Promoting the conservation and use of underutilized and neglected crops. 3.

Coriander

Coriandrum sativum L.

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International Plant Genetic Resources Institute
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Foreword

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

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

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Introduction

The importance of classical plant systematics as a tool for the conservation of biodiversity is becoming evident (Vane-Wright 1996). Yet this aspect of cultivated plants and their diversity on the infraspecific level is often neglected. Genebanks conserve much of the diversity of cultivated plants, and were formerly established to assist modern plant breeding and crop research. Today, genebanks must also confront the continuing gene erosion occurring in cultivated plants and in their wild relatives and weeds. But if the task facing genebanks has changed, the classical methods for studying the biodiversity of cultivated plants as presented by N.I. Vavilov (1992) are still fundamental to their description, to understanding their use, and, as stated above, to the protection of biodiversity.

This publication describes the genetic resources of coriander (*Coriandrum sativum* L.) and discusses various aspects of the origin, history, use, breeding and agronomy of a species whose entire potential has not yet been fully recognized. Many interesting publications on the breeding and genetic resources of coriander that were published in the former Soviet Union have gone unnoticed in Western countries, a fact to which particular attention is drawn here.

The main part of the book describes the variation of this species. It is a common complaint that the characterization of genebank material is insufficient (Becker 1993), and a systematic description of the variation of a cultivated species is essential to all further research and breeding activities, and of great interest to growers and consumers too. A considerable amount of data on the variation of individual characters has been obtained and made easily accessible to users of the Gatersleben Genebank collection. The information stored in the genebank is moreover used to propose an infraspecific classification of the species studied. This second step is critical, as it allows grouping of the entire genepool and consolidates all existing information on the behaviour of single characters. Definite groups are described and named at the infraspecific level, which is basic to all communication concerning coriander germplasm. Effective exchange of information as well as of germplasm is thus made possible.

Infraspecific classification is part of a holistic approach to biodiversity. This was recognized and clearly explained over 40 years ago by R. Mansfeld, who also describes the techniques necessary for such a classification (Mansfeld 1953, 1954). The importance of such a holistic approach has been increasingly highlighted by the acceleration of gene erosion.

The germplasm collection of the Gatersleben Genebank provided the basic material for the present study, which was enriched by several collecting missions (Hammer 1993b), as well as germplasm exchange at the international level.

1 Taxonomy and names of the species

1.1 The position of coriander in plant systematics

The genus *Coriandrum* includes the cultivated plant *C. sativum* and the wild species *C. tordylium*. The latter is described for southeastern Anatolia (Hedge and Lamond 1972) and northern Lebanon (Mouterde 1986). Herbarium specimens of *C. tordylium* from Edinburgh (Scotland) and Turku (Finland) demonstrate that this annual species is very similar to the cultivated *C. sativum*. The wild species might be interesting for coriander breeding, but it has not been reported whether crossing *C. sativum* and *C. tordylium* may be possible. This is an important question for future research, and may help to shed light on the evolution of the crop.

The closest genus to *Coriandrum* is *Bifora*. This genus includes the species *B. americana*, native to the southeastern areas of North America (Rickett 1969). It also includes two other species which originate in the Mediterranean area: *B. radians* and *B. testiculata* (Šiškin 1950). The latter species occurs as a weed in winter crops in southern Europe, the Mediterranean area and the Near East (Hanf 1990). *Bifora radians* is morphologically similar to coriander, but the fruits have a different shape and do not contain essential oils. On the other hand, the fatty oil content of the fruits is very high in both species, with 41.5% of the dry matter in *B. testiculata* and 49.5% in *B. radians* (Kleiman and Spencer 1982). Fruits of *C. sativum* contain, depending on the genotype, up to 27.7% of fatty oil (see Table 8). Plant breeders have tried to use *B. radians* as a genetic resource in coriander breeding, but even using embryo-rescue techniques, it was not possible to obtain crosses (Meier zu Beerentrup, 1995, pers. comm.). The green plant of *B. radians* has a very strong smell, which is similar to that of coriander, but it never became a cultivated plant. Hanf (1990) reports that the German name for *B. radians* is ‘Getreideverpester’ or ‘cereal polluter’, because of the unpleasant smell of this weed, which also affects the cereals in which it grows. Pater (1925) reports that the pungent odour produced by the plant could even be smelled in the town centre of Cluj-Napoca in Romania.

The six other genera belonging to the tribe Coriandreae comprise wild plants from Central Asia. They are perennials and, judging from the herbarium specimens at the Botanical Institute in St. Petersburg, their morphology is quite different from that of coriander. Thus it seems doubtful that they can be crossed successfully with the cultivar. None of the Central Asian species is available in any botanical garden or germplasm collection as a living sample, and it is difficult to judge whether they can be used for breeding purposes. The chromosome numbers are similar in most of the species (see Table 1); only for *B. radians* is a different number reported, which might explain the aforementioned difficulties encountered with crossing experiments.

The relatively small tribe Coriandreae belongs to the subfamily Apioideae, which includes most of the genera of the Umbelliferae and originates in the temperate geographical areas of Europe and Asia (Heywood 1971). The taxonomy of the other cultivated plants of the Umbelliferae is carefully presented by Mansfeld (1959).

Table 1 summarizes all species of the tribe Coriandreae and shows their position in the taxonomic hierarchy of the Umbelliferae[1]. Discussions on the taxonomy of the genera of Central Asia are still continuing. Some of the listed names may be synonyms, and further species not included in the list were recorded in the herbarium of the Botanical Institute in St. Petersburg.

Table 1. The tribe Coriandreae and its position in the family Umbelliferae (Source: different floras, Pimenov and Leonov 1993; chromosome numbers: Fedorov 1969; Tachtadžjan 1990; Goldblatt and Johnson 1994)

Family: Umbelliferae Juss. (455 genera, 3600-3751 species)
Subfamily: Apioideae Drude (404 genera, 2827-2936 species)
Tribe: Coriandreae W. Koch (8 genera, 21 species)
Genera:

- *Bifora* F. Hoffm. (3 species)
  - *B. americana* Benth. et Hook. (2*n*=20)
  - *B. radians* M.-Bieb. (2*n*=20, 2*n*=22 (?))
  - *B. testiculata* (L.) Spreng. ex Schultes (2*n*=22)
- *Coriandrum* L. (2 species)
  - *C. sativum* L. (2*n*=22)
  - *C. tordylium* (Fenzl) Bornm.
- *Fuernrohria* K. Koch (1 species)
  - *F. setifolia* K. Koch (2*n*=22)
- *Kosopoljanskia* Korovin (1 species)
  - *K. turkestanica* Korovin (*n*=11)
- *Lipskya* (Koso-Pol.) Nevski (1 species)
  - *L. insignis* (Lipsky) Nevski
- *Schrenkia* Fisch. et C. A. Mey. (10 species)
  - *Sch. congesta* Korovin
  - *Sch. golickeana* (Regel et Schmalh.) Fedch. (2*n*=22)
  - *Sch. involucrata* Regel et Schmalh.
  - *Sch. kultiassovii* Korovin
  - *Sch. lachnantha* Korovin
  - *Sch. papillaris* Regel et Schmalh. (2*n*=22)
  - *Sch. pulverulenta* M. Pimenov
  - *Sch. pungens* Regel et Schmalh. (*n*=11)
  - *Sch. ugamica* Korovin
  - *Sch. vaginata* (Ledeb.) Fisch. et C.A. Mey. (2*n*=22)
- *Schtschurowskia* Regel et Schmalh. (2 species)
  - *Sch. meifolia* Regel et Schmalh. (2*n*=22)
  - *Sch. margaritae* Korovin
- *Sclerotiaria* Korovin (1 species)
  - *S. pentaceros* Korovin

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[1] Authors of scientific botanical names and the publications cited are abbreviated according to the taxonomic conventions by Stafleu and Cowan (1976-1988).

1.2 Accepted botanical name of the species and synonyms

Coriandrum sativum L., Sp. Pl. (1753) 256. - *Coriandrum majus* Gouan, Hortus monsp. (1762) 145; Garsault, Fig. pl. méd. 2 (1764) 232, Descr. vertus pl. 2 (1764) 151; Thell. in Bull. Herb. Boissier ser. 2, 8 (1908) 789; *Coriandrum diversifolium* Gilib., Fl. lit. inch. 2 (1782) 26; *Coriandrum testiculatum* Lour., Fl. cochinch. (1790) 180, non L. (1753); *Coriandrum globosum* Salisb., Prod. stirp. Chap. Allerton (1796) 166; *Bifora loureirii* Kostel., Allg. med.-pharm. Fl. 4 (1835) 1183; *Coriandrum melphitense* Ten. et Guss., Ind. sem. hort. Neap. (1837) 3; *Selinum coriandrum* E. H. L. Krause in Sturm, Deutschl. Fl. ed. 2, 12 (1904) 163.

Typus: *Coriandrum sativum* L. Described from Italy, Herb. Linn. No. 363/1 (LINN) (Jafri, Fl. Libya 117 (1985) 23).

Family: **Umbelliferae** (Apiaceae).

1.3 Common names of the species*

Arab	kuzbara, kuzbura
Armenian	chamem
Chinese	yuan sui, hu sui
Czech	koriandr
Danish	koriander
Dutch	koriander
English	coriander, collender, chinese parsley
Ethiopian (Amharic)	dembilal
French	coriandre, persil arabe
Georgian (Caucasus)	kinza, kindza, kindz
German	Koriander, Wanzendill, Schwindelkorn
Greek	koriannon, korion
Hindi	dhania, dhanya
Hungarian	coriander
Italian	coriandolo
Japanese	koendoro
Malay	ketumbar
Persian	geshnes
Polish	kolendra
Portugese	coentro
Rumanian	coriándru
Russian	koriandr, koljandra, kišnec, kinza, vonjučee zel’e, klopovnik
Sanskrit	dhanayaka, kusthumbari
Serbokroatian	korijander
Spanish	coriandro, cilantro, cilandrio, culantro
Swiss	Chrapfechörnli, Böbberli, Rügelikümmi
Turkish	kişniş

*Further local names (including Indian ones) are given in Section 3.

2 Brief description of the crop

This section presents a general description of the crop. The ranges of variation are enormous for several characters, and this aspect is thoroughly discussed in Section 6.

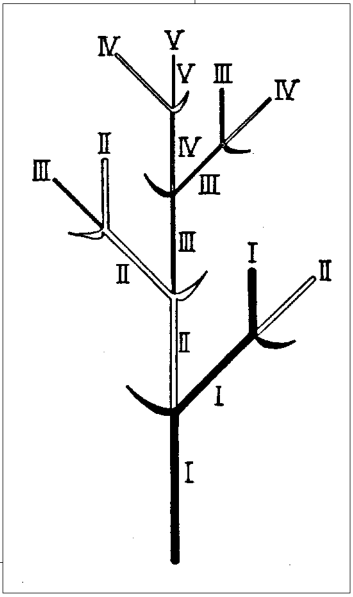
Coriander is an annual herb and, according to the climatic conditions, is cultivated as a summer or winter annual crop. At flowering, the glabrous plant can reach heights between 0.20 and 1.40 m. The germination is epigaeal and the plant has a tap root. The stem is more or less erect and sympodial, monochasial-branched, sometimes with several side branches at the basal node (Figs. 1 and 2). Each branch finishes with an inflorescence. The colour of the more or less ribbed stem is green and sometimes turns to red or violet during the flowering period. The stem of the adult plant is hollow, and its basal parts can reach a diameter of up to 2 cm. The leaves alternate, and the first ones are often gathered in a rosette. The plant is diversifolious (Fig. 3). The blade shape of the basal leaves is usually either undivided with three lobes, or tripinnatifid, while the leaves of the nodes following are to a higher degree pinnatifid. The higher the leaves are inserted, the more pinnate they are. Thus, the upper leaves are deeply incised with narrow lanceolate or even filiform-shaped blades. The lower leaves are stalked, while the petiole of the upper leaves is reduced to a small, nearly amplexicaul leaf sheath. The leaves are green or light green and their underside often shiny waxy. During the flowering period the leaves sometimes turn red or violet. They wither before the first fruits are ripe starting from the basal leaves. The inflorescence is a compound umbel (Fig. 4.1). Sometimes there are one or two linear bracts. The umbel has two to eight primary rays, which are of different length, in such a way that the umbellets are located at the same level. Two, three or more bracteols carry the umbellets with five to twenty secondary rays.

Flowering starts with the primary umbel. In every umbel the peripheral umbellets, and in every umbellet the peripheral flowers are the first ones to flower. These flowers are protandrous. The central flowers of the umbellets are staminiferous or sometimes sterile. Coriander has an inferior ovary and the five calyx teeth surrounding the stylopodium are still visible in the ripe fruit (Fig. 4.2). The five calyx teeth are of different length, as are the petals in peripherally situated flowers. The flowers have five petals. The peripheral flowers of every umbellet are asymmetric, as the petals toward the outside of the umbellets are lengthened. The central flowers are circular, with small inflexed petals (Fig. 4.1). The colour of the petals is pale pink or sometimes white.

In general the flowering and pollination biology of coriander is typical of that for umbelliferous plants, according to Bell (1971). The inner flowers of the umbellets are staminate. The umbels of higher order usually contain more staminate flowers than the first ones, and their flowering period is shorter. In a single flower, the five filaments of the staminas are located between the five petals. After the flower opens, the white filaments are visible between the petals, because they are bent and the pollen sacs at their top are hidden in the centre of the flower. This stage is the best

Fig. 1. Flowering coriander plant (CORI 154, origin: India).

