, New York NY USA |
| March 12–14 | Royal Botanic Garden, Edinburgh, SCOTLAND |
| March 17–20 | Royal Botanic Garden, Kew, Surrey, ENGLAND |
| March 19 | Linnaean Herbarium, Burlington House, London, ENGLAND |
| March 21 | British Museum, London, ENGLAND |
| March 24–25 | Museum Nationale d'Histoire Naturelle, Paris, FRANCE |
| May 5 | Gordon College, Rawalpindi, PAKISTAN |
| June 5 | Abu Ghraib Experiment Station, Abu Ghraib, IRAQ |
| June 9 | University College of Arts and Science, Baghdad, IRAQ |
| June 16 | University of Cairo, Cairo, EGYPT |
| June 21 | Deir Alla Station, Ministry of Agriculture, JORDAN |
| August 13 | University of Ankara, Ankara, TURKEY |
| August 26 | Hebrew University, Jerusalem, ISRAEL |
| September 3 | Institut Scientifique Chérifien, Rabat, MOROCCO |
| September 11 | Jardín Botanico, Madrid, SPAIN |
| September 22 | Estação Agronómica Nacional, Sacavém, PORTUGAL |
| October 1–3 | Jardin Botanique, Geneva, SWITZERLAND |

Those herbaria provided useful information on locations where safflower had been collected over a period of more than 100 years. Where collections were dated it was possible to identify the best time of year to make collections. Brief notes and sometimes photographs were taken of the specimens. Such information for the cultivated species and wild (weedy) species with 10, 11, 12, 22, and 32 pairs of chromosomes were compiled along with information on materials loaned by European herbaria subsequent to the visits made during the collection trip.

### Collection trip in 1964–65

On a sabbatic leave for a year, I again visited much of the area visited in 1958, but drove a mini-bus for about 31,000 miles (and 32 flat tires), most of the distance covered on the trip. With my own car I was able to visit out-of-the-way places. I was accompanied by my wife for the entire trip and by my son for the first six months. In India we had access to government rest houses which were inexpensive, but required that we carry our own bedroll and mosquito netting (Knowles 1965a). Our route and side-trips by air or sea are indicated in Figure 1.

Time was taken to search for and obtain photos of systems of growing safflower. Village-level processing facilities have been described and photographed (Knowles 1967). A total of 519 accessions of cultivated safflower (Appendix 1 Table 3), 136 accessions of wild *Carthamus* species (Appendix 1 Table 4), and 36 accessions of *Carduncullus* species (Appendix 1 Table 5) were obtained.

Two-row planter used for safflower. Hatta, Maharashtra State, India. Feb. 28, 1965. (Text and photos from Knowles 1965a.)

### Collection trip in 1975

It was realized that a few areas of the Near East had not been visited in a search for safflower. These were: Lebanon, western and eastern Turkey, and western Iran (see Table 3 for itinerary). Following a study of oilseed crops research needs in Egypt for the UN FAO in 1975, I extended my travels

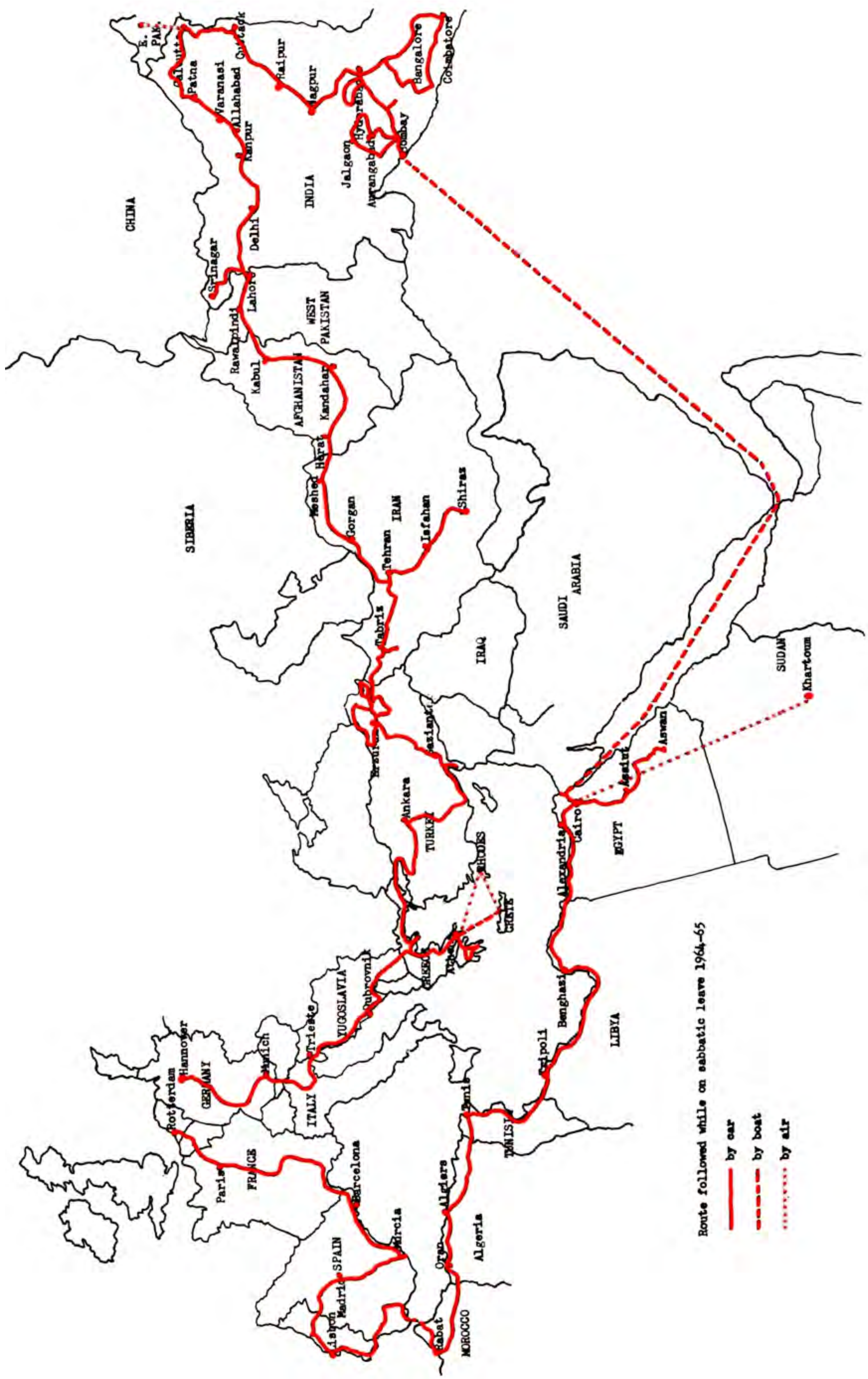



**Figure 1.** Route map of 1964–65 trip covering 31,000 miles.

to visit those areas. I was fortunate to visit Lebanon during a brief lull in the exchanges of rifle fire.

In Lebanon, the Ford Foundation provided me with a car and driver. I rented a car for travel alone in western Turkey, and in eastern Turkey with the help of Dr. Enver Esendal, on the staff of Atatürk University in Erzurum, I was able to rent another car with a driver. Dr. Esendal was my guide for the entire journey. In western Iran, Mr. H.G. Khadivi, Managing Director of the Oilseed Research and Development Company in Tehran, provided me with his personal car and driver. The late N.A. Ghanavati, the leading oilseed breeder in Iran at that time based at the Seed and Plant Improvement Center, Varamin, was my guide and interpreter. I am indebted to these persons or agencies for their generous assistance.

**Table 3.** Itinerary of 1975 collection trip.

| Date | Location |
|---|---|
| | **Lebanon** |
| July 13 | Arrive Beirut |
| July 14 | To the Bekaa Valley, north to Kfardan Research Station and south to the Tal Amara Research Station. Stayed at Zahle. |
| July 15 | Drove south along west side of Bekaa Valley to the end of the lake, then back through the center of the Valley and return to Zahle. The only wild species of safflower seen here was *C. anatolicus*. |
| July 16 | Drove north and east to Baalbek, then NW to Les Cedres, and return to Beirut via Becharra. |
| | **Turkey** |
| July 17–22 | Beirut to Ankara, Turkey. Visited research stations and collected in the Ankara area. |
| July 22 | To Izmir in western Turkey. |
| July 23–24 | Visited Agricultural Research and Introduction Center, P.K. 9, Menemen, Ege University, and a University station west of Izmir. |
| July 25–26 | Drove south to Bodrum via Efes (Ephesus), then via Mugla, Köyceğiz, and Dalaman to Feth'ye on the Mediterranean Sea. |
| July 27 | Returned to Izmir by an inland route via Kemer, Altinyayla, Gölhisar, Acıpayam, Denizli, and Aydin.. |
| July 29–30 | To Erzurum in eastern Turkey. Visit to Atatürk University and area of Cat. |
| July 31–Aug. 3 | Traveled east via Paşinler, Horasan, Tahir, and Eleşkirt, then south via Tutak, Patnos, Kocapinar, Erciş, and Timar to Van (7/31); then to Mardin via Tatvan, Bitlis, Baykan, Kurtalan, Besiri, Gercüş, Midyat, and Savur (8/1); then to Bingöl via Diyarbakir and Elazig (8/2); and return to Erzurum via Mus, Varto, Hınıs, and Paşinler (8/3). |
| | **Western Iran** |
| Aug. 5–6 | To Rezaiyeh in NW Iran via Tabriz. |
| Aug. 7–9 | In Rezaiyeh area |
| Aug. 10–13 | To Bukan via Mahabad and Mujandoah (8/10); to Kermanshah via Sarandaj (8/11); to Khorramabad via Shahabad, and Malavi, then to Hamadan (8/12); and to Tehran via the main highway (8/13). |
| Aug. 14–16 | Visiting research stations near Tehran. |
| Aug. 17 | Flew to Rome enroute to Spain. |

### Germplasm from China, 1988

Over a period of seven or eight years letters and seed samples were exchanged with Dr. Li Dajue at the Beijing Botanical Garden, Institute of Botany, Chinese Academy of Sciences, Xiangshan, Beijing. This led to a visit which my wife and I made to China in 1988. We bore all our own expenses except accommodation and travel expenses for me in China. We traveled both by plane and by train. Safflower nurseries were visited at: the Beijing Botanical Garden; the Qinghai Academy of Forestry and Agriculture, Xining, Qinghai Province; Institute of Industrial Crops, Chinese Academy of Sciences and Technology, Urumqi, Xinjiang Autonomous Region; and the Station of Agricultural Technology and Extension, Wengniute Qi, Chifeng City, Inner Mongolia.

Dr. Li had grown a nursery of Chinese germplasm at Beijing, all of it under a plastic cover to prevent both access of insects which would cause cross-pollination and exposure to rain which would lead to serious disease attacks. He shared seed from that planting and it was shipped (93 accessions along with 10 accessions collected by me during this trip, see Appendix 1 Table 6) via the American Embassy to the USDA Germplasm Resources Laboratory, Beltsville MD. There the collection was accessioned and sent to the USDA Regional Plant Introduction Station in Pullman WA for seed increase and characterization.

At my request the USDA had supplied Dr. Li with seed of all safflower entries in the National Plant Germplasm System. A single-replicate nursery was grown at the Station of Wengniute Qi, near Chifeng, Inner Mongolia. With the assistance of Dr. Li and others, superior plants or rows that were spineless and orange or red flowered were identified. These plants, like other germplasm that I had sent to Dr. Li, will be used in breeding programs at several stations.

# Distribution of cultivated safflower

This discussion consolidates information gained on collection trips in 1958, 1964–65, and 1975 (see Appendix 1 Tables 1, 3, and 6), including some information obtained in subsequent years.