Fig. 2. (below) Branching type of coriander: The primary umbel terminates branch I, the other umbels are of higher order (Strasburger 1983).



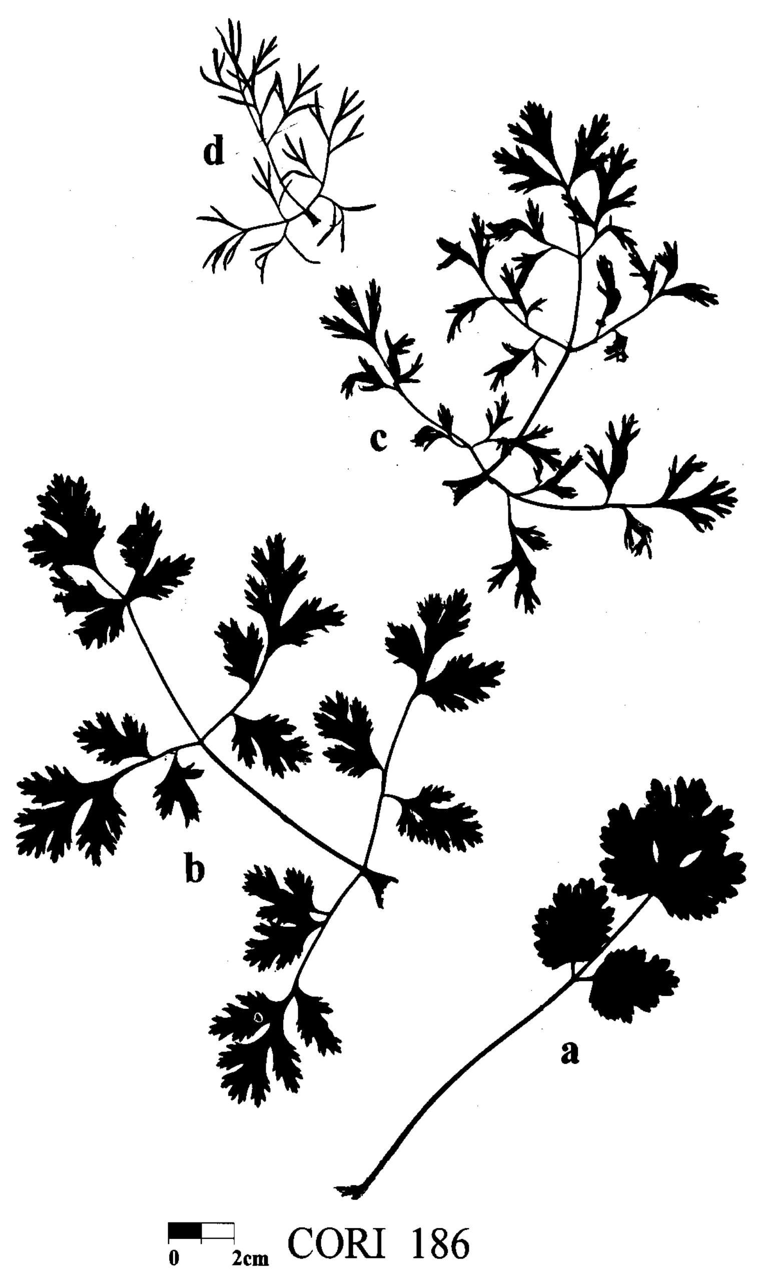


Fig. 3. Heterophylly of coriander: (a) longest basal leaf leaves; (b, c) leaves of the middle of the stem; (d) upper leaf (CORI 186, origin: Germany). (The longest basal leaf is always taken for the observations and measurements in leaf characterization, because if the plant forms a rosette, the basal leaves emerging first look different from the later ones. The longest basal leaf is usually neither the oldest nor the youngest (if there are three or more), but it is of characteristic shape and is easy to identify. See also Fig. 10).

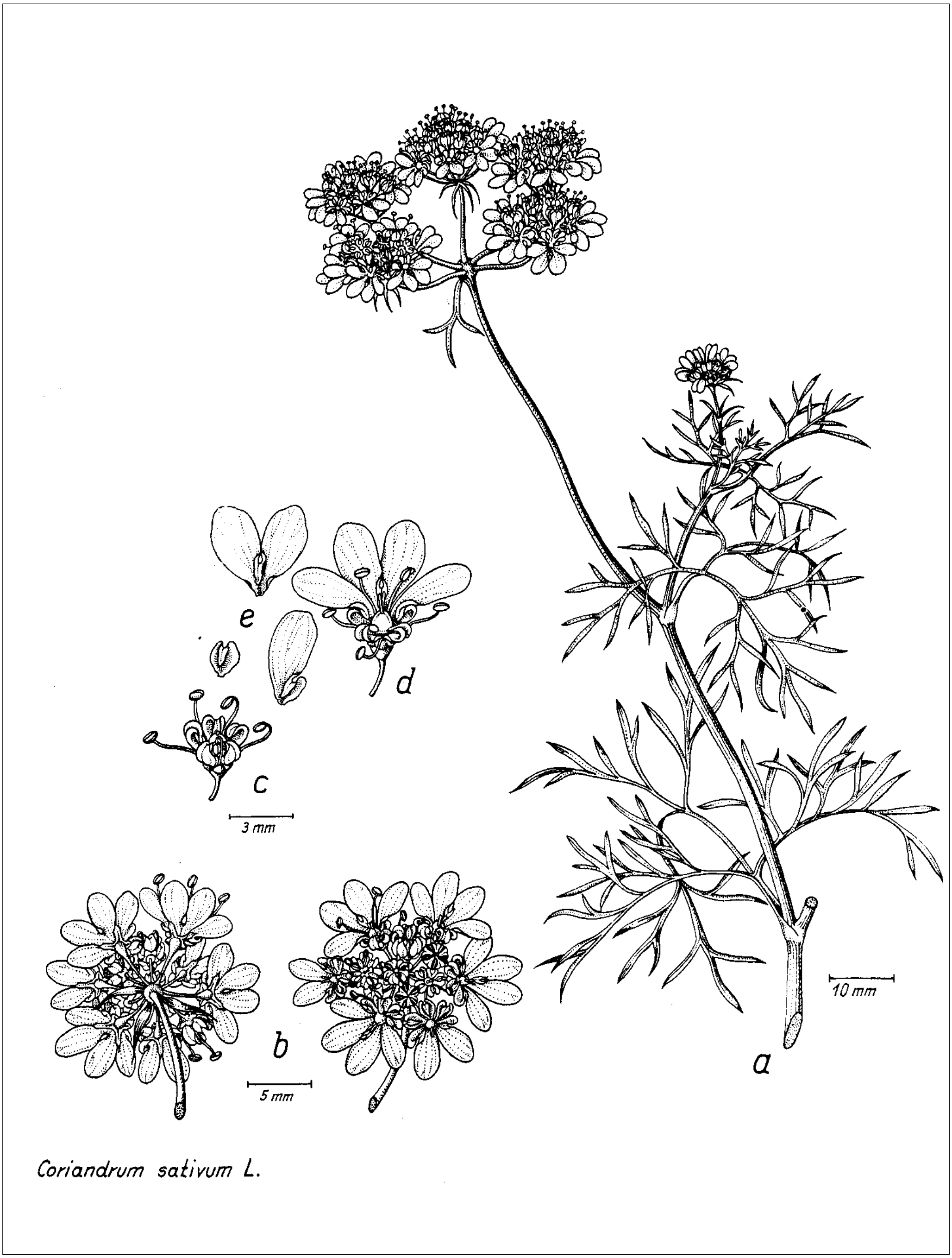


Fig. 4.1. (a) flowering branch of coriander; (b) umbellet from top and bottom; (c) central flower of an umbellet; (d) marginal flower of an umbellet with lengthened petals at the outside; (e) different shapes of petals. (Drawing: R. Kilian in Schultze-Motel 1986).

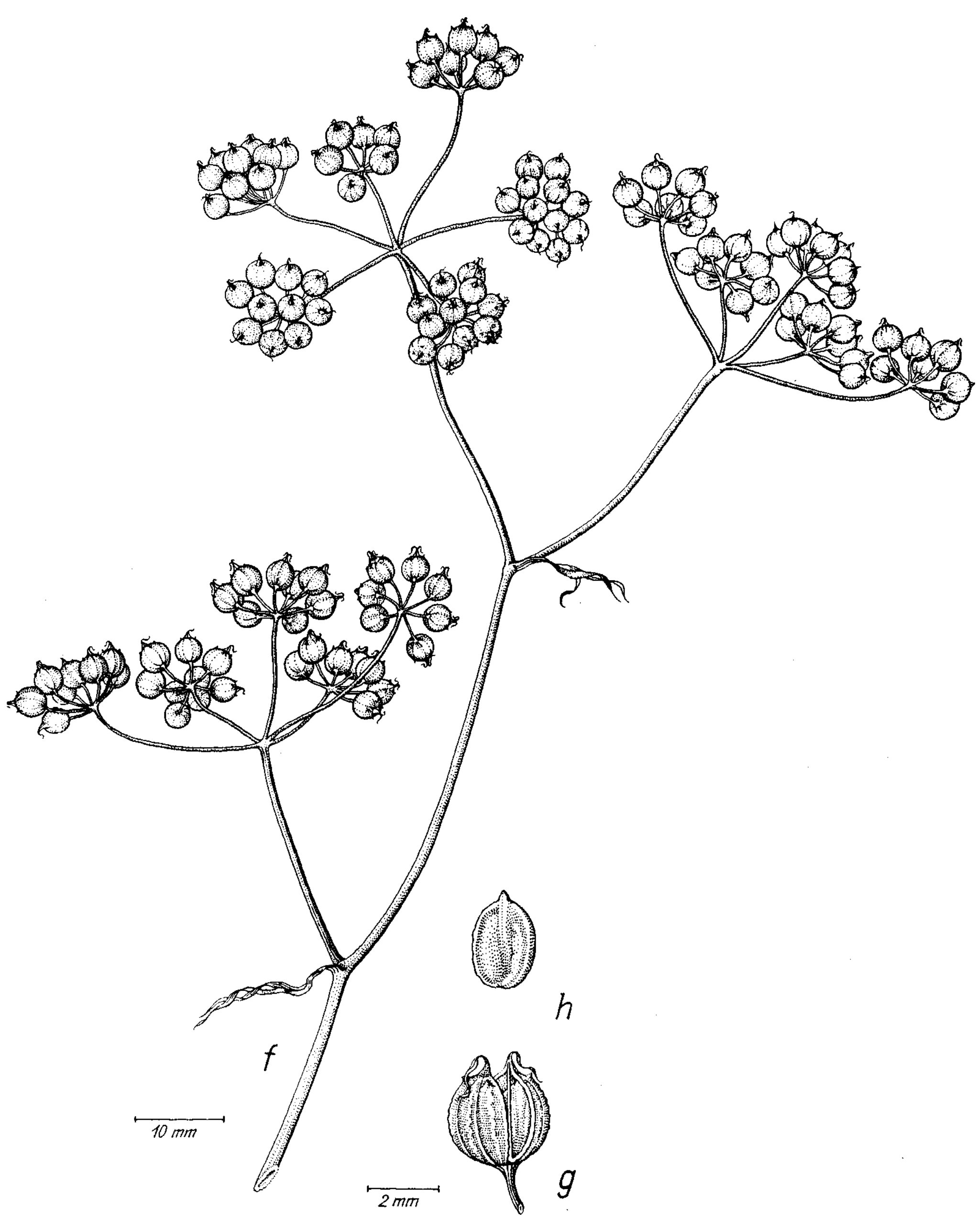


Fig. 4.2. (f) Branch of ripe coriander fruits; (g) ripe fruit, split; (h) seed after removal of the pericarp. (Drawing: R. Kilian in Schultze-Motel 1986).

for artificial emasculation of the flowers, because the filaments are easy to distinguish, and they have not yet spread any pollen grains. Since the peripheral flowers of every umbellet reach this stage earlier than the central flowers, the latter should be removed so that their pollen will not lead to fertilization. Depending on the weather conditions, 2-3 days after opening of the first flowers, the pollen sacs change their colour and become pink or violet, then the filaments stretch and the pollen sacs open and spread the pollen. The empty pollen sacs fall off and the filaments are left. When this process has finished, the two pistils become longer and separate from each other at the top. The former green colour sometimes changes to pink or violet too. This is the right moment for successful pollination. The stigma is receptive for pollination for a maximum period of 5 days. The plant can be artificially pollinated by placing pollen grains of the father plant on the stigma using a paintbrush or by carefully brushing the stigmas with flowering umbels of the father plant.

The complete process of flowering for one single umbel takes about 5-7 days, but as mentioned above, its length is very much dependent on the weather conditions, as is the length of the plant's flowering period. This is considerably lengthened by cold and rainy weather. As a result, flowers which encountered unfavourable weather will have a reduced number of fruits, or several fruits will have only one mericarp containing a seed. Furthermore, the important pollinating insects do not visit the flowers during periods of cold or wet weather (Luzina 1953).

Under optimum conditions, many different insect species are pollinators or visitors of coriander umbels. The species of insects that pollinate coriander depend on the area of cultivation. In India, studies have been done by Koul *et al.* (1989). In Egypt El-Berry *et al.* (1974) observed these insects and named them. Hussein and Abdel-Aal (1982) also reported that honey bees were frequent visitors of coriander in Egypt. Heeger (1989) mentions 10 different species of insects, some of which are endangered, that visit coriander flowers in Germany. Insects are attracted by the nectar that is secreted by the stylopodium, especially during the period when the stigma is receptive to successful pollination (Koul *et al.* 1989).

Studies at Gatersleben showed that selfing of the plants is possible, and there was no inbreeding depression visible in the first generation of offspring. But outcrossing will take place if pollen from other coriander plants reaches the stigma. Romanenko *et al.* (1991) showed that plants that were not emasculated but were pollinated with pollen of other plants still had a degree of selfing of 25%. This simple technique provides information about the pollination biology of the plant, but is also important to note for plant breeding, because it avoids the difficult process of emasculation and can be used for crossings, if the father plant has a marker gene. The same authors also stated that no inbreeding depression was observed after three generations of selfing (Romanenko *et al.*1992).

The offspring of an accession that was grown next to the accession having the dominant marker gene for pinnate basal leaves (Fig. 10.2, CORI 149[2]) in the experimental field in Gatersleben showed outcrossing to a degree of 19%. Thus, the pollination behaviour of coriander is that of a facultative cross-pollinator. The protandry

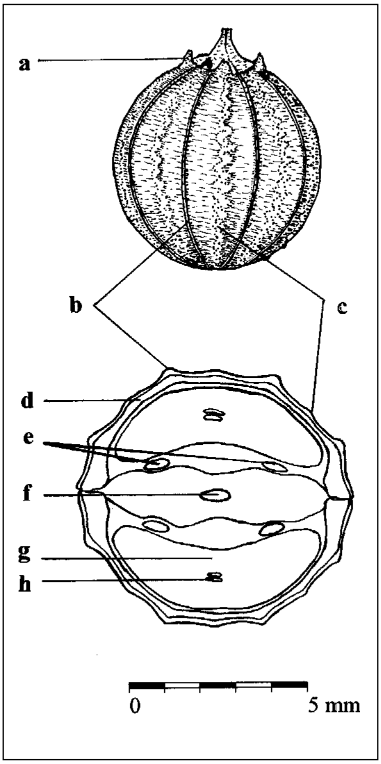


Fig. 5. Coriander fruit: (a) calyx teeth surrounding the stylopodium; (b) side rib; (c) main rib; (d) pericarp; (e) vittae; (f) carpophor; (g) endosperm; (h) embryo. (Cross-section after Gassner 1973).

and the observations made suggest that geitonogamy is common and xenogamy is possible. The impact of this on requirements for the regeneration of coriander accessions without affecting their genetic integrity will be discussed in Section 7.

The fruits are globular or ovate, with a diameter of up to 6 mm. Usually, the schizocarp does not spontaneously split into two mericarps. The two mericarps have a sclerotified pericarp at the convex outside, while the pericarp in the concave inside is pellicular. In the centre of the hollow fruits, the tiny carpophor is visible. Every mericarp has six longitudinal, straight side ribs on the convex outside, which alternate with five waved, often hardly visible main ribs (Fig. 5). On the convex inside there are two longitudinal vittae, containing the essential oil of the ripe fruit (Fig. 5). Starting from the root, there are schizogenic channels in all parts of the plant which contain essential oils. These give the green plant a characteristic smell, which is similar to that of bugs. Indeed, the plant's name is derived from the Greek name for bug, 'korion'. The plant's German name, 'Wanzendill', also derives from the German word for bug, 'Wanze', and the Russian name 'klopovnik' derives from the Russian word for bug, 'klop'. This smell is caused by different aldehydic components of the essential oil present in the green plant. During ripening, these aldehydic components disappear. Linalool is only present in the vittae of the fruits and not in other parts of the plant (Lassányi and Lörincz 1967). When completely ripe, only these vittae contain essential oil (Kokšarov 1977), while the additional channels in the mesocarp are flattened and disappear during ripening (Dave *et al.* 1992). Irregular, additional vittae in the ripe fruits of coriander types with high essential oil content have been reported by Ljubavina (1984). The aromatic properties of coriander change drastically during the ripening of the fruits, and the smell of the ripe fruits is very different from that of the unripe fruits and the green herb.

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[2] If individual genebank accessions of the Gatersleben Genebank are referred to in the text or in the figures, the respective genebank accession number follows the letters 'CORI', which abbreviate the genus *Coriandrum* and form part of the accession number.

The chromosome number of coriander is $2n=22$, as the cytologic investigation of eight genotypes by Das and Mallick (1989) demonstrated.

Very careful morphological descriptions of the species are given in English by Jansen (1981), in Russian by Stoletova (1931) and Ivanova and Stoletova (1990), and in German by Hegi (1926). The anatomy of the fruits is described in German by Rauh (1994) and Gassner (1973). The anatomy of the stem is presented in Russian by Bereznegovskaja (1930), and the anatomy and microanatomy of all parts of the plant are described in English by Szujkó-Lacza (1994). Very good agrobotanical descriptions, and also of all agronomical aspects of cultivation, are provided by Palamarja and Chotina (1953) and Luk'janov and Reznikov (1976). Some agronomic issues, especially the chemical and technological questions concerning the coriander fruits, as well as their economic aspects, are thoroughly discussed by Purseglove *et al.* (1981).

3 Origin of the species and centres of diversity

The origin of the cultivated species *Coriandrum sativum* is still not clear, and no certain information about the wild species exists. Nevertheless, several authors have named coriander as a wild plant. Linnaeus reported as long ago as 1780 that coriander also occurs as a weed in cereals. Alefeld (1866) mentioned that coriander was a common weed spread from southeastern Europe to southern Russia. Stoletova (1930) also reports on wild coriander from Armenia.

Coriander fruits endure in fields after a period of cultivation, and coriander may then occur as a weed in subsequent growing seasons. Such plants can also grow on roadsides or in disturbed areas, and have been described as 'wild coriander'. There are several coriander specimens in the herbarium of the Vavilov Institute in St. Petersburg which were not collected in fields or gardens, but are specimens of spontaneously growing coriander (e.g. specimens No. 1113 and No. 1114 from Armenia and specimen No. 26551 from Israel). Coriander was even found as an adventive plant at the coast of the Baltic Sea in Sweden (specimen No. 49971). A spontaneous find, which was recently made in Thuringia in Germany and entered in the Gatersleben Genebank, also turned out to be a usual form of the cultivated species *C. sativum*. Other reports on coriander in disturbed areas in Germany exist (Caspers 1986; Jung 1987). There exist further notes on the wild occurrence of coriander, and Korovina (1986) names places where 'wild coriander' may be presently found in Russia for use as a genetic resource. All these, however, are plants which have obviously escaped from cultivation. This behaviour is due to the fact that the ripe coriander fruit shatters relatively easily when the umbel is completely ripe. But it also shows that coriander has the potential to compete with crops and weeds in field stands. These facts strengthen the hypothesis that coriander itself is a secondary cultivated plant, which originated from a weed, and still has some features that are suggestive of this state. Its flowering behaviour would also indicate that coriander is a secondary cultivated plant, as flowering and ripening are quite extended, and the primary umbel flowers ripen much earlier than those of umbels terminating in branches of higher degree. This is a typical strategy adopted by wild plants to ensure successful reproduction. The plant not only tends to shatter the ripe fruits, but sometimes the fruits even split easily into the mericarps, which is also is a characteristic of wild plants.

In the list of centres of origin of cultivated plants Vavilov (1992) mentioned coriander for Central Asia, the Near East and Abyssinia. In each of these areas, distinct forms of coriander can be found. But the discussions since Vavilov have shown that centres of variation do not have to be the centres of origin at the same time (Zeven and de Wet 1982). Ivanova and Stoletova (1990) speak more cautiously of centres of formation of different types of coriander and name as cradles for distinct types: (i) India; (ii) Northern Africa; (iii) Central Asia, and (iv) Abyssinia. The geographically widespread cultivation of coriander since ancient times has resulted in a wide range of variation, which will be discussed in Section 6.

When considering the origin of this plant, another approach is to look for evidence of its cultivation in ancient times, using either archaeological or linguistic methods. Coriander is named in an Egyptian papyrus dating from 1550 BC that lists medicinal plants (van Harten 1974). Sinskaja (1969) even reports ancient Egyptian notes on coriander dating back to the time of the 5th dynasty, i.e. to 2500 BC. Coriander fruits were found in the tomb of Tutankhamun, and were common in other graves in ancient Egypt at that time (Germer 1989). The library of the Assyrian king Ashurbanipal of the 7th century BC also contains documents referring to the cultivation of coriander (van Harten 1974). It is interesting to note that the ancient Egyptian literature mentions varieties of coriander coming from Asia (Reinhardt 1911). According to Van Harten (1974), the Jews must have known coriander before coming to Egypt (around 2000 BC), since the Hebrew name ‘gad’ occurs in the Old Testament. ‘Gad’ is usually translated as coriander, but probably means wormwood, *Artemisia* L., and is misunderstood because of its similarity with the Punic name ‘goid’, which is the name for coriander in that language (Zohary 1986). Coriander is referred to as ‘dhanayaka’ or ‘kusthumbari’ in the Sanscrit literature. According to Prakash (1990), these references date as far back as 5000 BC. This claim seems doubtful, however. There are no references to coriander until the Egyptian period, and the Sanskrit language itself is not that old. Classical Greek authors such as Aristophanes, Theophrastus, Hippocrates and Dioscorides (van Harten 1974) and Latin authors such as Pliny and Columella also wrote about this crop. Egyptian coriander was especially praised by them for its quality (Reinhardt 1911; Hegi 1926). Göök (1977) reports that in the 12th century AD, flowering fields of coriander were seen on the banks of the river Nile in Egypt.

In China, coriander is mentioned as a vegetable in a book on agriculture from the 5th century (Li 1969). The Persian name for coriander was used in China, which lends support to the hypothesis that the plant was introduced to China from this area (Ivanova and Stoletova 1990). In Europe, the Romans brought coriander to the northern countries, and the name of the plant is similar in all of these countries. The old Russian name ‘kišnec’ is very similar to the Persian ‘geshnes’ and Turkish ‘kişniş’, and the crop probably came to Russia from the Caucasus or even from areas to the east of the Caspian Sea (Luk’janov and Reznikov 1976). Hegi (1926) mentions the Tartar name ‘ghiachnich’, which would also support his pathway.

In India, in addition to the Hindi and Sanskrit names cited (see Section 1.3), there exist many local names for this plant.

These different names bear witness to the role that coriander has played since ancient times in the Indian subcontinent. It is interesting to note that names are related to each other not only in Indian, but in many of the languages cited, and the name of the plant often starts with the consonant ‘k’. Characteristic types are found in Ethiopia, where local names for coriander indicate that here too it has a long tradition of cultivation.

Common Indian names
(after Bhatnagar 1950; Samba Murty and Subrahmanyam 1989)

Bengali	dhane, dhania
Gujarati	kothmiri, konphir, libdhane
Kannada	kothambri, kothmiri bija
Kashmiri	daaniwal, kothambalari
Malayalam	kothumpkalari bija, kothumpalari
Marathi	dhana, kothimber
Oriya	dhania
Punjabi	dhania
Tamil	kothamali
Telugu	dhaniyalu

Ethiopian local names
(reported by Jansen 1981; Goetsch *et al*. 1984)

Amharic	dembilal
Oromo	debo, shucar
Tigre	tsagha, zagda
Konso	tibichota

Compared with some other crops, there are fewer reports of coriander cultivation in ancient times, but the cultivated crop nevertheless spread through the Old World at an early date. The oldest coriander fruits discovered, in the Nahal Hemar cave in Israel, date to 6000 BC (Zohary and Hopf 1993). The ancient literature and the archeobotanical findings support the hypothesis that the crop has its origins in the Near East. The distribution of the other species of the tribe Coriandreae also lends support to Near Eastern origins of *C. sativum* (see Section 1.1). The first reports on the use of the fruits mention its medicinal purposes and the findings from Egyptian tombs show that coriander also had a mythological significance.

4 Composition and uses

There exist very different uses of coriander and these are based on different parts of the plant. The traditional uses of the plant, which are based on the primary products, i.e. the fruits and the green herb, are two-fold: medicinal and culinary. During industrialization, the specific chemical compounds of coriander were recognized and identified, and these became important as raw materials for industrial use and further processing. The essential and fatty oils of the fruits are both used in industry, either separately or combined. After extraction of the essential oil, the fatty oil is obtained from the extraction residues either by pressing or by extraction.

A further benefit of coriander derives from the reproductive biology of this plant. Coriander produces a considerable quantity of nectar and thereby attracts many different insects for pollination, an external effect which is of both ecological and economic value. Coriander is also a good melliferous plant, and Luk'janov and Reznikov (1976) state that one hectare of coriander allows honey bees to collect about 500 kg of honey.

4.1 The essential and fatty oils of the fruits

The uses of coriander fruits are related to their chemical composition. The general composition of the fruits is presented in Table 2. The most important constituents are the essential oil and the fatty oil. The essential oil content of the weight of ripe and dried fruits of coriander varies between 0.03 and 2.6%, and the content of fatty oil varies between 9.9 and 27.7% (see Table 8). The composition of the essential oil is shown in Table 3 and the composition of the fatty oil in Table 4.