Safflower was found in every country that was visited from Turkey to Bangladesh, except for Lebanon. It was not distributed uniformly. It is grown in the Murcia-Elche area of Spain where saffron is grown, and a few plants were seen in 1965 near Tavira in southern Portugal. No safflower was seen in southeastern Europe. I have no evidence of cultivated safflower being indigenous to any area from Alexandria in Egypt to Rabat in Morocco, except on a visit to the Kufra Oasis in Libya in 1969 where I did see a small planting of a spineless, red-flowered type which presumably was grown for the flowers. Local names for safflower varied greatly. Those which I encountered and those derived from the literature (Ashri 1957) are given in Table 4.

## Safflower Centers

From information available after the collection trips there appeared to be seven centers of safflower production in the Old World (Knowles 1969). These are described below.

**India—Pakistan Center.** India leads all countries in safflower production. Most of it is grown in the south-central area in what is called the Deccan. The safflower of Pakistan is closely related to that in India. The remarkable feature of Indian safflower, except for recently developed types, is its uniformity; with few exceptions plants are spiny, orange flowered, bushy, and early (Knowles 1969). On average, for collections in 1965, 99.3% were spiny and 98.9% were orange flowered. There is strong selection pressure against spineless types by birds and livestock. Bushy types would be favored because thin stands are common. It is hardly possible that orange flowers are a hold-over from a period over 150 years ago when orange and red flowers were a source of carthamin, an important dye of commerce. If so, red-flowered types should have been more frequent. It is possible that the original introduction to the Deccan was an orange-flowered, spiny type. At the present time it is grown for oil, much of it extracted using simple village-level equipment. The cake residue is used as a livestock feed. In many areas safflower seedlings up to 20 cm in height are used as a cooked vegetable. Sometimes seedlings are

**Table 4.** Local names for safflower.

| Country and area | | Local name |
|---|---|---|
| **China** | | hong hua (red flower) |
| **India** | Bihar State | kusumba |
| | Hyderabad area | kusuma |
| | Other areas | kusum, karadai |
| | Kashmir | hubulkhurtum |
| | Sanskrit | cusumbha*; kamalotarra* (supreme beauty) |
| **Pakistan** | | khurtum |
| **Afghanistan** | Kabul | muswar or maswarah |
| | Herat | kajireh |
| | Ghazni | kariza |
| **Iran** | Isfahan | kafsha, kafshe, or kosheh |
| | Tehran | kafsha |
| | Tabriz | zafaran-golu (Turkish) |
| | Rezaiyeh | kouchan gule |
| | South of Rezaiyeh in Kurdish area | kah'li |
| | Ghom | golbar aftab |
| | Meshed | kajireh or golzardu |
| | Shiraz | khasdonah or laba torbak |
| | Saveh | kajena goli or khardam |
| | Shahabad | brarta |
| | Malavi | kharkhool |
| **Iraq**, **Jordan**, **Syria**, and **Egypt** (Arabic) | | qurtum, gurtum, osfur, or asper |
| **Turkey** | | aspir or dikken (thistle) |
| **Sudan** | | Kosheh* |
| **Ethiopia** | | ssuff* |
| **Israel** (Hebrew) | | khariah* |

* from Ashri (1957)

"nipped" back to provide more plant as vegetable; it is believed by many that this practice will increase branching and yields.

**Middle East.** Much of the safflower in the Middle East is grown for the flowers which are harvested when fresh and then dried. They may be found in bazaars of larger towns or cities, often in stores that sell dried saffron. The dried flowers, like dried saffron, are used to color foods such as rice, breads, and soups. In contrast to saffron, the flowers of safflower have a bland taste. In many instances where saffron is pulverized or powdered before being offered for sale, it is adulterated with pulverized or powdered flowers of safflower. As might be expected, these safflower plants are mostly spineless and red or orange flowered.

**Egypt.** The flower colors of Egyptian safflower today are similar to that grown in 1600 BC, when the individual florets were sewn crosswise on long strips of fabric or papyrus to provide garlands for mummies. Present-day seeds are similar in shape and size to those used in Roman times when they probably served as a source of oil. Dried flowers are for sale in cites and larger towns. Some seed is sold as feed for larger birds. The major use of safflower seed is as a source of oil which is extracted in villages and towns of Upper Egypt with primitive equipment. In 1965 it was apparent that the safflower of Upper Egypt was being strongly modified by spiny, yellow-flowered Nubian types which, following the completion of the Aswan High Dam, had been carried along by the people migrating from Nubia to Komombo, about 15 miles north of Aswan. Many tests of American varieties in the Nile Valley will have influenced the characteristics of Egyptian safflower.

**Sudan.** The center of safflower production was in northern Nubia, the area along the Nile River in northern Sudan and southern Egypt, an area that is now largely covered by Lake Nasser behind the Aswan High Dam. There have been a limited number of Sudanese materials introduced into the US. Most have been yellow flowered, some have been orange flowered, and all have been spined, some strongly so. Two introductions from Sudan by the University of Nebraska showed commercial promise. Of these, N-852 became the commercial variety that was first used in commercial production in Nebraska, Colorado, and California. It was replaced by N-10, a selection from N-852. All varieties presently grown commercially stem back to N-852. Undoubtedly, prior to the construction of the Aswan High Dam, there was some migration of Sudan germplasm down the Nile River into Egypt.

**Ethiopia.** Vavilov (1951) had proposed Ethiopia as a primary center in the evolution of safflower. This is hard to accept because there are no wild species related to cultivated safflower in Ethiopia—the only wild species reported to be from Ethiopia has 32 pairs of chromosomes (Khidir and Knowles 1970a). All introductions from Ethiopia that I have seen are similar; they are tall, spiny, many branched, red flowered, and small headed. The Ethiopian Center concept requires more study.

**Europe.** At one time apparently, when safflower was grown as a source of carthamin, it was widely grown in Europe. Some relic populations undoubtedly still exist in warmer, drier areas, and several herbaria maintain seed stocks in small quantities. Flower colors are variable, and plants may be spiny or spineless. Field-scale plantings of up to one or two hectares in size are grown in the Murcia-Elche area of Spain where the prevailing type is red flowered, heads are intermediate in size, leaves are spineless to weakly

A minor use of safflower in India (and Egypt) was as a vegetable. Seedlings (left) are harvested, removing roots and part of the stem (center), chopping them up (right), and cooking them like spinach , either by boiling or by cooking in hot oil. (Text and photo from Knowles 1969a.)

spined, and there is an intermediate level of branching. The plantings of safflower are in the areas of Spain devoted to saffron production, suggesting that dried flowers of safflower may be used to adulterate saffron.

**Far East.** At the time that the introductions from the collection trips were studied, there were very few introductions from the Far East, so that center must be considered as provisional—it will need major revision.

At the First International Safflower Conference held at the University of California, Davis, June 12–16, 1981, Wu Ying-Siang and Li Dajue reported that 90% of the provinces in China grow safflower, mostly for its flowers (Wu and Li 1981). Li (1989) reported on the status of safflower research in China at the Second International Safflower Conference held in Hyderabad, India, January 9–11, 1989. The flowers are widely used solely or in admixture for medicinal purposes. Its primary benefits are reported to be to the circulatory system, particularly in the treatment of heart problems. It is also used for muscular strain, hypodermic congestion caused by bedsores, fracture of the bones, sprains, edema, abdominal distention, and problems of menstruation in women. About 1700 tons of dried flowers are processed each year. A few small factories extract the yellow flower color and red flower color (carthamin) from the orange- and red-flowered types, respectively. The former is being tested as a food dye to substitute for synthetic yellow colors which are in widespread use. The red color is used as an ingredient in medicines and probably as a food coloring. Safflower is reported to have been introduced into China from the "west", presumably Afghanistan and Iran, about 2100 years ago, which may explain the similarity of types grown in northwestern and central areas of China to those grown in Iran and Afghanistan. In both areas spineless, red- or orange-flowered types are most common, and in some areas winter types are found—winter types germinate in the fall and go through the winter in a rosette stage.

The northwestern region is referred to as the Xinganning Production Region and the central region as the Jiluyu Production Region. In the southeastern region, referred to as the Jiangzhemin Production Region, plants are short, early, very spiny, and have dentate leaves and orange flowers. In the southwestern region, referred to as the Chuandian Production Region, plants are similar in appearance to those of the southeastern region except for the less-dentate leaves. Safflower of the southeastern and southwestern regions of China appears similar in many respects to that grown in India. As in India it is grown during the warm, dry winter season. Most likely Indian-type safflower spread northward over a long period of time to southern China. In any case, as more is learned about safflower in China, revisions will be necessary in safflower centers.

In most of China safflower is a minor crop being grown as a border row to other crops. In the Xinjiang Autonomous Region, where about two-thirds of the safflower is grown, there were large fields, many of them handled by machinery except for harvest of the flowers which was done by hand. Harvest of the mature plants was done by hand or with a combine. The seeds were processed for oil with modern equipment.

Because indigenous germplasm in China is rapidly being replaced with introductions and newly developed varieties, and because of the culture of safflower over a wide range of different environments, it is important that an effort be made in the near future to collect additional material from that country.

Bullock-driven cart transporting harvested safflower. 9 mi E of Aurangabad, Maharashtra State, India, March 1, 1965. (Text and photos from Knowles 1965a.)

# Preservation of germplasm

In most cases safflower collections were routed through the diplomatic pouch to the Plant Quarantine Section of the USDA. After inspection for diseases and other pests and, if necessary, appropriate treatments, the seed was passed to the USDA Germplasm Resources Laboratory in Beltsville, Maryland. There documentation of each sample was completed and a Plant Introduction Number (PI number) was assigned. Subsequently safflower samples were sent to the USDA Regional Plant Introduction Station at Washington State University in Pullman, Washington. There they were kept in cold storage and grown out in a nursery at the first opportunity. Both selfed and open-pollinated seed were harvested from each introduction. Before the level of germination decreased a second grow-out was made, and again selfed and open-pollinated seed were obtained. This collection is known as the World Safflower Collection.

**Breeding programs.** An important function of the Regional Plant Introduction Station at Pullman is the maintenance of key germplasm of US oilseed breeding programs that have been terminated. To date those include programs at UC Davis, the USDA program at Davis, and the University of Arizona program at Tucson.

# Germplasm evaluation

**USDA Regional Plant Introduction Station, Pullman.** When safflower introductions are grown out here, always with appropriate checks, data are collected on plant development and morphology. Descriptions are standardized using descriptors published by the International Board for Plant Genetic Resources, Rome (IBPGR 1983). From time to time safflower researchers both in the US and in other countries evaluate the World Collection, usually for specific traits. The Regional Plant Introduction Station requests that such information be added to the database maintained at Pullman.[1] Periodically, the Introduction Station issues a list of entries in the World Collection which includes all evaluation data.[2]

**Other stations in the US.** The World Collection of Safflower was field evaluated in California for resistance to severe infestations of Fusarium wilt caused by *Fusarium oxysporum* Schlecht. f. sp. *carthami* Klis. & Hous. (Knowles et al. 1968). Resistance was found in 35 introductions from 11 countries. Seed from those introductions were sent to all safflower breeders who requested them. Klisiewicz and Urie (1982) identified and registered 14 selections from safflower introductions that were resistant to all four races of Fusarium wilt (Table 5). Bockelman (1974) found that two genes, a recessive gene at one locus and a dominant gene at a second locus, conferred resistance to race 3.

A second serious disease of safflower was Verticillium wilt caused by *Verticillium albo-atrum* Reinke & Berth. It threatened to eliminate safflower in all areas growing cotton, since safflower was susceptible to the same races of the disease that attacked cotton. In 1967 the World Safflower Collection, consisting of approximately 1300 entries, was grown in a field known to be infested with wilt (Urie and Knowles 1972). Forty-eight introductions that showed some resistant plants came from ten different countries (Table 6). For comparison, the level of infection in 'US-10', a susceptible line used as a check in the screening, was 61%.