4.2 Medical uses

Coriander has been used in medicine for thousands of years (Mathias 1994). The first medicinal uses of the plant were reported by the ancient Egyptians. General references to coriander's medical uses are also found in classical Greek and Latin literature (Manniche 1989), and instructions to cultivate coriander are contained in the German emperor Charlemagne's decree 'Capitulare de villis' in 812 (Gööck 1977). The coriander fruits are believed to aid digestion. Many other fruits of umbelliferous plants have been used in medicine since antiquity (French 1971) as they also affect the digestive system and some act as an aphrodisiac. Some of these, such as hemlock (*Conium maculatum* L.), are poisonous. Coriander is also used externally to treat ulcers and rheumatism; these and several other medicinal uses are recorded by Hegi (1926). Losch (1903) describes how the fruits need to be soaked in wine or in vinegar overnight before being re-dried, in order to remove chemical compounds contained in the fresh fruits, which cause dizziness. These are mentioned in the older references (Linnaeus 1780; Reichenbach 1833; Losch 1903; Hegi 1926). Fruits thus treated were used for medicinal purposes, and also to treat halitosis. Today, the plant is still sometimes used for these purposes in folk medicine. The medical uses of coriander in the modern era are described by Cicin (1962). In India, the fruits are considered carminative, diuretic, tonic, stomachic, antibilious, refrigerant and

Table 2. Chemical composition of the coriander fruits (König 1920 *in* Stoletova 1931)

Component	Content (%)
Water	11.37
Crude protein	11.49
Fat	19.15
Crude fibre	28.43
Starch	10.53
Pentosans	10.29
Sugar	1.92
Mineral constituents	4.98
Essential oil	0.84

Table 3. Composition of the essential oil in the ripe fruits of coriander (mean values, n=237, plants grown in Gatersleben, Germany in 1995)

Main components	% of total essential oil	Minor components (all with less than 2%)*
linalool	67.7	β-pinene
α-pinene	10.5	camphene
γ-terpinene	9.0	myrcene
geranylacetate	4.0	limonene
camphor	3.0	*p*-cymol
geraniol	1.9	dipentene
		α-terpinene
		n-decylaldehyde
		borenol
		acetic acid esters

* Gildemeister and Hoffmann 1931.

Table 4. Composition of the fatty oil in the ripe fruits of coriander (mean values, n=176, plants grown in Gatersleben, Germany, in 1994)

Main components	% of all fatty acids	Minor components
petroselinic acid	68.8	stearic acid
linoleic acid	16.6	vaccenic acid
oleic acid	7.5	myristic acid
palmitic acid	3.8	

aphrodisiac. They are used chiefly, however, to conceal the taste or smell of other ingredients in pharmaceutical preparations (this use is also reported by Jansen (1981), and to correct the gripping qualities of rhubarb and senna (Bhatnagar 1950). The seeds are chewed as a remedy for halitosis.

The drug, known as 'Coriandri fructus' or 'Fructus coriandri', is hardly used in current orthodox medicine. It is still on the German and Austrian official lists of pharmaceutical plant drugs, however (Ebert 1982). The antibacterial effects of the essential oil of coriander are mentioned by Pruthi (1980).

4.3 Use of the fruits as a spice

The ripe fruits of coriander have a pleasant flavour owing to the particular composition of the essential oil (Table 3). The use of coriander as a spice has also been reported since ancient times. The fruits are used in the preparation of fish and meat, but also for baking. The famous Russian rye bread 'Borodinskij chleb' is spiced with coriander (Fig. 11a). In India, coriander is very popular as a spice and is also cheap. In Ethiopia, coriander is widely used along with other spices to add flavour to 'berbere' which is a spiced, hot red-pepper powder used for numerous meat and vegetarian dishes (H. Fassil, 1996, pers. comm.). Today, most coriander is consumed in the form of curry powder, of which it forms 25-40% (Purseglove *et al.* 1981). In India, the fruits are also extensively employed as a condiment in the preparation of pickling spices, sausages and seasonings, and for flavouring pastry, cookies, buns and cakes, and tobacco products. The entire young plant is used to prepare chutneys and sauces. Coriander is used also to flavour several alcoholic beverages, e.g. gin (Jansen 1981). The German name 'Schwindelkörner' (pl.), or 'dizziness grains', seems to be connected with the former practice of using coriander fruits to flavour beer, which increased its inebriating effect (Gööck 1977). The ancient Egyptians made the same use of the plant in wine-making (Reinhardt 1911), and candied coriander fruits were once popular (Reichenbach 1833; Göök 1977).

4.4 Use of the green herb as a spice and vegetable

Another primary product is the fresh green herb of coriander, used because of its specific flavour, which is completely different from that of the ripe fruits. In the Caucasus, Iran, Iraq, Mexico and in South America, with the exception of Argentina, coriander is mainly used in this form. The green herb is also consumed on a large scale in India, China, Thailand, Malaysia, Indonesia, the American Midwest and in the Near East (Prakash 1990). The Georgian name 'kinza', also used in Russian, refers to the green plant, and the English term 'Chinese parsley' also describes the herb. The same is true for the Spanish name 'cilantro', which denotes the plant, while the fruits are called 'simiente de cilantro'. The name 'cilantro' is frequently used in American English to refer to the green herb or the dried leaves (Lamberts 1990), probably because the use of the green plant was introduced in the USA by Spanish-speaking Mexicans. The French name 'persil arabe' also means the green herb. It is interesting to note that the ancient Egyptian hieroglyphs 'venshivu' and 'ounshavu' refer to the coriander plant, and a different one, 'ounshi', to the fruits of this species (Sinskaja 1969). Whether the ancient Egyptians also used the green herb cannot be determined from the available literature, and the later Greek and Latin authors only mention the use of the fruits.

The smell of the green plants is often regarded as unpleasant, particularly by the inhabitants of industrialized countries. It has frequently been observed, however, that those who became accustomed to the smell cease to consider it disagreeable. In countries where use of the green herb is widespread, its flavour is highly regarded, and it is used in a variety of dishes. Several conservation techniques, e.g. drying, are applied to ensure a constant supply of the herb (Prakash 1990; Ivanova and Stoletova 1990). The green plant is used in soups, salads and dressings, and in India it is very commonly used in chutneys (Ilyas 1980). In the Transcaucasian area, the green plant is a most important ingredient in cooking (Stoletova 1930, 1931; Ivanova 1966). Here, the local varieties are characterized by high production of green matter (Alborišvili 1984). Although at present the use of the green herb is much more limited in the industrialized countries, its popularity seems likely to increase, as the market for such 'ethnic' foods is growing (Simon 1990). The characteristic smell of the green plant is caused by the aldehydic contents of the essential oil. During ripening, these decrease, and after ripening and drying, they are no longer found in the fruits (Lörincz and Tyihák 1965). Lastly, the green herb's high vitamin C (ascorbic acid, up to 160 mg / 100 g), vitamin A (carotin, up to 12 mg / 100 g) (Girenko 1982) and vitamin B2 content (up to 60 mg / 100 g) (Prakash 1990) should be noted.

In China even the root of coriander, which has channels that also contain essential oils, is used as a vegetable.

4.5 Use of the essential oil of the fruits

The first factory for the steam distillation of the essential oil of coriander was built in Russia in 1885 in the Voronež district (Stoletova 1931). In this area, the introduction of coriander as a field crop began as early as 1830, and it remains the principal producer of coriander for this purpose. The oil is obtained by steam distillation of the crushed fruits and a continuous and completely automated processing technique has been developed (Purseglove *et al.* 1981). Recently, the essential oil has also been processed by liquid carbon dioxide extraction. The extracted essential oil is used in the flavouring of a number of food products and in soap manufacture. It is principally used as a flavouring agent in the liquor, cocoa and chocolate industries. Like the fruits, it is also employed in medicine as a carminative or as a flavouring agent. It has the advantage of being more stable and of retaining its agreeable odour longer than any other oil of its class. Decylaldehyde (yield 0.1% of the weight of coriander oil), obtained by treating the oil with bisulphite, is reported to be useful for perfumery purposes. The commercial oil is extensively adulterated with sweet orange oil, cedar-wood oil, turpentine and anethole or aniseed oil (Bhatnagar 1950). The main component, linalool, is used as a base for further technical processing.

Today, oleochemically synthesized linalool is usually used in the non-food sector, as it is cheaper at present. The demand for essential oils is rising in Western countries, and the full potential of this use of coriander has not yet been recognized (Simon 1990).

After extraction of the essential oil, the residues are used as ruminant feed, since their composition is nearly the same as that of the whole fruits, and therefore still contains digestible fat and protein (Stoletova 1931). Because of the high crude fibre content, coriander oil cake can only be fed to ruminants, but the nutritional value of this feed is limited (Rohr *et al.* 1990).

4.6 Use of the fatty oil of the fruits

The fatty oil is obtained either by pressing or by extraction of the fruits. This oil has special qualities that make it suitable for use as a lubricant in some technical processes with special demands (Luk'janov and Reznikov 1976). The main component of the fatty seed oil, petroselinic acid ($C_{18:1(6c)}$) is an isomer of the usual oleic acid ($C_{18:1(9c)}$). In petroselinic acid, the single double bond has a different position; the biosynthesis is described by Meier zu Beerentrup (1986). The high petroselinic acid content gives the oil peculiar physicochemical properties that make it potentially suitable for use in surfactants, polymers or as oleochemical raw material (Barclay and Earle 1965). Petroselinic acid is a characteristic component of the fatty oil of umbelliferous plants, and the fruits of several medicinal and aromatic plants have been screened for this fatty acid (Kleiman and Spencer 1982; Hondelmann 1985). In temperate climates, coriander is the plant with the greatest potential for petroselinic acid production (Dambroth and Bramm 1991; von der Schulenburg *et al.* 1991). In the past, the ozonolysis of petroselinic acid at the double bond to yield lauric ($C_{12:0}$) and adipic acid was proposed, but this does not now seem interesting, owing to the ample supply of laureate in the rapidly expanding world market for palm oils (Röbbelen, 1996, pers. comm.).

5 Genetic resources

5.1 *In situ*/on-farm

The cultivation of coriander is widespread, but in many places occurs on a small scale only. As was mentioned above, coriander is to be found in gardens rather than in large fields, with the exception of those areas that have specialized in commercial production of the plant (see Table 10). Collecting undertaken over the last 20 years by the genebank and taxonomy departments of the Institute of Plant Genetics and Crop Plant Research at Gatersleben, Germany has shown that many landraces of coriander have been cultivated. This is especially true of the Caucasian Republic, Georgia (Beridze *et al.* 1986). In the Near East and the Indian subcontinent too, small-scale production of coriander has recently become widepread, and collecting has also been carried out in these regions (Hammer 1993b). Jansen (1981) reports: “In Ethiopia, coriander can be found on almost every market. Small-scale cultivation in gardens is widespread”. Recent reports from South American countries advise that the green herb is very popular in many dishes, and is often to be found growing in gardens.

Although interest in coriander continues to grow in the industrialized countries, the original diversity of the home gardens in which the crop is widely grown in the regions mentioned above appears to be under threat. This is due to the radical political and economic changes affecting these areas. The political changes during the last decade in Georgia, for example, have brought about a notable loss of on-farm genetic diversity (Beridze 1996), and the same is true for the Central Asian republics. In the developed countries, the traditional uses of coriander in folk medicine disappeared during the process of industrialization. Here, coriander is still a very rare garden crop, and the green plant is not yet used. In the industrialized countries, the distinct forms of coriander are only grown in home gardens by a few individuals with a special interest in the plant, and by nongovernmental organizations (NGOs). Examples of NGOs engaged in this field are the Seed Savers Exchange in the USA (Whealy 1993) and the Arche Noah (Arrowsmith 1993) in Austria.

Modern plant breeding of coriander will probably result in more or less uniform, genetically identical varieties. The little information available on the occurrence of the wild species (Table 1) makes it difficult to evaluate the state of its genetic resources. The latest information on the occurrence of *C. tordylium* is contained in herbarium specimens in Edinburgh (Scotland) and Turku (Finland) collected by R. Alava in 1968 (Alava, 1995, pers. comm.). The three existing species of the genus – *Bifora, B. americana, B. radians* and *B. testiculata* – are conditioned weeds and are therefore threatened by the perfection of herbicide weeding. In southern Germany, for example, where 70 years ago *B. radians* was often reported (Hegi 1926), it is now rarely found.

Table 5. Institutions with collections of coriander germplasm (source: FAO, 1995, with additions)

Institution	Address	
Genetic Resources Centre, Bangladesh Agricultural Research Institute	Joydebpur, Gazipur, GPO Box 2235, Bangladesh	
Institute of Crop Germplasm Resources (CAAS)	Beijing, 30 Bai Shi Qiao Road, China	
Institute of Crop Science, Federal Research Centre for Agriculture (FAL)	Bundesallee 50, 38116 Braunschweig, Germany	
Institute for Plant Genetics and Crop Plant Research (IPK) Genebank, Gatersleben	Corrensstr. 3, 06466 Gatersleben, Germany	
Plant Genetic Resources Centre	Addis Abeba, PO Box 30726, Ethiopia	
Banco Portugues de Germoplasma Vegetal (BPGV)	Quinta dos Peões - Gualtar, 4700 Braga, Portugal	
N. I. Vavilov All-Russian Research Institute of Plant Industry (VIR)	190000 St. Petersburg, Bolshaya Morskaja Str. 42-44, Russian Federation	
Horticultural Research Section, Agricultural Research Corporation	Wad Medani, PO Box 126, Sudan	
Plant Genetic Resources Dept., Aegean Agricultural Research Institute	Izmir, PO Box 9, Menemen, Turkey	
North Central Regional Plant Introduction Station, USDA-ARS	Iowa State University, Ames, Iowa 50011, USA	46
Centre for Plant Breeding and Reproduction Research (CPRO-DLO)	Droevendaalsesteeg 1, PO Box 16, 6700 AA Wageningen, The Netherlands	

***** nd = no data; the institution did not provide the information; sample: F=free available, R=restricted, N=not available; passport data: A=available, P=partly available, N=not available.

5.2 *Ex situ* conservation and collections

Ex situ collections of plant genetic resources of coriander with more than 10 accessions are listed in Table 5. The list is mainly based on the Food and Agriculture Organization of the United Nations (FAO) database FAO World Information and Early Warning System on Plant Genetic Resources, which contains information on genebank collections.

The collection of the Gatersleben Genebank has been used as the basis for the description of the range of variation in Section 6. Coriander belongs to the group of medicinal and aromatic plants of the Gatersleben Genebank, which contains 20 other unbelliferous species (Hammer 1993a). At Gatersleben, all passport, characterization and evaluation data for coriander are available and computerized. Herbarium specimens are available for every accession of the collection and are used as reference specimens to check the identity of genebank accessions after field reproduc-

Table 5, continued.

	Availability*			
No. of samples	**Sample**	**Passport data**	**Where collection kept****	**Year of updating**
10	nd	nd	L; M	1993
31	F	A	L	1990
36	F	A	L; M	1995
237	F	A	L, M; W	1995
30	F	P	L; M	1985
20	F	A	L; M	1995
342	F	A	L; M	1995
23	nd	nd	L	1993
17	F	nd	L; M	1995
F	A	L; M	1994	
65	R; N	P	W	1996

** L=long-term storage, M=medium-term storage, W=working collection.

tion. The reproduction of all accessions is done at Gatersleben and the characterization data are recorded during every reproduction cycle. In 1995, the collection contained 344 accessions; 237 of these have been subjected to an evaluation programme, which began in 1993. Only these accessions are considered in this publication. Further accessions obtained between 1994 and 1995 will be evaluated carefully before it is decided whether to enter them in the collection.

The geographic origin of the coriander accessions of the Gatersleben Genebank is listed in Table 6. Eight of the accessions are modern cultivars and the others are landraces. More than 50% of the accessions were acquired during several collecting missions carried out by the genebank and taxonomy departments of the Instutute at Gatersleben (Hammer 1993b). In particular, the collecting done in the Caucasian area over a period of several years produced numerous coriander accessions (Beridze *et al.* 1986). About 40 accessions are duplicates of other collections mentioned in Table 5. The geographic origin of 51 accessions in the collection is unknown. These are mostly from European botanical gardens.

All the other *ex situ* collections listed in Table 5 largely contain landraces and some old and new cultivars. Accessions are often declared as 'wild type', which needs to be understood as 'weedy type'. The species *C. sativum* is not a wild plant, but can persist for some years after a period of cultivation (see Section 3).

One of the largest collections of coriander germplasm, with about 600 accessions, is kept in the N.I. Vavilov All Russian Research Institute of Plant Industry (VIR[3]), St. Petersburg. Until 1938, a large collection of about 600 accessions of coriander from countries all over the world was gathered in St. Petersburg (at that time called Leningrad). Most of the herbarium specimens of the VIR are based on this material. E.A. Stoletova (1887-1964) studied this material, and in 1931 published the first monograph on coriander and also an infraspecific classification of the plant. In 1938, this collection was transferred to the town of Alekseevka, about 150 km south of the town of Voronez. This is the site of the experimental station of the All-Union Research Institute of Volatile Oil Crops (BNIIEMK), whose headquarters are located in the Crimean town of Simferopol'. The institute in Simferopol' still exists and houses a collection of coriander germplasm (see Appendix 1 for address) (Sil'čenko, 1996, pers. comm.). The former collection of the VIR was transferred to this institution, and only some of the former accessions are still available (Girenko, 1996, pers. comm.). The description of variability and infraspecific typification given by Ivanova and Stoletova (1990), which was compiled by Girenko and published in 1990, is partly based on notes, herbarium specimens and drawings of former accessions of the VIR, most of which no longer exist in the collection.

In 1982, an inventory and evaluation of the remaining accessions of the former collection was undertaken, and 329 accessions were eventually returned to the collection of the VIR (Sil'cenko *et al.* 1984). Together with the other samples that have been collected by the Institute's staff since 1945 on many collecting missions, the number of accessions of this exceptional collection now stands at about 600 (Girenko, 1995, pers. comm.). From World War II until 1965, K.V. Ivanova (1903 - 1989) worked with the collection of coriander at the VIR, whose present curator is M.M. Girenko. Passport data and evaluation data are available for the accessions, partly in computerized form. In 1980, Girenko and Cytovič published descriptions of important characters of 62 accessions for vegetable use (1980). For a further 67 accessions, there are descriptions available that include additional information about the chemical composition of the fruits (Girenko 1992). The present VIR collection includes accessions of cultivated coriander from all parts of the world, and the range of variation of the collection exceeds that described by Ivanova and Stoletova (1990). The VIR is currently facing numerous funding problems, however, which are threaten-

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[3] Vsërossijskij (*or*: Vsësojuznyi) naučno-issledovatel'skij institut rastenievodstva imeni N. I. Vavilova=N. I. Vavilov All-Russian (*or*: All-Union) Research Institute of Plant Industry.

Table 6. Geographic origin of the coriander accessions of the Gatersleben Genebank

Area of origin	No. of accessions	Specification of origin (No. of accessions)
Unknown (Botanical Gardens)	51	
Caucasus	61	Georgia (54), Armenia (6), Azerbaidzan (1)
Former Soviet Union	11	Daghestan (4), Belorussia (1), Ukraine (1), without specification (5)
Central Asia	6	Mongolia (1), Kirgysia (1), Tadjikistan (2), Kasachstan (2)
Near East	32	Syria (15), Oman (10), Afghanistan (2), Jemen (2), Iraq (2), Iran (1)
Indian subcontinent	17	Pakistan (8), India (2), Bhutan (7),
China	7	
North Africa	14	Tunisia (6), Algeria (4), Libya (4)
Africa	12	Sudan (5), Ethiopia (3), Egypt (3), Somalia (1)
Americas	8	Canada (1), USA (1), Cuba (2), Mexico (1), Columbia (1), Chile (2)
Europe	18	Germany (9), Netherlands (2), Italy (2), Romania (1), Hungary (1), former Czechoslovakia (1), Austria (1), Spain (1)
Total	237	Origin known for 186 accessions*

*Of which 178 are from the Old World.

ing the regular regeneration of the accessions. Many herbarium specimens of the VIR represent accessions from the collection existing before 1938, and therefore refer to accessions that no longer exist in the germplasm collection. Herbarium specimens are only taken from those accessions which entered the collection later if they possess any extraordinary traits. The collection of herbarium specimens of coriander is the largest in the world and contains more than 1030 specimens from all over the planet.

The collection of the North Central Regional Plant Introduction Station, Iowa, USA contains 46 accessions. The passport data only report the country of origin. All germplasm collections and the work of this station are briefly described by Roath *et al.* (1990).

The collection of the Institute of Crop Science (FAL), Braunschweig, Germany, contains accessions from German and other botanical gardens or institutions. In 1991, nine accessions were collected during a mission to the Caucasus. The passport data have been computerized.

The collection of the Centre for Plant Breeding and Reproduction Research (CPRO-DLO) in the Netherlands was established during the period 1988-93. It contains material from botanical gardens and other institutions. The accessions have not been multiplied, and only 50% are available without any guarantee of viability (van Soest, 1996, pers. comm.). The Centre for Genetic Resources of the Netherlands (CGN) does not conserve coriander germplasm, despite the fact that Stoletova (1931) and Heeger (1989) named the Netherlands as an important producer of coriander fruits. It was not possible to present such additional information for the collections of the other institutions listed in Table 5.

It should be noted that only limited information is available on coriander germplasm collections in India. Under the Indian Council of Agricultural Research (ICAR), the Jobner (Rajasthan), Jagudan (Gujarat), Coimbatore (Tamil Nadu), Guntur (Andhra Pradesh), Hisar (Haryana) and Dholi (Bihar) centres maintain 683, 146, 372, 230, 58 and 100 accessions respectively (Anonymous 1994-95). This information clearly is not entered in the FAO information system and apparently the germplasm in these collections is not freely accessible. There exist several Indian publications on diversity and resistance breeding that are based on existing germplasm collections. One possible source for germplasm information might be the germplasm collection of the Tamil Nadu Agriculture University, Coimbatore, India. According to Suthanthirapandian *et al.* (1980), this contains at least 60 accessions of coriander. In 1991, Bhandari and Gupta reported 171 Indian coriander accessions available, and their institution, the College of Technology and Agriculture Engineering, Udaipur still keeps a collection.

The wild species of the tribe Coriandreae, *B. radians* and *B. tordylium* are sometimes found in botanical gardens, but as described above (Section 5.1), they have never been collected and studied systematically.

6 Diversity of the species

6.1 Infraspecific classification

Coriander has a wide range of variation in several traits, which make the plant suitable for different uses. The classical agrobotanic approach to diversity has always been to divide the total genepool into differently named groups whose characters can be distinguished from each other morphologically, geographically, chemically or cytologically. The names given to the infraspecific taxa contain a great deal of information, which, for those unfamiliar with the respective classification system, requires considerable interpretation. A large amount of information on single character expressions and molecular structure can be stored in databases. For the practical work of collecting and communicating this information, however, the naming of groups is essential. The value of infraspecific grouping in plant genetic resources work was outlined by Mansfeld (1953, 1954) and is also stressed by Hanelt and Hammer (1995).

Coriander has been classified intraspecifically, on the strict basis of a description of the diversity of the species. The first contribution to this intraspecific classification was made in 1830 by A.P. de Candolle (1830), who is author of the name *C. sativum* L. var. *microcarpum* DC., used for the forms of coriander with small fruits, which he described. De Candolle was followed by Alefeld (1866), who states that the types of coriander with large fruits are the ones commonly found as a weed and as a crop in Europe. According to his system, plants with a weight of 1000 fruits less than 10 g belong to the variety *C. sativum* L. *microcarpum* DC., and those with larger fruits to *C. sativum* L. *vulgare* Alef. (Alefeld 1866). The rules of the International Code of Botanical Nomenclature (Greuter 1994) state that the latter name should not be used, because for this variety, the name of Linnaeus is autonomous. The correct name is therefore *C. sativum* L. var. *sativum*. The weight of 1000 fruits and diameter of the fruits are characters that have a high, significant positive correlation (r=0.92) (Diederichsen and Hammer 1994). Therefore, an infraspecific classification of coriander that distinguishes these two groups should be used as follows:

Coriandrum sativum L. var. *sativum*: weight of 1000 fruits more than 10 g, diameter of fruits more than 3 mm

Coriandrum sativum L. var. *microcarpum* DC.: weight of 1000 fruits less than 10 g, diameter of fruits less or not much more than 3 mm.

This is a very sound method of formal classification that is simple but which nonetheless conveys important information, because the fruit size is correlated with many other traits of agronomic and commercial interest (these correlations are presented in Section 6.3.2). Traders have also been interested in classification by this character, because it is to some extent possible to determine the geographic origin and thereby the quality of the fruits from their size alone (Harrod 1960).

A considerable amount of work in reviewing the diversity of the species has been done at the Vavilov Institute (VIR) in St. Petersburg. Stoletova's monograph

(1931) provides a good description of variability by morphological traits, and a key based on morphological characters, which leads to the determination of 11 geographical groups. It is an informal classification, and the key presented is difficult to use, but the description of several types is excellent. In 1939, Stoletova gave a short summary of her studies on this subject, together with four maps and some information about the essential oil content of plants of different geographic origin. Girenko (1974), who studied 200 accessions of the VIR, also made a geographical grouping and stated the range of variation to be greater than that recognized by Stoletova. The geographical groups were reduced to nine by Šestopalova *et al.* (1975), who studied 300 accessions and also gave information about the composition of the essential oil of some of these. In 1982, during the preparation of inventories of the BNIIEMK and VIR collections, 520 accessions of coriander were studied and grouped according to their essential oil content (Sil'čenko *et al*. 1984). All the descriptions of variation in the species provided were intended to deliver important information to plant breeders, to enable them to integrate material from the collections into their breeding programmes.

The work published in 1990 by Ivanova and Stoletova is the first to present a formal system of infraspecific classification of coriander that goes further than A.P. de Candolle's. Several morphological characters are used for the division of the species into four subspecies and nine varieties. The work contains diagnoses in Latin. According to the rules of the International Code of Botanical Nomenclature (Greuter 1994), however, the typification is not correct, because no herbarium collection type-specimens are named. The original plant material has been lost. The description of the range of variability of the species is very good, owing to the authors' careful consideration of the vegetative parts of the plant. Nevertheless, the key to the infraspecific taxa, especially the varieties, is difficult to follow, because some of the characters used are not easy to observe. This work may tend toward overclassification, which Harlan and de Wet (1971) recognized as a general danger in the classification of cultivated plants. For this reason, these authors rejected formal infraspecific classification and suggested that infraspecific grouping should not be done within the frame of strict nomenclatural rules.

The following section contains the findings of a study of the Gatersleben collection carried out to establish a sound method of formal infraspecific classification, which is essential to the wider communication needed to maintain and work with genetic diversity. The various types of coriander that can be distinguished are presented. According to taxonomic terminology (Hanelt *et al.* 1993; Hanelt and Hammer 1995), the investigation results in an informal ecogeographic classification at the infraspecific level (see Section 6.4).