Another serious disease in safflower is Phytophthora root rot, caused by *Phytophthora drechsleri* Tucker, *P. parasitica* Dast, and *P. cryptogea* Pethyb. & Laff. It is primarily a disease of irrigated safflower, with the damage magnified if the plants have been stressed from lack of water prior to the irrigation or plants stand in water after an irrigation. In tests over a 5-year period on heavy clay soil following a crop of rice at the UC Davis Rice Facility, 15 out of 1547 entries in the World Collection were found to carry some degree of resistance (DaVia et al. 1981).

1 Editors' note: Johnson, Stout, and Bradley 1993.

2 Editors' note: All data are available on request through the USDA ARS Germplasm Resources Information Network (GRIN), http://www.ars-grin.gov/npgs/.

Zimmer and Leininger (1965) tested 1200 introductions and selections for rust caused by *Puccinia carthami* Cda., and found 20 to have resistance. Introductions with resistance came from India, Afghanistan, Iran, Iraq, Turkey, Ethiopia, and Morocco. A high level of resistance was found in an accession of *C. oxyacantha* M. Bieb., a wild species, from Iran (Zimmer and Urie 1968).

**USDA at UC Davis.** From June, 1976 through 1984, USDA Research Agronomist A. Lee Urie was assigned to safflower research and based with the USDA oilseeds group at the UC Davis campus. In addition to work reported above, several other safflower-related objectives were accomplished during that period.

- The genetic relationships between partial hull safflower pericarp type and all known pericarp types was determined (Urie 1986). A partial hull safflower plant produces approximately 40% white seeds and 60% partially dark seeds. The dark area of the seeds are due to a reduction in the outer layer of the pericarp. This reduction results in a seed with low hull content and a high oil content. Partial hull is recessive to white (normal) hull and reduced hull but is inherited independently of striped hull and thin hull. The partial hull gene can be visually identified in filial generations thus safflower breeders can easily screen large populations.
- Several multiple-disease resistant safflower germplasms were developed and released in cooperation with plant pathologists at Davis, California and Beltsville, Maryland. A verticillium and fusarium wilt resistant striped hull safflower germplasm was released (Urie et al. 1976). A phytophthora root rot resistant germplasm known as 14-5 was released after four years of screening in infested field root rot nurseries. This germplasm was one of the 27 families that comprised VFstp-l. (Urie et al. 1980). Another lettuce mosaic virus resistant germplasm originating from VFstp-l was released (Thomas et al. 1978).
- When the USDA oilseeds unit was closed out at Davis in 1984, a collection of "specialized safflower germplasm" was sent to the USDA Regional Plant Introduction Station at Pullman WA. This was a diverse collection of about 1800 samples. Included were about 900 entries from a selected plant introduction nursery, rust-resistant and multiple disease-resistant lines, bulks from partial hull progenies, VFstp-l families, fusarium-resistant lines from Klisiewicz, pure lines with Nebraska and Utah numbers, Mexico Dwarf selections, about 200 packets of wild species crosses from the Knowles' program, and several other miscellaneous seed lots.

**Table 5.** Selections of safflower with resistance to four races of Fusarium wilt and registered with Crop Science Society of America.*

| Registration number. | Germplasm number | PI number | Country of origin |
|---|---|---|---|
| 18 | 3992 | 250010 | Iran |
| 19 | 4297 | 250538 | Egypt |
| 20 | 4305 | 250608 | Egypt |
| 21 | 4309 | 250079 | Egypt |
| 22 | 4298 | 250539 | Egypt |
| 23 | 4343 | 306596 | Egypt |
| 24 | 4046 | 250828 | Iran |
| 25 | 4011 | 250827 | Iran |
| 26 | 4258 | 253387 | Israel |
| 27 | 4022 | 251398 | Iran |
| 28 | 3133 | 250830 | Iran |
| 29 | 3238 | 209288 | India |
| 30 | 4043 | 250823 | Iran |
| 31 | 3119 | 250523 | Egypt |

*Source: Klisiewicz and Urie 1982

**Table 6.** Summary of number and origin of Verticillium wilt-resistant introductions.*

| Country | Number of introductions | Range of resistance (in %) |
|---|---|---|
| Egypt | 5 | 3–17 |
| India | 9 | 2–11 |
| Iraq | 1 | 4 |
| Iran | 15 | 2–11 |
| Israel | 3 | 6–8 |
| Italy | 1 | 4 |
| Pakistan | 1 | 14 |
| Philippines | 1 | 2 |
| Portugal | 2 | 2–6 |
| Turkey | 10 | 2–3 |

*Source: Urie and Knowles 1972.

# Species relationships in *Carthamus*

All wild species of safflower are spiny weeds, some of them very serious because they occupy fields sown to other crops. Others are more prevalent in roadsides and waste places. Wild species extend from around the Mediterranean Sea to northwestern India. Some species are serious weeds in Australia, and three species, *C. lanatus* L., *C. baeticus* (Boiss. & Reuter) Nyman, and *C. leucocaulos* Sibth. & Sm. are minor but potentially serious weeds in California. Collections of wild species that were made in the 1958 and 1964–65 missions are listed in Appendix 1 Tables 2 and 4, respectively. Species of the genus (wild and cultivated) fall into five groups based on chromosome number (10, 11, 12, 22, and 32 pairs of chromosomes).

**Species with 10 pairs of chromosomes.** These species are found around the eastern margins of Mediterranean Sea and extending eastward into northwestern Iran. Foliage is grey green in color, flowers range from purple to white in color, and the pollen is white, but there is a great deal of variation in other morphological characters. Crosses of different species indicated that it is a complex taxonomic group (Schank and Knowles 1964). The $F_1$ plants of most crosses have normal chromosome pairing, but a translocation differentiates parents of some crosses.

One species in the group, *C. leucocaulos*, which was not included in studies of Schank and Knowles (1964), is distinctly different from other species. Stems are smooth, head size is small, when colored, flowers are light purple or light pink instead of purple, and self-fertility is high. It is endemic to the Aegean Islands, but has been introduced to southern Europe, Australia, and the US. Studies of crosses to other species with 10 pairs of chromosomes showed a close relationship, though in one cross there was a translocation and paracentric inversion (Estilai and Knowles 1978). Crosses to *C. nitidus* Boiss. with 12 pairs of chromosomes gave a sterile $F_1$ hybrid with very irregular chromosome configurations at metaphase I of meiosis. There was very poor chromosome pairing in a sterile $F_1$ hybrid of a cross between *C. leucocaulos* and *C. tinctorius*.

**Species with 11 pairs of chromosomes.** Only one species, *C. divaricatus* (Beg. & Vacc.) Pamp. is known with this chromosome number. It is endemic to Libya and is distinct morphologically. It has horizontal branches; strongly divaricate outer involucral bracts; yellow, purple, and white flowers; yellow pollen; and dark-purple-striped anthers. It is self-incompatible, and different flower-color types cross readily to give fertile hybrids (Estilai and Knowles 1976). It appears that *C. divaricatus* is closely related to the species with 10 pairs of chromosomes, because crosses are easily achieved, the hybrids' pollen is partially viable, there is good chromosome pairing in PMCs of $F_1$ plants, and the $F_1$ hybrids are partially fertile. $F_1$ hybrids with *C. tinctorius* were vigorous, but produced no seed on selfing or in backcrosses to *C. tinctorius*. *C. divaricatus* crossed readily with *C. lanatus*, but the $F_1$ plants were sterile. Additional studies are necessary to state positively the origin of *C. divaricatus*.

**Species with 12 pairs of chromosomes.** Cultivated safflower (*C. tinctorius*) belongs to this group. Three species are known to be closely related to cultivated safflower: *C. flavescens* Spreng, found in continental areas of Turkey, Syria, and Lebanon, usually as a weed in wheat fields; *C. oxyacantha*, found in continental areas from western Iraq through northwestern India, and extending northwards to southern USSR, in all areas a very serious weed; and *C. palaestinus* Eig., found in desert areas of Iraq, Jordan, and Israel. *C. flavescens* is self incompatible (Imrie and Knowles 1970), *C. palaestinus* is self compatible like the cultivated species, and *C. oxyacantha* is mixed self compatible and self incompatible. Two other species, *C. gypsicola* Iljin, similar to *C. oxyacantha* and restricted to the USSR, and *C. curdicus* Hanelt, with characteristics of both *C. gypsicola* and *C. flavescens* and restricted to northern Iraq, obviously belong to the 12-chromosome-pair group (Hanelt 1963). They have not been introduced to the US. All of the above species have yellow flowers, except *C. palaestinus* in which there are both yellow- and white-flowered types. All, including the cultivated species, have yellow pollen.

Ramanamurthy (1963) found that the self-incompatibility system in *C. oxyacantha* was of a sporophytic type and was determined by multiple alleles at a single locus, termed S, with evidence of dominance between the alleles in the pollen. Imrie and Knowles (1971) found a similar situation in *C. flavescens*, with evidence of considerable nonhomology of S alleles in *C. flavescens* and *C. oxyacantha*.

Imrie and Knowles (1970) found in crosses of *C. flavescens* and *C. tinctorius* that the following respective differences between them were due to alleles at a single locus: long vs. short rosette stage of growth; lobed vs. entire leaf margins; shattering vs. nonshattering of the seed; pigmented vs. white seed; presence vs. absence of pappus; and purple vs. green midveins of the cotyledonary leaves.

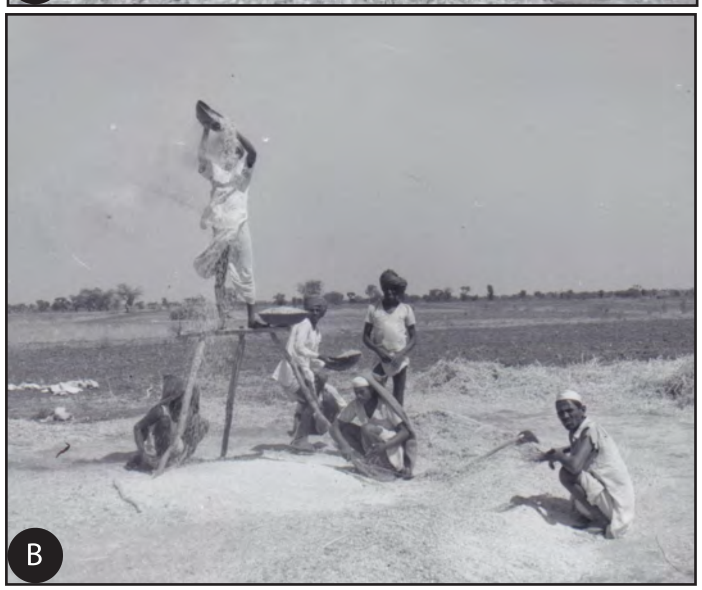
It is believed that all of the above 12-chromosome-pair species originated from a common ancestor, probably in the area of northern Iraq and northwestern Iran (KNOWLES 1976[1]). All are adapted to an arid or desert climate with some winter rainfall.

A final species with 12 pairs of chromosomes is *C. nitidus*, which is mainly distributed in the Syrian-Palestine region. With white to light rose-colored flowers, white pollen, and grey-green foliage, it is distinctly different from other species with 12 pairs of chromosomes. It resembles species of the 10-chromosome-pair group, but in crosses with the latter group no seed was produced (KNOWLES and SCHANK 1964). However, in crosses with cultivated safflower some seeds were produced which gave $F_1$ plants that were intermediate between the parents, and which failed to produce seed. Backcrosses to the cultivated species did not produce seed. *C. nitidus* is self fertile, and its taxonomic status is still in doubt.

**Species with 22 pairs of chromosomes.** Only one species, *C. lanatus*, has 22 pairs of chromosomes. It is mostly yellow flowered, but there are some white-flowered types. It has yellow pollen and is self fertile. Its range is very wide, extending in the Old World from Spain and Portugal on the west, around the Mediterranean Sea and eastward into eastern Turkey. At first it was assumed that it was an alloploid resulting from natural crosses of species with 10 and 12 pairs of chromosomes. However, a study by HARVEY and KNOWLES (1965) included crosses of species of the two groups and artificial alloploids developed from their $F_1$ hybrids, crosses of artificial alloploids to *C. lanatus* and diploid species, and crosses of 10- and 12-chromosome-pair species to *C. lanatus*. Morphological characters and chromosome behavior at MI did not provide convincing evidence that any of the 10- and 12-chromosome-pair species of the study were ancestral species of *C. lanatus*. Also, in an earlier study (ASHRI and KNOWLES 1960) with only four species with 10 pairs of chromosomes, and three with 12 pairs, inconclusive results were obtained. Further study is necessary to ascertain the origin of *C. lanatus*.

**Species with 32 pairs of chromosomes.** There are two species in this group, *C. turkestanicus* M. Popov and *C. baeticus*. *C. turkestanicus* ranges from Turkey on the west to northern Pakistan and Kashmir on the east, with presumably introduced populations in Ethiopia. *C. baeticus* may be found around the entire Mediterranean Sea and on its islands. As an introduced weed, it is found in California[2] and British Columbia.

Both species have grey-green foliage, light yellow to white flowers, light-colored anthers often with purple to brown stripes, and white pollen (KHIDIR and KNOWLES 1970a). *C.*


Threshing safflower (A, south of Buldana, Maharashtra State, India, February 24, 1965) and winnowing safflower (B, near Bhir, Maharashtra State, India, March 4, 1965). (Text and photos from KNOWLES 1969a).

1 Editors' note: Updated in: KNOWLES and ASHRI 1995.
2 Editors' note: As *C. creticus* L.

*baeticus* has less pubescence; fewer, longer, and narrower involucral bracts; narrower heads with fewer florets and achenes; and shorter corolla lobes. *C. turkestanicus* resembles *C. lanatus* more closely than does *C. baeticus*, but compared to *C. lanatus* it has wider bracts, a more distinct floret saccation, less pubescence, and white instead of yellow pollen. Chromosome pairing of both *C. turkestanicus* and *C. baeticus* was regular, but hybrids between them had a few trivalents and quadrivalents.

Alloploids synthesized from *C. leucocaulos* × *C. lanatus* were similar to *C. baeticus* (Khidir and Knowles 1970b). Because the parental species overlap in the eastern Mediterranean, it is assumed that *C. baeticus* had its origin there. The situation was similar for alloploids developed from crosses of *C. glaucus* ssp. *glaucus* (I.B.) Schrank by *C. lanatus*; they were similar to *C. turkestanicus*. It is assumed that *C. turkestanicus* originated in Transcaucasia, just west of the Caspian Sea where the two species overlap (Hanelt 1963).

Both *C. baeticus* and *C. turkestanicus* cross readily with *C. lanatus*, the hybrids having about 40% stainable pollen and producing some selfed seed. Similar results were obtained by Ashri and Knowles (1960). Where *C. lanatus* and *C. baeticus* occur together on the island of Crete, the two species are similar in appearance except for pollen color (Khidir and Knowles 1970b). The same is true of *C. lanatus* and *C. turkestanicus* in Thrace. This suggests that there is considerable gene exchange between *C. lanatus* and the species with 32 pairs of chromosomes.

**Evolution in the genus.** A tentative pattern of evolution in the genus *Carthamus* is presented in Figure 2. Khidir and Knowles (1970b) suggested the genomic formula $A_2A_2$ for *C. leucocaulos*, but later studies (Estilai and Knowles 1978) indicated that the chromosomal differences between $A_2A_2$ and AA did not warrant different formulas. A genomic formula was not assigned to *C. nitidus* with $2n=24$ nor to *C. divaricatus* with $2n=22$. However, the evidence from the studies of Estilai and Knowles (1976) would indicate that it resulted from a cross between a species with $2n=20$ and either the species *C. lanatus* ($A_1A_1B_1B_1$) or a species with the genomic formula BB ($2n=24$).

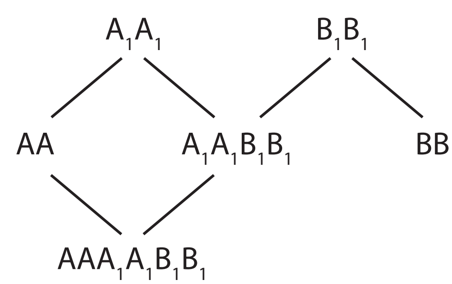



**Figure 2.** Genome evolution in genus *Carthamus*. AA is the assumed genome formula for species with $2n=20$; $A_1A_1$ for an ancestral species with $2n=20$; BB for species with $2n=24$; and $B_1B_1$ for an ancestral species with $2n=24$.

**Wild species in the improvement of *C. tinctorius*.** With the exception of *C. nitidus*, *C. tinctorius* has crossed readily with wild species having 12 pairs of chromosomes, to give fertile $F_1$ and $F_2$ progeny. The fact that $F_1$ plants have been obtained from crosses of *C. tinctorius* to species with 10 pairs of chromosomes (Ashri and Knowles 1960; Estilai 1977; Estilai and Knowles 1978), with *C. divaricatus* with 11 pairs of chromosomes (Estilai and Knowles 1976), with *C. lanatus* with 22 pairs of chromosomes (Ashri and Knowles 1960; Heaton and Klisiewicz 1981; Hill 1981), and with *C. nitidus*, a distantly related species with 12 pairs of chromosomes (Knowles and Schank 1964) indicates that these distantly related species may prove to be a source of useful genes.

From a cross of a wild species as the female parent to *C. tinctorius* (A.B. Hill, personal comm.) cytoplasmically male-sterile plants were obtained. Heaton and Klisiewicz (1981) produced an alloploid from a cross of *C. tinctorius* and *C. lanatus*. Tested against diseases to which *C. tinctorius* is susceptible, bacterial blight caused by *Pseudomonas syringae* van Hall, leaf spot caused by *Alternaria carthami* Chowd., and wilts caused by *Fusarium oxysporum* f. sp. *carthami* and *Verticillium albo-atrum*, *C. lanatus* and the alloploid were resistant or highly resistant. The authors speculated on the use of the alloploid in breeding programs.

Among a number of wild species that were examined for the fatty acid composition of the seed oil, none was found to be markedly different from high linoleic *C. tinctorius* (Knowles 1972).

# Fatty acid composition of safflower oil

For several years safflower germplasm was examined for fatty acid using the iodine value which was measured using a hand refractometer. The iodine value gave a reasonably accurate measure of the saturation of the oil (Knowles 1965b), as there was some variation in two fatty acids, oleic and linoleic. Iodine values varied between 138 and 145, with fatty acid compositions averaging about 76% linoleic, 16% oleic, 1% stearic, and 7% palmitic (Knowles and Mutwakil 1963).

Several introductions from India were found in 1957 to have iodine values much lower than that of the standard type. It turned out that these were mixtures of the standard type and a mutant type which had iodine values averaging about 90, a complete reversal in the amounts of oleic and linoleic acid, and little change in the amounts of stearic and palmitic acids. It was found (Knowles and Mutwakil 1963) that the difference in levels of linoleic and oleic acids was governed by one gene.

Through backcrossing, the high oleic version of the gene was transferred from the mutant type to US-10, to give a commercially acceptable high oleic cultivar that was named UC-1 (Knowles et al. 1965). Though the oilseed industry showed little interest in the mutant type when first discovered, its attitude had changed when UC-1 was developed. UC-1 was grown commercially for a few years, but was soon replaced by cultivars developed by seed companies that had used UC-1 in their breeding programs.

The discovery of the high oleic gene, termed *ol*, meant that there were two totally different oils available from safflower. The high linoleic type was used in many food preparations because of its high polyunsaturation. It was also a useful oil in the manufacture of varnishes, paints, and similar products. On the other hand, the high oleic type, being monounsaturated and heat stable, has had increasing use in the food industry. Its chemical composition is similar to that of olive oil, but it has a bland taste. Details of this development are recorded in "The Errant Gene", a chapter in the book *Garden in the West* (Wells 1969).

Subsequently, another mutant was found, this one with about equal amounts of oleic and linoleic acids, and with no change in levels of palmitic and stearic acids. It was found in the town of Mianeh in Iran—interestingly, "mianeh" is the Iranian word for intermediate—and was assigned PI 254717 by the USDA. A study of its inheritance (Knowles and Hill 1964) showed that it was caused by the allele $ol^1$, at the same chromosome locus as *ol*. The oilseed industry had little interest in this intermediate type of oil, since it could be constituted by a blend of equal amounts of the high linoleic and high oleic oils. Furthermore, the seed oil proved to be sensitive to temperature: high temperatures during the seed development period giving an oil high in oleic acid, and cool temperatures giving a high linoleic oil (Bartholomew 1971).

Third and fourth mutants were found in introductions PI 226993 from Israel and PI 262430 from Russia, respectively. They each had seed oil with stearic acid levels of 5 to 12% instead of the usual levels of 1.0 to 2.5%. An inheritance study (Ladd and Knowles 1970) showed that genes at one locus governed the difference—both mutants had the genotype *stst* and the standard low stearic acid type had the genotype *StSt*. The *st* locus was independent of the *ol* locus (Ladd and Knowles 1971). The high stearic type was of no commercial interest because levels were low, and stearic acid could be obtained more cheaply from other sources.

A study by Hill and Knowles (1968) showed that the genes governing fatty acid composition showed their effects about 10 days after flowering, when oil content and seed weight were increasing at a rapid rate.

A final fatty acid mutant was found in an introduction from Portugal (PI 253568). This introduction had linoleic acid contents of the seed oil between 85 and 90%, some 10% higher than the standard high linoleic type grown commercially. The levels of all other fatty acids were reduced. One gene, termed *li*, at a different locus from the *ol* and *st* genes, was responsible for the very high levels of linoleic acid (Futehally 1982).

The UC Davis experience with fatty acid composition of safflower clearly shows the value of making collections of safflower from many geographic areas. In some cases, because of the very small populations providing mutants, germplasm collection was a rescue operation that preserved genes that may have future commercial value.

# Male sterility

A very thin-hulled mutant of safflower was discovered by Rubis (1962) which was governed by the recessive gene *th*. The mutant trait was associated with weak stems and much-delayed pollen release. It was believed that delayed pollen release would serve as a form of structural male sterility. Efforts by plant breeders to develop genotypes to develop usable structurally male-sterile genotypes were unsuccessful. The delay in, and amount of, pollen release was unpredictable, so there could be an unpredictable amount of thin-hulled types, which were low yielding in hybrid varieties. Efforts were made through selection to separate the thin-hulled trait from weak stems, delayed pollen release, and low yield, but without success.

Ebert and Knowles (1968) found that the genotype *thth* for thin hulls had one primary effect: it reduced or prevented secondary wall formation in the cells of "fibrous" tissues. This resulted in thin hulls of the seeds, weak stems and branches, and delayed dehiscence of the anthers—*th* was a gene with a pleiotropic effect. The absence of secondary wall formation in the anthers, which is involved in dehiscence, resulted in a collapse of the walls in a disorganized manner, resulting in failure or delay in the release of pollen.

Heaton and Knowles (1982) reported the discovery of genetic male sterility in accession PI 263914 from Afghanistan that had been treated with colchicine. It was governed by a single recessive gene *ms*. Two germplasm releases were made, UC-148 with orange flowers, developed from the original mutant, and UC-149 with white flowers developed from a cross of UC-148 with PI 340088, an introduction from Turkey (Heaton and Knowles 1980).

Genetic male sterility was not acceptable for commercial use in the US because of labor costs necessary to remove fertile (*Msms*) genotypes from the female parent (a 1:1 mixture of *Msms* and *msms*). In India, however, it is being used by one company which is experimenting with a female parent that has appressed branches (*apap*) and is spineless—this makes removal of the male-fertile types much easier. If the male parent has spreading branches and spines, the $F_1$ hybrid will be the same.