6.2 Important characters of the species

The species *C. sativum* has a wide range of diversity. Several characters are important; they can be used to distinguish different groups, and should be documented for accessions in the *ex situ* collections. The use of the vegetative as well as the

Table 7. Important characters of coriander

Group of characters	Character no.	Character
Vegetative parts of the plant*	1	Number of basal leaves
	2	Length of the longest basal leaf
	3	Habitus of the basal leaves: 1=very flat, prostrate;4=raised with an arcus of about 45°; 6=very erect
	4	Blade shape of the longest basal leaf**: 1=entire or slightly insected 2=deeply incised with 3 lobes 3=once pinnate with 3 or 5 leaflets 4=leaves twice pinnate 5=leaves more than twice pinnate 6=like 5, lance-shaped parts 7=like 5, linear-shaped parts 8=like 5, filiform-shaped parts
	5	Blade shape of the upper stem leaves: notes no. 4
	6	Foliation of the plant: 1=very few leaves, 5=middle, 9=very many leaves
	7	Plant height in cm
	8	Branching of the plant: 1=up to 10 terminated branches 9=more than 50 terminated branches
Generative parts of the plant	9	Anthocyan in the petals: 1=without anthocyans 9=petals with violet colour
	10	Shape of the fruits: 1=round or even flattened 3=slightly lengthened 9=ovate
	11	Weight of 1000 fruits
Phenological characters	12	Number of days until stem elongation
	13	Number of days until start of flowering
	14	Number of days until end of flowering
	15	Number of days until harvesting
Chemical composition of the fruits	16	Essential oil content of the air dried fruits in %
	17	Linalool in the essential oil in %
	18	Fatty oil content of the air dried fruits in %
	19	Petroselinic acid of all fatty acids in %

* These characters are recorded when the vegetative stage of development is finished, i.e. at the start of flowering.

** Examples are shown in Fig. 10.

generative parts of the plant makes it necessary to consider both aspects carefully. There are two reasons for this. First, during cultivation, selection is often concentrated on a single use of the above-mentioned parts of the coriander plant. Distinct types have been created for one use, and a large variation can be expected, particularly in the characters of those parts of the plant that are of high diagnostic value in the determination of infraspecific groups. Secondly, these characters are of the greatest interest to users of plant genetic resources. The vegetative characters should be recorded when the plants start flowering, because at this stage the basal leaves are completely developed, and shortly after that they start to wither. A further group of important characters are the phenological ones: these describe the length of the different phases of ontogenesis in the plant.

The characters no. 1 to 15 listed in Table 7 should be considered essential for characterization work and the primary evaluation of coriander, for a true assessment of its diversity. Examples of leaf variation are provided in Fig. 10. A fourth group of important characters to be considered are those related to the biochemical composition of the plant, such as the essential and the fatty oil content of the fruits (see characters 16 to 19 in Table 7). These characters are important for breeding programmes, and are appraised through secondary evaluation. The same is true for the results of screenings for resistance against diseases.

6.3 Variation and geographic distribution of important characters

The ongoing project at the Gatersleben Genebank focuses on the description of the diversity of coriander and has the objective of creating a sound infraspecific classification. For this reason, all the morphological and chronological characters listed in Table 7, and some others that showed themselves to be less important, have been noted for all accessions of the collection in the years 1994-95. The content and the components of the essential and the fatty oil were also investigated (Tables 3 and 4). The results of the year 1995 only are considered in the present description of diversity. This excludes the climatic and other environmental influences that affect the expression of the characters. These environmental influences and the final results of the three years of observations and experiments will be discussed in a later publication (Diederichsen, in preparation).

The weather during the vegetation period in the experimental year 1995 started with a relatively cold April (mean temperature: 8.6°C), May (11.9°C) and June (14.8°C), while July (20.2°C) and August (18.8°C) were hot months. The sum of average temperatures higher than 4°C of the days from sowing (7 April) to harvesting of the latest accessions (22 August) was 2143°C. The rainfall of 211 mm was evenly spread over the months of the vegetation period, but was concentrated in a few rainy days. The climatic conditions during the growing season of 1995 in Germany were extremely favourable for the cultivation of coriander, and the trials therefore produced exceptionally high essential oil yields.

All accessions were grown in the same experimental field without replications. The soil at Gatersleben is a very fertile chernozem-like alluvial soil. The chemical analyses of the essential and fatty oils were performed in Göttingen by gas liquid chromatography as described by Thies (1993, 1994). The fatty oil content was measured by near-infrared spectroscopy (Tillmann and Reinhardt 1994).

The 15 important characters listed in Table 7 will be discussed according to their ranges of variation and their geographic distribution. For the description of the variation of the species, all 237 accessions listed in Table 6 are considered, but only the 186 accessions with known geographic origin documented in the passport data are included in the geographic discussion. Nearly all areas in which coriander is cultivated are represented, and it is therefore possible to discuss this point too. Further comments on the genetic behaviour of single traits are added from the literature and from the author's own experiments.

Table 8 summarizes the results of the investigation. Statistical analysis indicated that the values of the character expressions do not follow a normal statistical distribution, but show significant skewness and kurtosis. Therefore, the parameters of standard deviation (SD) and coefficient of variation (CV) are not used here. For the characters described by the numerical scale from 1 to 9, even the arithmetical mean value cannot be used without problems. The variation is therefore more

Table 8. Ranges of variation (min., max.), lower quantile value ($x_{0.25}$), central value ($x_{0.50}$) and upper quantile value ($x_{0.75}$) for important characters of coriander (n=237)

No.	Character	min.	$x_{0.25}$	$x_{0.5}$	$x_{0.75}$	max.
1	Number of basal leaves*	1	2	3	4	>10
2	Length of the longest basal leaf (cm)	5	9	13	17	30
3	Habitus of the basal leaves	1	3	4	5	6
4	Blade shape of the longest basal leaves	1	3	3	3	6
5	Blade shape of the upper stem leaves	4	5	5	6	7
6	Foliation of the plant	1	4	5	7	8
7	Plant height (cm)	20	55	75	90	130
8	Branching of the plant	1	4	6	7	9
9	Anthocyan in the petals	1	3	3	3	5
10	Shape of the fruits	1	2	2	3	6
11	Weight of 1000 fruits (g)	4.3	8.2	9.6	12.5	20.0
12	Number of days until stem elongation	43	43	55	62	77
13	Number of days until start of flowering	64	73	80	82	88
14	Number of days until end of flowering	99	103	108	110	123
15	Number of days until harvesting	109	110	123	123	137
16	Essential oil content of the air-dried fruits (%)	0.03	0.36	0.55	0.91	2.60
17	Linalool in the essential oil (%)	19.8	63.9	68.2	72.2	82.0
18	Fatty oil content of the air dried fruits (%)**	9.9	13.5	15.7	17.8	27.7
19	Petroselinic acid of all fatty acids (%)**	54.6	67.7	69.2	70.6	75.7

* The basal leaves were counted if there were less than 10; accessions with more basal leaves were assigned the number 10.

** Investigation carried out in 1994; n=76.

correctly described by the statistical parameters listed below:

min.=minimum, or the lowest value observed

$x_{0.25}$=the lower quantile value; 25% of the observed accessions have a lower value of expression than the named value

$x_{0.50}$=the central value or median; 50% of the observed accessions have a lower and 50% of the accessions a higher value of expression than the named value

$x_{0.75}$=the upper quantile value; 75% of the observed accessions have a lower value of expression than the named value

max.=maximum, or the highest value observed.

The values of the lower and upper quantiles indicate the range of variation of the respective character, which includes 50% of the observed accessions. If the distance between $x_{0.25}$ and the minimum or $x_{0,75}$ and the maxium values respectively is large, this indicates that there are some accessions with extremely low or high values of expression of the character under discussion. The coefficient of correlation (r) between all observed characters has been calculated. This coefficient will be mentioned in the following discussion only, if P=0.01.

Figure 6 presents the diversity of some selected characters of coriander graphically, using the parameters named above.

6.3.1 Variation of the vegetative parts

Accessions of different origin possess very characteristic vegetative parts. Since the use of coriander as herb or spice is the most neglected use of coriander, this group of characters is of particular interest, but has rarely been noted in the literature. Many accessions have only one leaf at the stem base. Most of the accessions have from two to four basal leaves, which form a rosette. As Figure 6 shows, the distribution of the accessions according to this character is highly asymmetric, and there are a few accessions forming enormous rosettes with more than 10 leaves. This character is most apparent and needs to be discussed in detail.

A large number of basal leaves is positively correlated with long basal leaves (r=0.701), basal leaves that are twice or more times pinnate (r=0.687), plants with a high degree of foliation (r=0.601), plants with many branches (r=0.705), high plants (r=0.622), and a long period of time until elongation of the stem (r=0.751) and end of flowering (r=0.653). A large number of basal leaves is negatively correlated with the weight of 1000 fruits (r=–0.466) and slightly negatively correlated with the linalool content of the essential oil (r=–0.374). Given its many significant correlations with other characters, the number of basal leaves of an accession, which is very easy to determine, clearly furnishes much valuable information about its other properties.

The environment has some effect on the number of basal leaves on a plant, but accessions with one or two basal leaves did not grow more basal leaves when exposed to different environmental influences. This could be seen when accessions were grown in greenhouses at Gatersleben. Those accessions with more than three basal leaves, i.e. plants with a lengthened juvenile stage, will form additional basal leaves, provided the weather conditions do not accelerate ontogenesis.

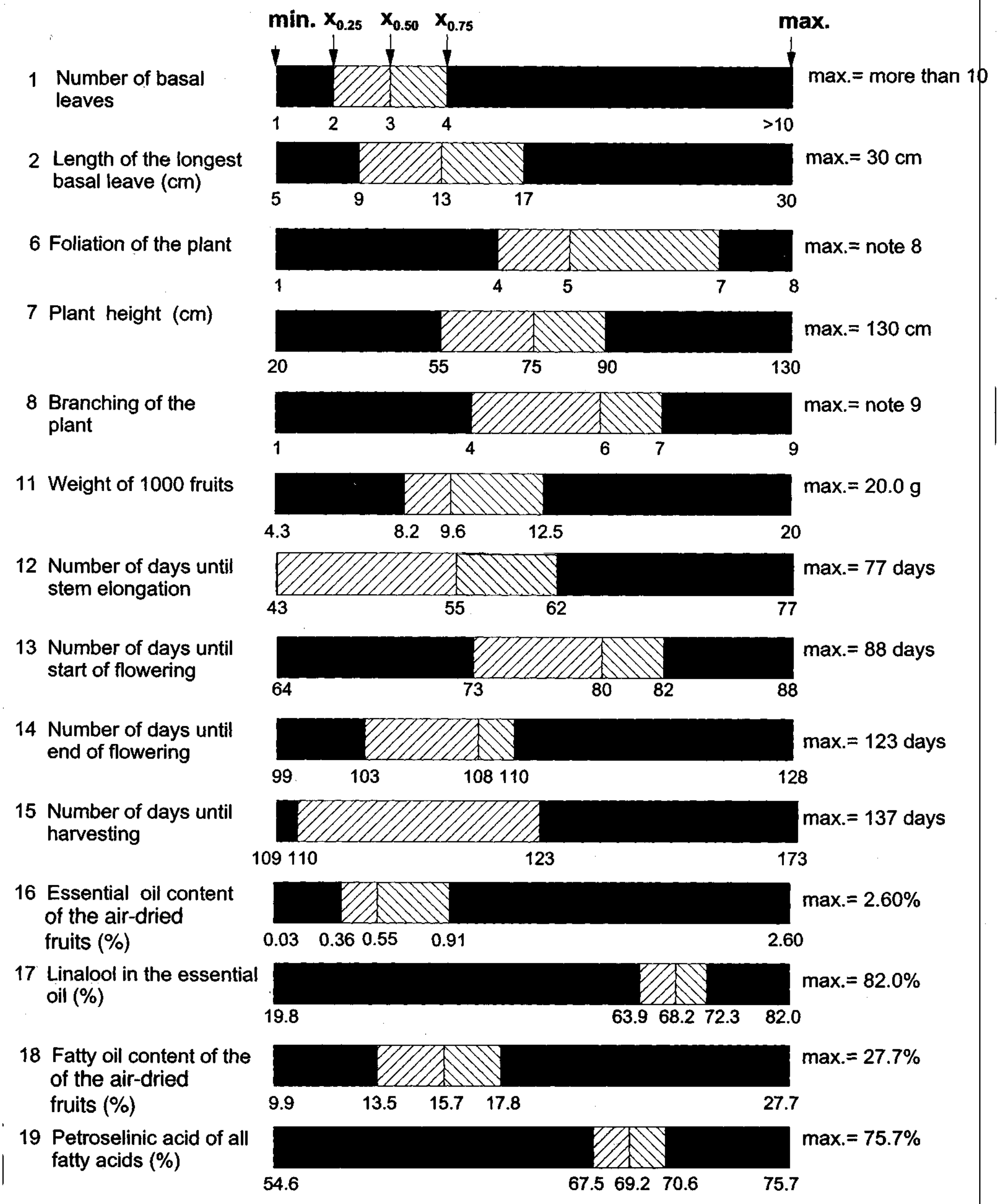

Fig. 6. Range of variation (min., max.), lower quantile value ($x_{0.25}$), central value ($x_{0.50}$) and upper quantile value ($x_{0.75}$) for some important characters of coriander (n=237;for Nos. 18 and 19, n=176).