The first step in processing safflower for oil in Egypt was cracking seed with a stone grinder sufficiently to loosen the hulls. Screens were used to separate hulls from seed. The second step was grinding of the seed with a rolling round stone, pictured in A (Large roller used to crush oil seeds. Assiut, Upper Egypt. June 19, 1958). Finally this ground seed was placed in tight flat straw baskets shaped like a beret pictured in B (Flat basket made of reeds. Assiut, Upper Egypt. June 19, 1958). Several filled baskets were stacked one on top of the other and pressure applied to the top with either a hand-operated screw press or a heavy wooden lever. About 125 kilos of seed gave 20 kilos of oil. (Text and photos from Knowles 1959.)

Already mentioned are the cytoplasmic male-sterile genotypes developed by AB Hill. They are not yet being used commercially.

In many crosses of distantly related safflower species, sterile types appear in the $F_2$. Carapetian and Knowles (1976) studied such sterile types and found that the sterility was governed by three genes, tentatively identified as *a*, *b*, and *c*. Sterile genotypes were *aabbC_*, *aaB_cc*, and *aabbcc*; the expected ratio in $F_2$ was 57 fertile to 7 sterile. A study by Carapetian indicates that *a* is linked to *ol*, the gene causing high levels of oleic acid in the seed oil.[1]

1 Editors' note: Now published: Carapetian and Knowles 1993.

# Miscellaneous traits

In the course of germplasm evaluation and inheritance studies over several years, several mutants have been identifed. Some were studied in detail, others not, and they will be briefly discussed. Some studies included introductions different from commercial cultivars.

**Branching attitude.** Several introductions, most of them from India, had branches appressed against the main stem, the angle of branching was not above 20°. Commercial cultivars had branch angles above 40° and rarely above 80°. One recessive gene, *ap*, governed the appressed trait (Leon and Knowles 1964).

A mutant was found with decumbent branches, where the angle of branching was 80 to 90° and sometimes exceeded 90°. Temple and Knowles (1975) found that one recessive gene, *dec*, was involved. Fernández and Knowles (1978) found that *dec* was independent of *ap*. The genotype *ap*/*ap*, dec/*dec* had spreading branches indicating the genes counteracted one another.

**Closed flowers.** Three different closed-flower types were identified and were termed arrowhead (Type A), bar (Type B), and cage (Type C). The petal lobes of Type A are closed in the upper half and separated slightly in the lower half. The style projects through the fused portion and attains normal length. Seed set is normal. In Type B the petal lobes are strongly fused through their entire length, and the style and anther tube do not emerge. Seed set is greatly reduced. In Type C only the tips of the corolla lobes are fused which prevents emergence of the style and anther tube, though the latter may emerge laterally. Seed set is reduced about 50%. Dillé and Knowles (1975) found that fusion of petal lobes was due to epidermal cells of the margins of lobes being differentiated into papillae with pointed appendages that extend into or mesh with papillae of adjacent lobes. Limited data from inheritance studies indicated that independent single recessive genes were responsible for the development of the aberrant papillae.

**Brittle stems.** A brittle-stemmed safflower mutant appeared in the $F_6$ of a cross between an introduction from Turkey (PI 175624) and 'Pacific 7'. It was weak and droopy in appearance. When bent slightly the branches and main stem broke cleanly, so that at maturity there were many branches lying on the ground. Hulls were frequently soft and bubbly in appearance. A single recessive gene br was involved (Temple and Knowles 1975). Limited chemical analysis showed that brittle plants had lower crude fiber, higher protein content, and higher levels of starch and soluble polysaccharides than did tough-stemmed cultivars.

**Black foliage.** The black mutant, which appeared in the breeding nursery, expressed the trait as the plants approached maturity. Only leaves and bracts were involved. When homozygous, one recessive gene, *bl*, resulted in a black plant (Temple and Knowles 1975).

**Crinkle leaves.** A crinkle-leaved mutant was found to be due to a single recessive gene, *cr* (Temple and Knowles 1975).

**Light-green leaves.** The light-green mutant was due to a single recessive gene that was not assigned a symbol (Temple and Knowles 1975).

**Table 7.** Association of flower colors of safflower with chromatography colors.

| | | Chromatography colors | | | |
|---|---|---|---|---|---|
| | | Under natural light | | | |
| Emergent color[2] | Mature color[2] | Carthamin[2] | Safflower yellow | Yellow pigment[3] | No. of spots under UV radiation |
| white | white | 0 | 0 | | 3 |
| cream | near white | 5[4] | 0 | 3 | 5 |
| sulfur | sulfur | 0 | 4 | 3 | 0 |
| pc yellow | pink | 3 | 2 | 3 | 0 |
| pc yellow | light orange | 2 | 4 | 3 | 2 |
| c yellow | yellow | 0 | 10 | 3 | 0 |
| l yellow | orange | 4 | 6 | 3 | 0 |
| l yellow | orange red[5] | | | | |
| orange | red | 10 | 10 | 3 | 0 |

1 On a scale of 0 (none) to 10 (intense).

2 Flower and chromatography colors: c = canary; l = lemon; pc = pale canary.

3 Unidentified.

4 Straw yellow, not red.

5 Same as red but amounts of carthamin reduced by an unspecified amount.

**Flower color.** Hartman (1967) identified a corolla-color type in safflower based on emergent flower color just as the flower emerged from the bud and before the lobes open, and mature color obtained as flowers wilted when flower color was most intense. Fresh flower color was obtained when the flowers had opened but not yet wilted.

Descending paper chromatography was used to separate pigments in fresh flowers that had been dried immediately and the petals ground to a powder. The flower colors were identified under natural and long-wave ultraviolet (UV) radiation. Three main pigments were identified under natural light: carthamin which remained as a reddish spot at the site of the placement of the pigment extract and safflower yellow and an unidentified yellow pigment, both of which separated out near the advancing edge of the solvent. Under UV radiation several additional colors were identified. Table 7 associates flower colors with colors identified under UV radiation. The chemistry of carthamin and safflower yellow are well known. Before the development of aniline dyes in the last century, carthamin, from safflower, and indigo were the most important sources of dye for textiles. The uses in China today of carthamin, safflower yellow, and dried petals have already been mentioned.

On the basis of $F_2$ analyses of crosses of the different flower color types, Hartman (1967) identified four loci that governed flower color: *c* with three alleles, *y* with three, *o* with two, and *r* with three.

**Thin hull.** There has been a gradual increase in oil content in commercial cultivars of safflower from about 37% in 1950 to about 43% in the 1970s. This was achieved mostly by reduction in the amount of seed hull. A very thin-hulled mutant has already been mentioned as a possible female parent for hybrid cultivars—it was not acceptable.

Urie and Zimmer (1970) found types which they designated reduced hull that increased oil content from 34% for US-10 to an average of 42.7%. Later a partial-hull mutant was found (Urie 1986) that reduced hull content still further—the six original mutant plants had an oil content of 49.0%. In yield trials the yield of partial hull and the average yield of two commercial cultivars were 1688 and 1668 lb/ac (1890 and 1868 kg/ha), respectively. One recessive gene, *par*, governed the expression of partial hull. It should prove to be a useful gene in breeding programs.

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# Appendix 1

**Appendix 1. Table 1.** Count of accessions of cultivated safflower (*Carthamus tinctorius*) collected in 1958*.

| Country | Area | Count | Remarks |
|---|---|---|---|
| **India** | Pusa Station | 30 | |
| | Hyderabad | 88 | 34 m from Rajenderonayer Sta. |
| | Poona | 0 | Seed samples promised later |
| | Amritsar | 7 | From bazaars |
| | Delhi | 0 | |
| *Total* | | *125* | |
| **Pakistan** | Lahore | 9 | All from bazaars |
| | Lyallpur | 14 | From Lyallpur Station |
| | Gujerat | 24 | From bazaars and farmers |
| | Rawalpindi | 13 | From bazaars |
| | Peshawar | 3 | From bazaars |
| | Karachi | 12 | From bazaars |
| *Total* | | *75* | |
| **Afghanistan** | Kandahar | 0 | |
| | Lashkar Gah | 0 | |
| | Kabul | 15 | From bazaars and fields |
| | Ghazni | 1 | From a border of a field |
| *Total* | | *16* | |
| **Iran** | Tehran | 10 | From bazaars and Karaj Sta. |
| | Khuzestan | 0 | |
| | Isfahan | 22 | From bazaars and fields |
| | Tabriz | 7 | From bazaars and homes |
| | Mashad | 14 | From bazaars and fields |
| *Total* | | *53* | |

**Appendix 1. Table 1.** *Continued.**

| Country | Area | Count | Remarks |
|---|---|---|---|
| **Iraq** | Baghdad | 4 | From bazaars |
| | Mosul | 0 | |
| | Sulaimaniya | 0 | |
| *Total* | | *4* | |
| **Jordan** | Amman Jerusalem | 13 | Mostly from fields |
| **Syria** | Damascus Aleppo | 6 | From bazaars |
| **Israel** | Near Jerusalem | 1 | From a villager |
| | Near Nazareth | 3 | From villagers |
| *Total* | | *4* | |
| **Turkey** | Univ. of Ankara | 3 | |
| | Eskişehir Exp.Sta. | 7 | |
| | Eskişehir area | 4 | Farmers' fields |
| | Belikesir area | 1 | Farmers' fields |
| *Total* | | *15* | |
| **Greece** | Larissa Station | 11 | From Turkey |
| **Egypt** | Cairo | 7 | From bazaars |
| | Giza Station | 2 | |
| | Near Giza | 2 | |
| | Alexandria | 2 | Bazaar and Exp. Sta. |
| | Kena | 15 | Warehouses |
| | Near Luxor | 1 | Farmer |
| | Sohag | 4 | Oilseed mill and farms |
| | Assiut | 3 | Bazaar and oilseed mill |
| *Total* | | *36* | |
| **Morocco** | | 0 | |
| **Spain** | Cuenca area | 5 | Jefatura Agronomica |
| | Teruel area | 2 | Villagers |
| | Alicante | 1 | Seed store |
| | Elche | 2 | Seed store |
| | Southern Spain | 0 | |
| Total | | *10* | |
| **Portugal** | Southern part | 10 | Sacavem Station |
| | Herbaria of Asia and Europe | 52 | Sacavem Station |
| *Total* | | *62* | |
| Total all countries | | 420 | |

*Source: Knowles 1959.

**Appendix 1. Table 2.** Count of accessions of wild species of safflower (genus *Carthamus*) collected in 1958*.

| Species/country | Count | Species/country | Count |
|---|---|---|---|
| ***C. flavescens*** | | ***C. alexandrinus*** | |
| Iraq | 2 | Egypt | 4 |
| Syria | 7 | ***C. lanatus*** | |
| Turkey | 8 | Afghanistan | 5 |
| ***C. oxyacantha*** | | Egypt | 2 |
| Afghanistan | 12 | Iran | 14 |
| India | 14 | Iraq | 5 |
| Iran | 44 | Morocco | 15 |
| Iraq | 42 | Spain | 15 |
| Pakistan | 68 | Turkey | 15 |
| ***C. nitidus*** | | Pakistan | 9 |
| Jordan | 2 | Portugal | 3 |
| Syria | 2 | ***C. baeticus*** | |
| ***C. dentatus*** | | Morocco | 4 |
| Turkey | 17 | Spain | 2 |
| ***C. glaucus*** | | ***C. palaestinus*** | |
| Iran | 9 | Greece | 17 |
| Iraq | 13 | Iraq | 4 |
| Israel | 4 | ***C. arborescens*** | |
| Jordan | 3 | Spain | 2 |
| Syria | 1 | ***C. caeruleus*** | |
| Turkey | 7 | Morocco | 5 |
| ***C. syriacus*** | | Turkey | 1 |
| Jordan | 9 | **Species hybrids** | |
| Syria | 2 | Iran | 3 |
| ***C. tenius*** | | Iraq | 3 |
| Israel | 15 | Israel | 11 |
| Jordan | 2 | Jordan | 4 |
| Syria | 3 | | |
| Turkey | 2 | **Total** | 431 |

*Source: Knowles 1959.

**Appendix 1. Table 3.** Count of accessions of cultivated safflower (*Carthamus tinctorius*) collected in 1964–65*.

| Country | Area or location | Date | Type of collection | Count | Use |
|---|---|---|---|---|---|
| **Turkey** | Eskişehir | 7/29-30 | Seed | 3 | Oil |
| | Eskişehir Res. Sta. | 7/30 | Seed | 12 | Oil |
| | Eskişehir to Ankara | 7/30 | Heads | 2 | Oil |
| | Ankara Univ. | 7/31 | Seed | 2 | Oil |
| | İskenderun–Antakya–Reyhanlı | 8/5 | Seed & heads | 2 | Flowers |
| | Gaziantep–Maras | 8/6-7 | Seed & heads | 8 | Flowers |
| *Total* | | | | *29* | |
| **Iran** | Azerbaijan | 9/2-6 | Seed & heads | 15 | Flowers & seed |
| | Teheran–Isfahan–Shiraz | 9/7-17 | Seed | 25 | Flowers & seed |
| | Gorgan–Mashad | 9/19-21 | Seed | 2 | Flowers & seed |
| *Total* | | | | *42* | |
| **Afghanistan** | Herat bazaar | 9/24 | Seed | 6 | Flowers & seed |
| | Kabul–Ghazni | 9/26-29 | Heads | 3 | Oil |
| *Total* | | | | *9* | |
| **Pakistan** | Lyallpur bazaar | 10/5 | Seed | 1 | Seed |
| **Bangladesh** | Dacca area | 11/23 | Seed | 5 | Seed |
| **India** | Kashmir | 10/10-11 | Seed | 13 | Flowers & seed |
| | Pathankot area | 10/13 | Seed | 3 | Seed |
| | Nainital area | 10/28 | Seed | 1 | Seed |
| | Allahabad Agric. Inst. | 11/8 | Seed | 2 | Oil |
| | Banares Hindu Univ. | 11/12 | Seed | 1 | Oil |
| | Muzaffarpur, Bihar State | 11/15 | Seed | 40 | Oil & vegetable |
| | Sabour area, Bihar State | 11/18 | Seed | 11 | Vegetable |
| | Mysore State | 1/5-2/9 | Seed & heads | 25 | Oil |
| | Andhra Pradesh State | 1/21-/2/8 | Seed & heads | 75 | Oil |
| | Maharashtra State | 2/9-3/4 | Seed & heads | 218 | Oil & vegetable |
| *Total* | | | | *389* | |
| **Sudan** | Univ. of Khartoum and Hudeiba Res. Sta. | 3/30-4/1 | Seed & heads | 18 | Roasted seed |
| **Egypt** | Upper Egypt | 4/14-22 | Seed & heads | 23 | Oil & flowers & vegetable |
| **Spain** | Cordoba area | 5/30 | Seed & heads | 1 | Oil |
| | Elche area | 6/12 | Seed & heads | 2 | Flowers |
| *Total* | | | | *3* | |
| Total all countries | | | | 519 | |

*Source: Knowles 1965a.

**Appendix 1. Table 4.** Accessions of wild species of safflower (genus *Carthamus*) collected in 1964–65*.

| Species/country and area | Collection number |
|---|---|
| ***C. flavescens*** | |
| Turkey, eastern | 146, 149, 157, 164, 212, 214, 215, 216 |
| Turkey, southern | 103, 104, 106–111, 127, 128, 129, 131, 135, 138 |
| Turkey, western | 94, 96, 97, 99 |
| ***C. oxyacantha*** | |
| Iran, northeast | 275, 276 |
| Iran, southern | 264, 265 |
| Iran, western | 218, 222, 232, 237, 238, 239 |
| ***C. dentatus*** | |
| Crete | 6, 9 |
| Greece, northern | 50, 55, 57, 64 |
| Greece, southern | 38, 39, 42 |
| Rhodes | 32, 33, 34, 35 |
| Turkey, eastern | 163, 213 |
| Turkey, southern | 102, 112, 123, 126 |
| Turkey, Thrace | 65 |
| Turkey, western | 69, 75 |
| Yugoslavia, southern | 4 |
| ***C. dentatus* × *C. glaucus*** | |
| Turkey, southern | 125 |
| ***C. glaucus* × *C. flavescens*** | |
| Turkey, eastern | 150, 161 |
| Turkey, southern | 134 |
| ***C. tenuis*** | |
| Rhodes | 297, 307, 317, 377 |
| Turkey, southern | 1137 |
| ***C. alexandrinus*** | |
| Egypt | 863, 875 |
| Libya | 868, 873 |
| ***C. leucocaulos*** | |
| Crete | 13, 25 |
| Greece, northern | 52 |
| ***C. lanatus*** | |
| Algeria | 898, 910, 911 |
| Crete | 17, 18, 27 |
| Greece, northern | 46, 48, 51, 53, 54, 58, 59, 63 |
| Greece, southern | 40, 41 |
| Libya | 871, 872, 875, 876, 877 |
| Morocco | 922, 926 |
| Turkey, Thrace | 66 |
| Turkey, western | 70, 73 |
| Tunisia | 878, 885, 892 |
| Yugoslavia, Adriatic | 1, 2, 3 |
| Yugoslavia, southern | 4 |
| ***C. lanatus* × *C. dentatus*** | |
| Greece, northern | 56 |
| ***C. turkestanicus*** | |
| Iran, northeastern | 274 |
| Iran, western | 217, 224, 240 |
| Turkey, eastern | 203, 211 |
| Turkey, Thrace | 67, 68 |
| Turkey, western | 71 |
| ***C. baeticus*** | |
| Greece, northern | 47, 49 |
| Morocco | 929 |
| Portugal | 940 |
| Turkey, southern | 114 |
| ***C. creticus*** | |
| Crete | 8, 10, 11, 12, 14, 15, 16, 20, 26, 28 |
| Rhodes | 36 |
| ***C. arborescens*** | |
| Spain | 933 |
| **Unknown species** | |
| Libya | 869 |

*Source: Knowles 1965a

**Appendix 1. Table 5.** Accessions of *Carduncellus* species collected in 1964–65*.

| Species/country | Collection number |
|---|---|
| ***C. caeruleus* (syn. *Carthamus caeruleus*)** | |
| Algeria | 895, 899, 902–907, 909, 912, 913, 917 |
| Crete | 8 |
| Morocco | 923, 928, 931 |
| Portugal | 941 |
| Spain | 932, 934, 935, 936, 937, 939 |
| Tunisia | 891 |
| ***C. calvus*** | |
| Morocco | 920, 921 |
| ***C. ariocephalus*** | |
| Egypt | 866 |
| Tunisia | 879 |
| ***C. helenoides* (syn. *Carthamus helenoides*)** | |
| Algeria | 916, 918, 919 |
| ***C. hispanicus*** | |
| Spain | 958, 963 |
| ***C. ilicifolius*** | |
| Algeria | 901 |
| ***C. mareoticus*** | |
| Egypt | 861 |
| Libya | 867 |

*Source: Knowles 1965a.

**Appendix 1. Table 6.** Safflower germplasm selected in China in 1988*.

| No. | PI no. † | Source |
|---|---|---|
| Seed supplied by Dr. Li Dajue from his safflower nursery at the Beijing Botanical Garden, Institute of Botany. | | |
| 11 | 544015 | Kunming City, Yunnan Province |
| 14 | 657784 | Tacheng County, Xinjiang Province |
| 19 | 544016 | Zhangye County, Gansu Province |
| 26 | 576979 | Xiapu County, Fujian Province |
| 27 | 544017 | Ruicheng County, Shanxi Province |
| 45 | 544018 | Xiapu County, Fujian Province |
| 54 | 544019 | Yanjin County, Henan Province |
| 82 | 653135 | Jinxian County, Hebei Province |
| 89 | 544020 | C. lanatus from Holland |
| 90 | 544021 | Botanischer Garden, University of Frankfurt, West Germany |
| 94 | 576980 | Milan, Italy |
| 96 | 544022 | Botanical Garden, Liege University, Belgium |
| 141 | 544023 | Fukang County, Xinjiang Province |
| 142 | 543974 | Hetian County, Xinjiang Province |
| 151 | 576984 | Yinchuan City, Ningxia Province |
| 157 | 576985 | Jardins Botaniques de la Ville et de l'Université Nancy, Meurthe-et-Moselle, France |
| 161 | 576986 | Hongze County, Jiangsu Province |
| 163 | 576987 | Mengzi County, Nunnan Province |
| 168 | 576988 | Huaxian County, Henan Province |
| 177 | 576983 | Qinghe County, Hebei Province |
| 180 | 543975 | Nanxi County, Sichuan Province |
| 182 | 543976 | Heze County, Shandong Province |
| 183 | 543977 | Zhecheng County, Henan Province |
| 187 | 653133 | Wuhu City, Anhui Province |
| 194 | 543978 | Yingshan County, Sichuan Province |
| 200 | 543979 | Tongliao City, Inner Mongolia |
| 201 | 543980 | Qiubei County, Yunnan Province |
| 203 | 543981 | Botanical garden, Johannes Butenberg University, Mainz, West Germany |
| 220 | 543982 | Kalaqinzuoyi County, Liaoning Province |
| 224 | 543983 | Zhangye County, Gansu Province |
| 225 | 543984 | Qixian County, Henan Province |
| 226 | 543985 | Huolu County, Hebei Province |
| 227 | 543986 | Danxian County, Shandong Province |
| 228 | 543987 | Dangshan County, Shandong Province |
| 229 | 543988 | Qixian County, Henan Province |
| 232 | 543989 | Gaotang County, Shandong Province |
| 233 | 576982 | Yongnian County, Hebei Province |
| 235 | 543990 | Fengqui County, Henan Province |

* Source: Knowles 1989.

† PI designations are from subsequent accessioning in 1989 by USDA Regional Plant Introduction Station, Pullman WA USA.

**Appendix 1. Table 6.** *Continued.**

| No. | PI no. † | Source |
|---|---|---|
| 237 | 543991 | Boxian County, Anhui Province |
| 238 | 543992 | Juye County, Shandong Province |
| 239 | 543993 | Lingquan County, Anhui Province |
| 240 | 543994 | Caoxian County, Shandong Province |
| 242 | 543995 | Jingxian County, Hebei Province |
| 243 | 543996 | Weishan County, Shandong Province |
| 244 | 543997 | Daming County, Hebei Province |
| 245 | 543998 | Liangshan County, Shandong Province |
| 249 | 543999 | Sixian County, Anhui Province |
| 252 | 653134 | Chengwu County, Shandong Province |
| 296 | 544000 | Ningling County, Henan Province |
| 297 | 544001 | Taikang County, Henan Province |
| 299 | 544002 | Yucheng County, Henan Province |
| 301 | 544003 | Linzhang County, Hebei Province |
| 306 | 544004 | Czechoslovakia |
| 317 | 544005 | Xiuxian County, Anhui Province |
| 321 | 544008 | Lingxian County, Shandong Province |
| 323 | 544009 | Donghai County, Jiangsu Province |
| 324 | 544010 | Changyi County, Shandong Province |
| 326 | 544011 | Ningjin County, Shandong Province |
| 327 | 544012 | Guangde County, Anhui Province |
| 331 | 544013 | Xinchang County, Zhejiang Province |
| 332 | 544014 | Shanghe County, Shandong Province |
| 337 | 544024 | Shucheng County, Anhui Province |
| 338 | 544025 | Huaiyuan County, Anhui Province |
| 341 | 544026 | Xianxian County, Hebei Province |
| 342 | 544027 | Xingtang County, Hebei Province |
| 344 | 544028 | Yuhuan County, Zhejiang Province |
| 346 | 544029 | Liuan County, Anhui Province |
| 348 | 544030 | Chengxian County, Zhejiang Province |
| 350 | 544031 | Anji County, Zhejiang Province |
| 351 | 544032 | Zouping County, Shandong Province |
| 356 | 544033 | Kuerle City, Xinjiang Autonomous Region |
| 369 | 544034 | Fukang County H1-001, Xinjiang Autonomous Region |
| 375 | 544035 | Fukang County H1-002, Xinjiang Autonomous Region |
| 383 | 544036 | Yutian County, Xinjiang Autonomous Region |
| 400 | 544037 | Jimushaer County, Xinjiang Autonomous Region |
| 407 | 544038 | Tongjiang County, Sichuan Province |
| 416 | 544039 | Changning County, Yunnan Province |
| 417 | 544040 | Dahongpao, Yanjin County, Henan Province |

* Source: Knowles 1989.
† PI designations are from subsequent accessioning in 1989 by USDA Regional Plant Introduction Station, Pullman WA USA.