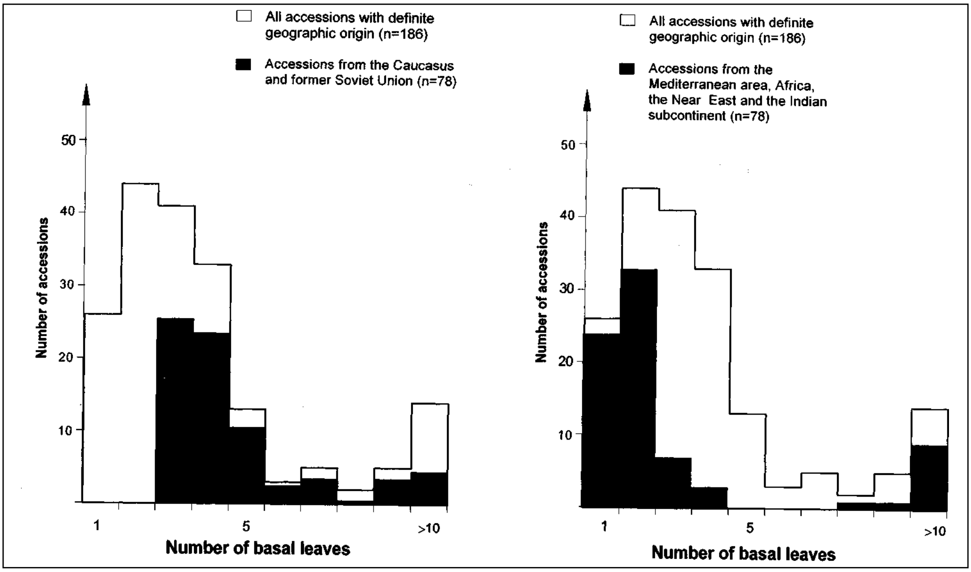

Fig. 7. Histograms for the geographic distribution of the character 'number of basal leaves'.

The accessions with few rosette leaves have their geographic origin in the Mediterranean countries, Africa, the Near East and the Indian subcontinent. The histograms in Figure 7 indicate that the group with less than two basal leaves is almost entirely made up of the accessions originating in these areas. But Figure 7 also shows that this geographic group contains some accessions with very well-developed rosettes, and even the extreme types with more than ten basal leaves. These latter accessions are the very distinct types of coriander that can be found in Ethiopia and Syria, respectively.

The Ethiopian types have well-developed rosettes of from four to nine basal leaves of characteristic shape (Fig. 10.2). The heterophylly is only slightly expressed, and the plants have many leaves and are very branched. There exist extreme, characteristic Syrian types that have up to 25 basal leaves and form very large rosettes (Fig. 11b). The shape of the rosette leaves of these types is also characteristic (Fig. 10.2) and the rosette leaves are not prostrate but upraised and curving. Habitus and the shape are important when distinguishing these accessions from the Central Asian types of coriander, which also form enormous rosettes, but whose leaves are completely prostrate and have a different shape (Fig. 10.2). In Syria, both extreme types of foliation of the stem base can be found: plants with only one basal leaf (Fig. 10.1) and plants with more than ten basal leaves. This is an example of disruptive selection in very different types of a cultivated plant in one area.

Figure 8 shows a young plant of Syrian origin in a juvenile stage. The number of basal leaves has not reached the final number, but at this stage the plants are used as a vegetable, and the production of green mass by these types is enormous. This becomes particularly clear if the plant in Figure 8 is compared with that in Figure 9,

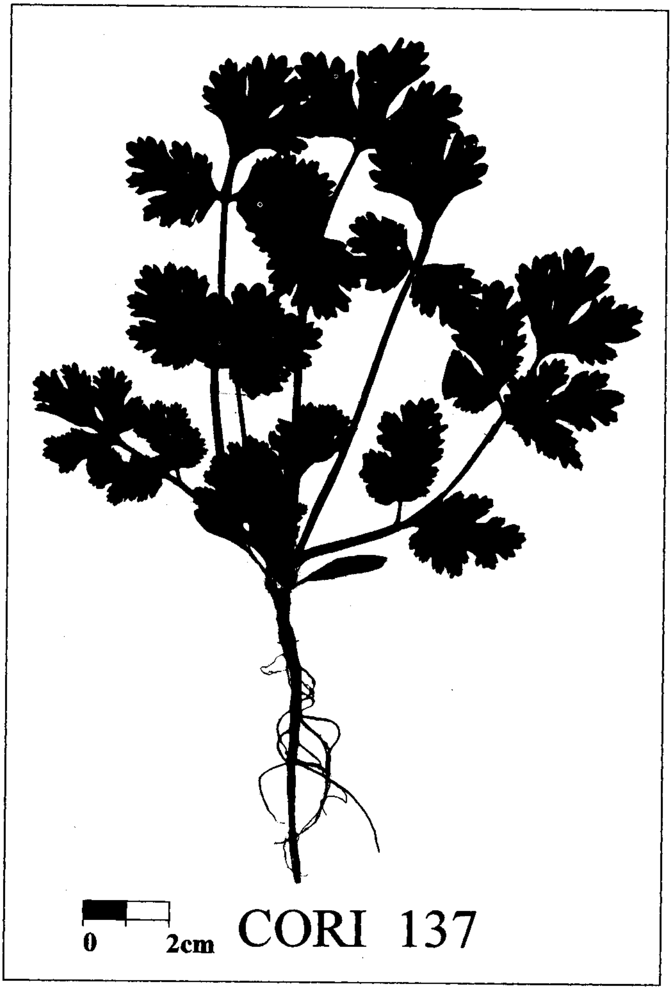

Fig. 8. Coriander: young plant with many basal leaves (CORI 137, origin: Syria).

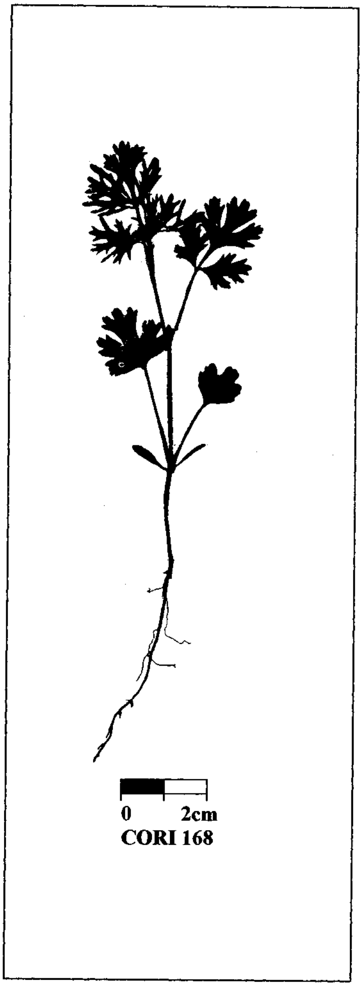

Fig. 9. (Right) Coriander: young plant with few basal leaves (CORI 168, origin: Algeria).

which has its origin in Algeria and forms a typical example of coriander of Near Eastern and Mediterranean origin, with just two basal leaves.

Figures 7 and 11c also show that the accessions from the Caucasus and the former Soviet Union always form rosettes consisting of at least three basal leaves. Nearly all accessions forming rosettes originate in this area, with the exceptions of Ethiopia and Syria, as mentioned above. In this group, the types with eight, nine or more than ten remarkable prostrate basal leaves have their origin in Armenia, Georgia, Daghestan, and in the Central Asian states of Kasachstan and Kirgysia. These accessions form a special group. But most accessions of Georgian origin only have from three up to five basal leaves which are not prostrate. Figure 14 summarizes the geographic distribution of the character 'number of basal leaves'.

The length of the longest basal leaf is closely correlated with the number of basal leaves (*r*=0.701). Therefore, the two columns for these characters in Figure 6 look very similar; the distribution is asymmetric, and some accessions have very long basal leaves. If there are just one or two basal leaves, these are only longer than 10 cm in a small number of cases. Plants that form rosettes of at least three leaves always have basal leaves which are longer than 10 cm, and in the extreme Syrian types, the basal leaves can exceed 20 cm.

As stated above, environment affects the length of the basal leaves: if the individual plants have a lot of space, and/or a lengthened juvenile period caused by cold weather, they produce longer basal leaves. Light reduces the length of the basal leaves. The wide range of variability of this character (from 5 to 30 cm) makes it noteworthy, and length of basal leaf can be used to determine the geographical area of origin for plants grown under the same conditions.

The habitus of the basal leaves is usually more or less the same for all accessions. Accessions from Central Asia and the Caucasian areas have very prostrate basal leaves with large and conspicuous rosettes (Fig. 11c). The prostrate habit of the rosette is very apparent in these accessions, and can be used to distinguish them from the Syrian type(s) (Fig. 11b). This feature should be included in the characterization of coriander. According to Sil'čenko (1981), the formation of a prostrate rosette is a monogenic and recessive character, and plants with prostrate rosette leaves possess high frost resistance (Romanenko *et al.* 1990a). This makes them suitable for autumn sowing. If the rosette is flattened, the vegetative cone is beneath the earth, and therefore has better protection against low temperatures (Romanenko *et al.* 1991).

The blade shape of the basal leaf was always noted from the longest basal leaf of the plant formed, and proved to be a very characteristic trait. Table 8 shows that at least 50% of the accessions received the number 3 on the scale suggested in Table 7. That means that their longest basal leaf has a blade shape that is once pinnate, with three or five leaflets. But in this case too, it is interesting to note the extreme expression of the character in both directions, which can easily be distinguished. Figure 10 presents examples of basal leaves of coriander.

A high degree to which the longest basal leaf is pinnate is correlated with a high number of basal leaves (*r*=0.687), the length of the leaf (*r*=0.655), a high degree of foliation (*r*=0.733), plants with many branches (*r*=0.769), the height of the plants (*r*=0.830) and plants which flower and ripen relatively late.

Basal leaves that are only lobed, i.e. that were assigned the number 1 or 2, are found almost exclusively on plants that have just one or two basal leaves. A typical example is contained in Figure 9. The weight of 1000 fruits of these accessions is usually higher than 10 g (e.g. 13.4 g for the Algerian accession shown in Figure 9).

The blade shape of leaves inserted in the middle of the stem (see character no. 5 in Table 8) does not exhibit as wide a range of variation as that of the basal leaves, but this character has some important aspects too. The plants which originate in the Caucasus and other parts of the former Soviet Union have a heterophylly which develops more or less continuously from the stem base, with leaves once pinnate to

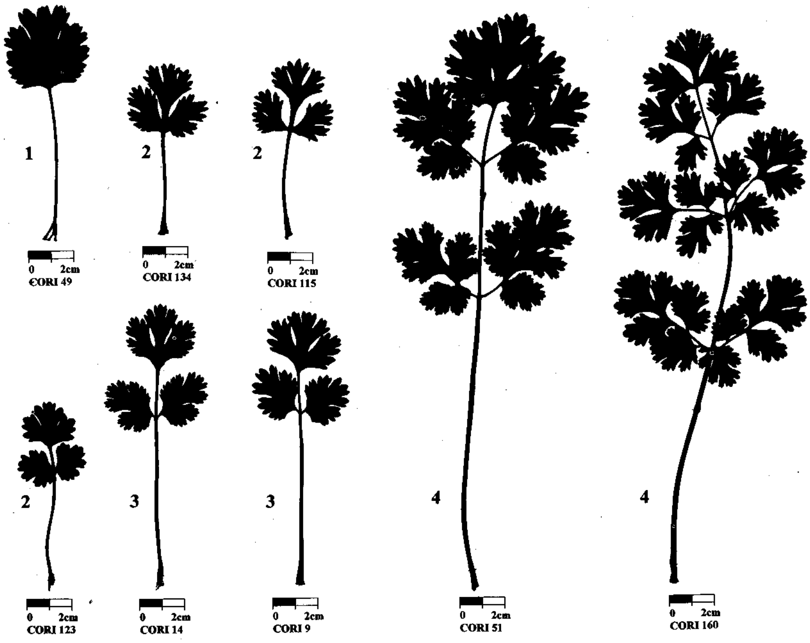

Fig. 10.1. The longest basal leaf of different coriander accessions: the numbers beside the blades are those contained in the key for the character ‘blade shape of the longest basal leaf’ set out in Table 7 (CORI 49, origin: Spain; CORI 134, origin: Syria; CORI 115, origin: Sudan; CORI 123, origin: Bhutan; CORI 14, origin: Germany; CORI 9, origin: China; CORI 51, origin: Georgia; CORI 160, origin: Kasachstan).