**Appendix 1. Table 6.** *Continued.**

| No. | PI no. † | Source |
|---|---|---|
| 418 | 544041 | Xizang, Lasa City, Tibet |
| 424 | 544042 | Ledu County, Qinghai Province |
| 444 | 544043 | Taixing County, Jiangsu Province |
| 445 | 544044 | Nanjing City, Jiangsu Province |
| 479 | 544045 | Funing County, Jiangsu Province |
| 480 | 544046 | Lingquan County, Anhui Province |
| 495 | 544047 | Jiangyin County, Jiangsu Province |
| 496 | 544048 | Wuwei County, Anhui Province |
| 509 | 544049 | Taiping County, Anhui Province |
| 511 | 544050 | Wuxi City, Jiangsu Province |
| 593 | 544051 | Chuanhong-1, Chongqing City, Sichuan Province |
| 629 | 576989 | Weishan County, Yunnan Province |
| 2155 | 544052 | ZW-971, Zhangye County, Gansu Province |
| 2156 | 544053 | ZW-972, Zhangye County, Gansu Province |
| 2157 | 576981 | ZW-973, Zhangye County, Gansu Province |
| Seed from other sources visited by PF Knowles. | | |
| C-1 | 544054 | Hangzhou Pharmaceutical Institute |
| C-2 | 544063 | Qinghai Academy of Agriculture and Forestry, Xining |
| C-3 | 544062 | Qinghai Academy of Agriculture and Forestry, Xining |
| C-4 | 544055 | From Prof. Wang Zhao-mu, Institute of Industrial Crops, Urumqi, Xinjiang Autonomous Region, 7/28/88. Local type XJ-12 |
| C-5 | 544056 | From Prof. Wang Zhao-mu, Institute of Industrial Crops, Urumqi, Xinjiang Autonomous Region, 7/28/88. Local type XJ-26 |
| C-6 | 544057 | From Prof. Wang Zhao-mu, Institute of Industrial Crops, Urumqi, Xinjiang Autonomous Region, 7/28/88. Local type XJ-59 |
| C-7 | 544058 | From Prof. Wang Zhao-mu, Institute of Industrial Crops, Urumqi, Xinjiang Autonomous Region, 7/28/88. Local type XJ-68 |
| C-8 | 544059 | From Prof. Wang Zhao-mu, Institute of Industrial Crops, Urumqi, Xinjiang Autonomous Region, 7/28/88. Local type XJ-80 |
| C-9 | 544060 | From Prof. Wang Zhao-mu, Institute of Industrial Crops, Urumqi, Xinjiang Autonomous Region, 7/28/88. Local type XJ-81 |
| C-10 | 544061 | Seed used for planting on the Red Flag farm, 30km S of Jimusaer, NE of Urumqi, Xinjiang Autonomous Region. Spineless type with red or orange flowers, used as a source of flowers to obtain both yellow and red pigments. Seed from 1987 crop obtained 7/23/88. |

* Source: Knowles 1989.

† PI designations are from subsequent accessioning in 1989 by USDA Regional Plant Introduction Station, Pullman WA USA.

# **Appendix 2.**
# Publications of P.F. Knowles on oilseed crops.

1949 Houston, B.R. and P.F. Knowles. Fifty-year survival of flax fusarium wilt in the absence of flax culture. *Pl Dis Reptr* **33(1)**:38.

1949 Knowles, P.F. Castor beans studied for potential values as oil crop for California production. *Calif Agric* **3(3)**:13–14.

1949 Knowles, P.F. Dual purpose safflower seed. Produces drying oil for the paint industry and seed meal for livestock and poultry feed. *Calif Agric* **3(2)**:11,16.

1949 Knowles, P.F. Safflower, a new crop. Univ. of California Agric Ext Service leaflet. Berkeley CA USA. [20 pages]

1949 Knowles, P.F. Safflower production in California. Univ. of California Agr. Expt. Sta. Ext. Service Leaflet. Berkeley CA USA. [7 pages]

1949 Knowles, P.F. Shall I grow sunflowers? Univ. of California Agr. Expt. Sta. Ext. Service Leaflet. Berkeley CA USA. [16 pages]

1951 Knowles, P.F. and L.L. Davis. Safflower, a new oil crop. Univ. of California Agr. Expt. Sta. Ext. Service Leaflet. Berkeley CA USA. [24 pages]

1953 Houston, B.R. and P.F. Knowles. Studies on Fusarium wilt of flax. *Phytopath* **43**:491–495.

1953 Knowles, P.F. and B.R. Houston. Resistance of flax varieties to Fusarium wilt. *Agron J* **45**:408–414.

1954 Knowles, P.F. and L.L. Davis. Do castor beans have a place? Univ. of California Agr. Expt. Sta. Ext. Service Leaflet. Berkeley CA USA. [14 pages]

1954 Knowles, P.F. and L.L. Davis. Sunflowers as a field crop. Univ. of California Agr. Expt. Sta. Ext. Service Leaflet. Berkeley CA USA. [12 pages]

1954 Knowles, P.F. and B.R. Houston. Inheritance of resistance to Fusarium wilt of flax in Dakota selection 48–94. *Agron J* **47**:131–135.

1954 Knowles, P.F. and W.H. Lange. The sunflower moth: Preliminary experiments indicate parathion, DDT effective controls. *Calif Agric* **8(4)**:11–12.

Appendix 2. *continued*

1955 Knowles, P.F. Safflower—production, processing, and utilization. *Econ Bot* **9**:273–299.

1956 Knowles, P.F., B.R. Houston, and J.B. McOnie. Inheritance of resistance to Fusarium wilt of flax in Punjab 53. *Agron J* **48**:135–137.

1957 Knowles, P.F., G.H. Abel, R.T. Edwards, and M.D. Miller. Soybean tips. Univ. of California Agr. Expt. Sta. Ext. Service Leaflet 94. Berkeley CA USA.

1958 Knowles, P.F. Safflower. *Adv Agron* **10**:289–323.

1958 Knowles, P.F. and A. Ashri. Wild safflower in California: Improvement of cultivated safflower through plant-breeding program to obtain desirable characteristics of wild species. *Calif Agric* **12(4)**:4–5.

1958 Knowles, P.F., R.T. Edwards, and M.D Miller. Soybeans in California. *The Cotton Gin and Oil Mill Press* March 8, 1958.

1958 Zimmerman, L.H., M.D Miller, and P.F. Knowles. Castorbeans in California. Univ. of California Agr. Expt. Sta. Ext. Service Circular 468. Berkeley CA USA. [12 pages]

1959 Ashri, A. and P.F. Knowles. Further notes on *Carthamus* in California. *Leaflets in Western Bot* 9:5–8.

1959 Knowles, P.F. Plant Exploration report for safflower and miscellaneous oilseeds: Near East and Mediterranean countries, March-October 1958. Dept. of Agronomy, Univ. of California, Davis CA USA, in collaboration with USDA-ARS Crop Research Division, CR-43-5. [42 text pages plus photos]

1959 Knowles, P.F. Oilseed crops in California. *The Cotton Gin and Oil Mill Press* October 1, 1959.

1959 Knowles, P.F., W.H. Isom, and G.F. Worker. Flax production in the Imperial Valley. Univ. of California Agr. Expt. Sta. Ext. Service Circular 480. Berkeley CA USA. [28 pages]

1959 Knowles, P.F., B.D. Sandlin, and M.D. Miller. Flax production in San Mateo County. Univ. of California Agr. Expt. Sta. Ext. Service Circular 482. Berkeley CA USA. [16 pages]

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

1960 Knowles, P.F. New crop establishment. *Econ Bot* **14**:263–275.

1960 Knowles, P.F. Safflower's native home. *Crops and Soil* **12**:4.

1960 Knowles, P.F. and M.D. Miller. Safflower in California. Univ. of California Agr. Expt. Sta. Ext. Service Manual 27. Berkeley CA USA. [26 pages]

1960 Knowles, P.F. and M.D. Miller. Tips on safflower growing. Univ. of California Agr. Expt. Sta. Ext. Service Leaflet 126. Berkeley CA USA. [6 pages]

1960 Yermanos, D.M. and P.F. Knowles. Effects of gibberellic acid treatment on safflower. *Agron J* **52**:596–598.

1961 Schank, S.C. and P.F. Knowles. Colchicine induced polyploids of *Carthamus tinctorius* L. *Crop Sci* **1**:342–344.

1962 Knowles, P.F. Complementary genes cause a lethal seedling character in flax. *Crop Sci* **2**:270.

1962 Knowles, P.F. Safflower oil mutant types under study. *Calif Agric* **16(4)**:7.

1962 Yermanos, D.M. and P.F. Knowles. Fatty acid composition of the oil in crossed seed of flax. *Crop Sci* **2**:109–111.

1963 Knowles, P.F. Relationship and inheritance of fatty acids of safflower oil. *in: Proc. Second Safflower Conference*. Tucson AZ USA.

1963 Knowles, P.F., M.D. Miller, and W.H. Isom. Safflower—An established crop in California. Univ. of California Agr. Expt. Sta. Ext. Service Leaflet 162. Berkeley CA USA. [12 pages]

1963 Knowles, P.F. and A. Mutwakil. Inheritance of low iodine value of safflower selections from India. *Econ Bot* **17**:139–145.

1964 Knowles, P.F. and A.B. Hill. Inheritance of fatty acid content in the seed oil of a safflower introduction from Iran. *Crop Sci* **4**:406–409.

1964 Knowles, P.F. and S.C. Schank. Artificial hybrids of *Carthamus nitidus* Boiss. and *C. tinctorius* L. (Compositae). *Crop Sci* **4**:596–599.

1964 Leon, R. and P.F. Knowles. Inheritance of appressed branching in safflower. *Crop Sci* **4**:441.

1964 Schank, S.C. and P.F. Knowles. Cytogenetics of hybrids of *Carthamus* species (Compositae) with ten pairs of chromosomes. *Am J Bot* **10**:1903–1102.

1965 Harvey, B.L. and P.F. Knowles. Natural and artificial alloploids with 22 pairs of chromosomes in the genus *Carthamus* (Compositae). *Can J Genet Cytol* **7**:126–139.

1965 Knowles, P.F. Oil plants. pages 902–904. *Encyclopaedia Britannica*. William Benton, Publisher.

1965 Knowles, P.F. Variability in oleic and linoleic acid contents of safflower oil. *Econ Bot* **19**:53–62.

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# **Appendix 3.** List by species, year, and PI number of 1175 safflower accessions associated with P.F. Knowles in the collection at the USDA-ARS-RPIS, Pullman WA USA[1].

1 Editors' note: List was current as of a 1995 request to the USDA Pullman Regional Plant Introduction Station (and includes an additional 93 accessions from a 1988 safflower nursery at the Beijing Botanical Garden selected by PF Knowles for acquisition by the RPIS). Current status of any accession can be determined via query by PI number at the USDA Genetic Resources Information Network (http://www.ars-grin.gov/npgs/acc/acc_queries.html).

***Carthamus tinctorius***

**1958** 248355, 248356, 248357, 248358, 248359, 248360, 248361, 248362, 248363, 248364, 248365, 248366, 248367, 248368, 248369, 248370, 248371, 248372, 248373, 248374, 248375, 248376, 248377, 248378, 248379, 248380, 248381, 248382, 248383, 248384, 248385, 248386, 248387, 248388, 248389, 248624, 248625, 248626, 248627, 248628, 248629, 248630, 248631, 248632, 248633, 248793, 248794, 248795, 248796, 248797, 248798, 248799, 248800, 248801, 248802, 248803, 248804, 248805, 248806, 248807, 248808, 248809, 248810, 248811, 248812, 248813, 248814, 248815, 248816, 248817, 248818, 248819, 248820, 248821, 248822, 248823, 248824, 248825, 248826, 248827, 248828, 248829, 248830, 248831, 248832, 248833, 248834, 248835, 248836, 248837, 248838, 248839, 248840, 248841, 248842, 248843, 248844, 248845, 248846, 248847, 248848, 248849, 248850, 248851, 248852, 248853, 248854, 248855, 248856, 248857, 248858, 248859, 248860, 248861, 248862, 248863, 248864, 248865, 248866, 248867, 248868, 248869, 248870, 248871, 248872, 248873, 248874, 248875, 248876, 248877, 248878, 248879, 248880, 250006, 250007, 250008, 250009, 250010, 250011, 250075, 250076, 250077, 250078, 250079, 250080, 250081, 250082, 250083, 250179, 250180, 250182, 250183, 250186, 250187, 250188, 250189, 250190, 250191, 250192, 250193, 250194, 250195, 250196, 250197, 250198, 250199, 250200, 250201, 250202, 250203, 250204, 250205, 250208, 250335, 250336, 250337, 250338, 250341, 250342, 250343, 250345, 250346, 250347, 250348, 250350, 250351, 250353, 250473, 250474, 250475, 250476, 250477, 250478, 250479, 250480, 250481, 250482, 250523, 250524, 250525, 250526, 250527, 250528, 250529, 250530, 250531, 250532, 250533, 250534,

Appendix 3. *continued*

***Carthamus tinctorius***

**1958** *continued*
250535, 250536, 250537, 250538, 250539, 250540, 250541, 250595, 250596, 250597, 250598, 250599, 250600, 250601, 250603, 250604, 250605, 250606, 250607, 250608, 250609, 250610, 250611, 250708, 250709, 250710, 250711, 250712, 250713, 250714, 250715, 250716, 250717, 250718, 250719, 250720, 250721, 250722, 250723, 250724, 250819, 250820, 250821, 250822, 250823, 250824, 250825, 250826, 250827, 250828, 250829, 250830, 250831, 250832, 250833, 250834, 250835, 250836, 250837, 250838, 250839, 250840, 250841, 250842, 250920, 250921, 250922, 250924, 250925, 250926, 251262, 251264, 251265, 251266, 251267, 251268, 251284, 251285, 251288, 251289, 251290, 251291, 251398, 251462, 251977, 251978, 251979, 251980, 251981, 251982, 251983, 251984, 251985, 251986, 251987, 251988, 251989, 252040, 252041, 252042, 253384, 253385, 253386, 253387, 253388, 253389, 253390, 253391, 253392, 253393, 253394, 253395, 253396, 253511, 253512, 253513, 253515, 253516, 253517, 253518, 253519, 253520, 253521, 253522, 253523, 253524, 253527, 253528, 253529, 253531, 253534, 253535, 253537, 253538, 253540, 253541, 253542, 253543, 253544, 253546, 253547, 253548, 253549, 253550, 253552, 253553, 253554, 253555, 253556, 253559, 253560, 253561, 253562, 253563, 253564, 253566, 253567, 253568, 253569, 253570, 253571, 253758, 253759, 253761, 253762, 253763, 253764, 253765, 253892, 253893, 253894, 253895, 253896, 253897, 253898, 253899, 253900, 253902, 253903, 253905, 253906, 253907, 253908, 253909, 253910, 253911, 253912, 253913, 253914, 253916, 254090

**1959** 254976

**1964** 301047, 301048, 301049, 301050, 301051, 301052, 301053, 301054, 301055

**1965** 304408, 304409, 304411, 304437, 304438, 304439, 304440, 304441, 304442, 304443, 304444, 304445, 304446, 304447, 304448, 304449, 304450, 304451, 304452, 304453, 304454, 304455, 304456, 304457, 304458, 304459, 304460, 304461, 304462, 304463, 304464, 304465, 304466, 304467, 304468, 304469, 304470, 304471, 304472, 304473, 304474, 304475, 304476, 304494, 304495, 304496, 304497, 304498, 304499, 304500, 304501, 304502, 304503, 304504, 304505, 304506, 304507, 304508, 304509, 304510, 304590, 304591, 304592, 304593, 304594, 304595, 304596, 304597, 304598, 304599, 305151, 305152, 305153, 305154, 305155, 305156, 305157, 305159, 305160, 305161, 305162, 305163, 305164, 305165, 305166, 305167, 305168, 305169, 305170, 305171, 305173, 305174, 305175, 305176, 305178, 305179, 305181, 305182, 305185, 305186, 305187, 305188, 305189, 305190, 305191, 305192, 305193, 305195, 305196, 305197, 305198, 305199, 305200, 305202, 305204, 305205, 305206, 305207, 305208, 305209, 305210, 305211, 305212, 305214, 305215, 305216, 305217, 305218, 305219, 305220, 305221, 305253, 306593, 306594, 306595, 306596, 306597, 306598, 306599, 306600, 306601, 306602, 306603, 306604, 306605, 306606, 306607, 306608, 306609, 306610, 306611, 306612, 306613, 306614, 306820, 306821, 306822, 306823, 306824, 306825, 306826, 306827, 306828, 306829, 306830, 306831, 306832, 306833, 306836, 306838, 306839, 306840, 306841, 306842, 306843, 306844, 306845, 306846, 306847, 306848, 306849, 306850, 306851, 306852, 306853, 306854, 306855, 306856, 306857, 306858, 306861, 306865, 306866, 306867, 306868, 306869, 306870, 306872, 306873, 306874, 306875, 306876, 306877, 306878, 306879, 306880, 306881, 306883, 306885, 306886, 306887, 306888, 306889, 306890, 306891, 306892, 306894, 306896, 306897, 306898, 306899, 306900, 306901, 306902, 306903, 306904, 306905, 306906, 306907, 306908, 306909, 306910, 306911, 306912, 306913, 306915, 306916, 306917, 306918, 306920, 306921, 306922, 306923, 306924, 306925, 306926, 306927, 306928, 306929, 306930, 306931, 306932, 306933, 306934, 306935, 306936, 306939, 306940, 306941, 306942, 306943, 306944, 306945, 306946, 306947, 306948, 306949, 306950, 306951, 306952, 306953, 306954, 306955, 306956, 306957, 306958, 306959, 306960, 306961, 306962, 306963, 306964, 306965, 306967, 306968, 306969, 306970, 306971, 306972, 306973, 306974, 306975, 306976, 306977, 306978, 306979, 306980,

Appendix 3. *continued*

***Carthamus tinctorius***

**1965** *continued*
306981, 306983, 306984, 306985, 306986, 306987, 306988, 306989, 306991, 306992, 306993, 306994, 306995, 306996, 306997, 306998, 306999, 307000, 307001, 307002, 307003, 307004, 307005, 307006, 307007, 307008, 307009, 307010, 307011, 307012, 307013, 307014, 307015, 307016, 307018, 307019, 307020, 307021, 307022, 307023, 307024, 307025, 307026, 307027, 307028, 307029, 307030, 307031, 307032, 307033, 307034, 307035, 307036, 307037, 307038, 307039, 307040, 307041, 307042, 307043, 307044, 307045, 307046, 307047, 307048, 307049, 307050, 307051, 307052, 307053, 307054, 307055, 307056, 307057, 307058, 307059, 307060, 307061, 307062, 307063, 307064, 307065, 307066, 307067, 307068, 307069, 307070, 307071, 307072, 307073, 307074, 307075, 307076, 307077, 307078, 307079, 307080, 307081, 307082, 307083, 307084, 307085, 307086, 307087, 307088, 307089, 307090, 307091, 307092, 307093, 307094, 307095, 307096, 307097, 307098, 307099, 307100, 307101, 307102, 307103, 307104, 307105, 307106, 307107, 307108, 307109, 307110, 307111, 307112, 307113, 307114, 307115, 307116, 307117, 307118, 307119, 307120, 307121, 307122, 307123, 307124, 307125, 307126, 307127, 307128, 307129, 307130, 307131, 307132, 307133, 307134, 307135, 307136, 307137, 307138

**1967** 572434

**1969** 343772, 343773, 343774, 343775, 343776, 343777, 343778, 343779, 343780, 343781, 343782, 343783

**1972** 372914

**1974** 387820, 387821, 393498, 393499, 393500

**1975** 405954, 405955, 405956, 405957, 405958, 405959, 405960, 405961, 405962, 405963, 405964, 405965, 405966, 405967, 405968, 405969, 405970, 405971, 405972, 405973, 405974, 405975, 405976, 405977, 405978, 405979, 405980, 405981, 405982, 405983, 405984, 405985, 405986, 405987, 405988, 405989, 405990, 405991, 405992, 405993, 405994, 405995, 405996, 405997, 405998, 405999, 406000, 406001, 406002, 406003, 406004, 406005, 406006, 406007, 406008, 406009, 406010, 406011, 406012, 406013, 406014, 406015, 406016, 406017, 406018, 406019, 406020, 407605, 407606, 407607, 407608, 407609, 407610, 407611, 407612, 407613, 407614, 407615, 407616, 407617, 407618, 407619, 407620, 407621, 407622, 407623, 407624

**1978** 426186, 426521, 426523, 426524

**1989** 543974, 543975, 543976, 543977, 543978, 543979, 543980, 543981, 543982, 543983, 543984, 543985, 543986, 543987, 543988, 543989, 543990, 543991, 543992, 543993, 543994, 543995, 543996, 543997, 543998, 543999, 544000, 544001, 544002, 544003, 544004, 544005, 544008, 544009, 544010, 544011, 544012, 544013, 544014, 544015, 544016, 544017, 544018, 544019, 544021, 544022, 544023, 544024, 544025, 544026, 544027, 544028, 544029, 544030, 544031, 544032, 544033, 544034, 544035, 544036, 544037, 544038, 544039, 544040, 544041, 544042, 544043, 544044, 544045, 544046, 544047, 544048, 544049, 544050, 544051, 544052, 544053, 544054, 544055, 544056, 544057, 544058, 544059, 544060, 544061, 544062, 576979, 576980, 576981, 576982, 576983, 576984, 576985, 576986, 576987, 576988, 576989, 653133, 653134, 653135, 657784

**1991** 544063, 560161, 560162, 560176, 560177

Appendix 3. *continued*

***Carthamus oxyacantha***

**1958** 249970, 252022, 253843

**1975** 407602

**1978** 426182, 426183, 426184, 426185, 426427, 426428, 426429, 426430, 426431, 426433, 426434, 426435, 426436, 426437, 426438, 426439, 426440, 426441, 426442, 426443, 426444, 426445, 426447, 426449, 426450, 426451, 426452, 426454, 426456, 426457, 426458, 426459, 426463, 426464, 426467, 426468, 426469, 426470, 426472, 426473, 426476, 426477, 426478, 426479, 426480, 426481, 426482, 426483, 426484, 426485, 426486, 426487, 426488, 426489, 426490, 426492, 426493, 426494, 426495, 426496, 426498, 426499, 426500, 426501, 426502, 426503, 426504, 426505, 426506, 426507, 426508, 426509, 426510, 426511, 426512, 426514, 426515, 426516, 426517, 426518, 426519, 426520

***Carthamus glaucus***

**1958** 2551254

***Carthamus glaucus alexandrinus***

**1958** 250588

***Carthamus lanatus***

**1958** 2553862

**1989** 544020

***Carthamus lanatus turkestanicus***

**1978** 426180, 426181, 426425 ,426426

***Carthamus* sp.**

**1978** 426187, 426188, 426189