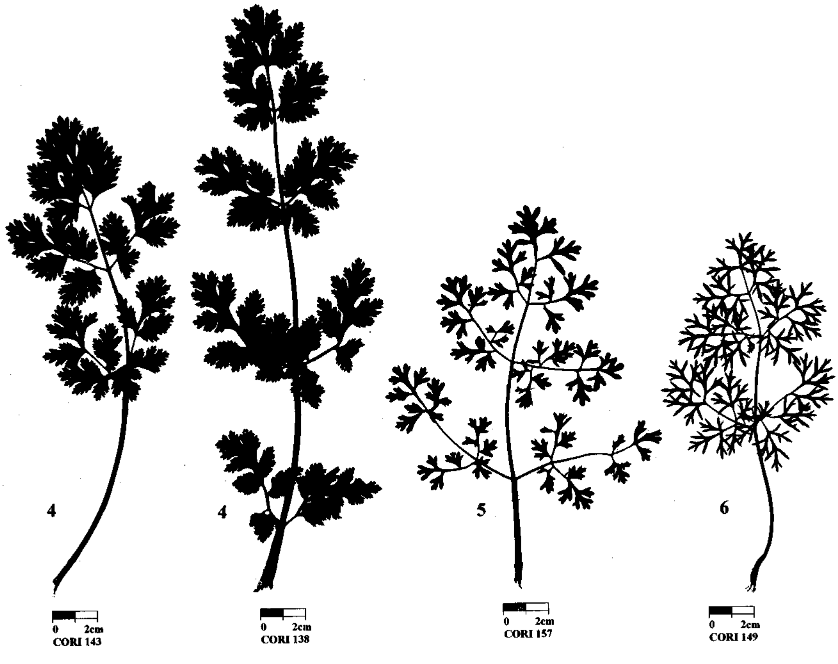

Fig. 10.2. The longest basal leaf of different coriander accessions: the numbers beside the blades are those contained in the key for the character ‘blade shape of the longest basal leaf’ set out in Table 7 (CORI 143, origin: Ethiopia; CORI 138, origin: Syria; CORI 157, origin: Kasachstan; CORI 149, origin: Belorussia).

sessile, twice or more times, and pinnate leaves with filiform-shaped parts at the top of the plant (Fig. 3). Those plants with more than ten basal leaves show a rosette whose development ranges from more or less lobed leaves to leaves that are pinnate to a high degree. The leaves of the next node, according to the general rule observed in coriander, are pinnate to a higher degree.

The plants that have their origin in the Mediterranean area, the Near East and the Indian subcontinent, and which have one or two lobed, or once pinnate basal leaves, have leaves at the next node that are pinnate to a high degree, and often have lance-shaped parts (Figs. 1 and 9). The different-shaped leaves of the upper nodes appear suddenly, but even at the top of the plant, these accessions do not acquire the extremely minute and filiform-shaped blade which can be found in the former group (plants with more than three basal leaves).

Figure 10.2 shows one extreme type of a pinnate basal leaf, which belongs to a landrace originating in Belorussia. A landrace of coriander with basal leaves of this type was also found in eastern Kasachstan (Girenko, 1995, pers. comm.). Basal leaves of this type are connected to one dominant gene (Sil'čenko 1981). Crossing experiments at Gatersleben showed that this character can be used as a morphological marker in coriander breeding. The Soviet breeding variety 'Tminovidnyi', or 'carvey-like', has basal leaves of this type and Glusčenko (1963, 1972; Glusčenko and Sil'čenko 1973) produced a graft hybrid with carvey (*Carum carvi* L.). It seems more probable that the independent occurrence of this monogenic character at geographically remote locations is due to spontaneous mutation towards the dominant allele rather than this breeding technique, however.

The foliation of the plant has an asymmetric distribution in the studied group, and there are some accessions that have extremely few leaves (Fig. 1). This character shows the same geographic distribution as the length of the longest basal leaves, with which it is closely correlated (r=0.733). Thus, plants with many leaves, which can be called 'leafy types', have a basal rosette with long basal leaves.

The height of the flowering plant shows a wide range of variation from 20 to 130 cm. The character has a symmetric distribution in the genepool studied. The shortest accessions have their origin in North Africa. One extreme type has been observed from Egypt (CORI 26), which can be called a dwarf form. It only reaches a height of 20 cm and the fruits are small (weight of 1000 fruits=8.9 g). The height of the plant is thus negatively correlated with the weight of 1000 fruits (r=–0.519). Morever, the North African types are usually short and have large fruits. The plants with long stems are typical of the Caucasian area, but the leafy types from Syria and Central Asia mentioned above also have long stems (Figs. 11b and 11c). The heritability (h^2) of this character, 81.7%, is high (Diederichsen and Hammer 1994). Sil'čenko (1973) gives a lower figure of 47-76%.

The branching of the plant is very strongly correlated with its height (r=0.829). Since every branch of the plant terminates in a flower, this character can also be interpreted as the number of umbels per plant. A high number of branches or umbels is positively correlated with a high plant yield (r=0.785). Those plants with

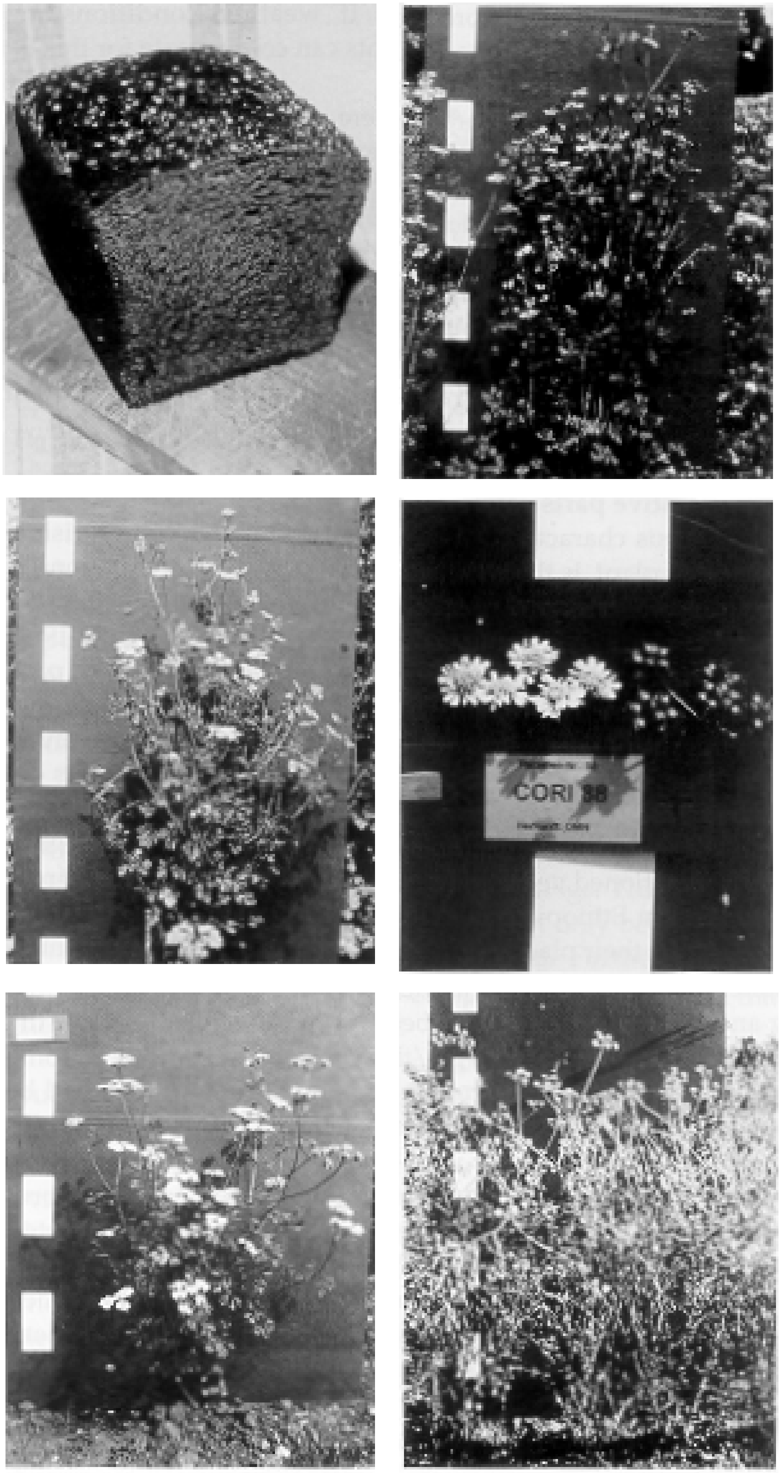

Fig. 11. (a) ‘Borodinskij chleb’; (b) growth habit of Syrian type; (c) growth habit of Caucasian type; (d) flowers of Near Eastern type; (e) growth habit of Near Eastern type; (f) mature plant.

many umbels produce more fruits. Moreover, if weather conditions are unfavourable during the flowering period, these plants can compensate for this by forming umbels over a longer period of time.

The root also belongs to the vegetative parts. There are reports from China on the use of the roots, which are aromatic, because they also contain channels with essential oil. The characters of the roots have not been studied at Gatersleben, but it was obvious that the plants with many basal leaves sometimes reach a diameter of more than 2 cm at the stem base, and that they have a well-developed tap root. The plants with few leaves have a tiny stem and tap root. The discussion of those characters concerning the vegetative parts of the plant showed that they can be used to clearly group all the accessions studied. Moreover such grouping by these characters is a very good indicator of the plants' geographic origin, and are very important for the proposed infraspecific grouping of coriander set out in Box 1.

6.3.2 Variation of the generative parts

The first and very conspicuous character of this category, which becomes visible during the ontogenesis of the plant, is the colour of the petals. The observations at Gatersleben showed that this character is very much influenced by the environmental conditions. In 1994, a year with less favourable weather conditions than 1995, the petals of several accessions contained so much anthocyans that they looked pink or even violet. Diseased plants in particular showed more anthocyans in the flowers, as well as in the stems and leaf sheaths. The ability to synthesize anthocyans is obviously caused by the same gene, and to some degree is strengthened in its expression by environmental or physiological stress, as it is known in many other plants. Nevertheless, some accessions did not contain any anthocyans in the organs of the flower or in the forementioned vegetative parts. These were a landrace from China and three landraces from Ethiopia. In Table 8**,** these accessions received the number 1 for this character. At their places of origin there must have been an interest in selecting to create populations with completely white flowers. Individual plants not containing any anthocyans also have been found in landraces from the Sudan, Algeria, Egypt, Oman, Spain and Georgia / the Caucasus, as well as in some accessions from botanical gardens. These single plants were isolated and will be used to establish new populations with white flowers, which can be used for pollination experiments.

Crossing experiments at Gatersleben showed that the ability of coriander to form anthocyans is due to one dominant gene, as Romanenko (1990) had already noted for the petals of the plant. The mutation towards the recessive state, which causes white flowers, may have happened spontaneously and independently at the named locations of origin. The character can be used as a morphological marker in coriander breeding, and can be evaluated before the plants flower. As mentioned, anthocyans are also visible in other parts of the plant and appear during the period of ripening in particular. At this stage, some accessions have dark-coloured stems

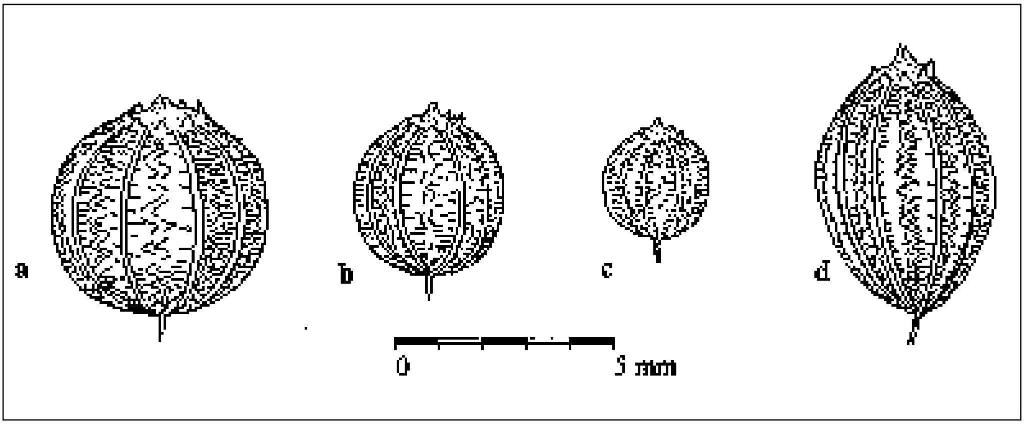

Fig. 12. Size and shape of the fruits of coriander: (a) Near Eastern type; (b) Ethiopian type; (c) Caucasian type; (d) Indian type. (After Ivanova and Stoletova 1990).

and fruits. Ivanova and Stoletova (1990) used this character for the infraspecific differentiation of coriander, but the differences in colour are gradual, with the exception of the easily distinguished populations that do not contain any anthocyans. The completely ripe fruits of accessions with a lot of anthocyans in the fruits also had a relatively dark brown colour. However, this character is difficult to judge, because the fungal infection *Alternaria* causes dark fruits too.

The size of the petals also shows some variation. In general, the types with large fruits have larger petals too. The accessions originating in Oman have flowers in the peripheral positions of the umbellets, with very lengthened petals towards the outside, of an almost ornamental nature (Figs. 11d and 11e). The flowers of this group of origin are more conspicuous, not only because of their size, but also because of the limited foliation of these plants. Furthermore, the relation between the flowers and vegetative parts is completely different from that in the leafy types of the Caucasus and Central Asia.

The fruits of coriander vary not only in size, but also in shape. Figure 12 shows fruits of different sizes and shapes. Table 8 and Figure 6 show that nearly all accessions have more or less round fruits: 75% of the accessions received a number between 1 and 3. Of interest are the extreme types, i.e. the accessions with lengthened, ovate fruits, which were assigned the numbers 5 and 6 respectively. These accessions originated exclusively in the Indian subcontinent, i.e. India and Pakistan. The seven accessions originating in Bhutan, on the other hand, had very round fruits. These seemed to be related to the Near Eastern types, which always have completely globular fruits that are sometimes flattened to some degree. Ovate coriander fruits have also been reported in Morocco (Hegi 1926). There were no accessions from Morocco available for this study, but coriander fruits sold in Germany as a spice and declared as a product of Morocco were very ovate. Ovate fruits were also reported in North Africa by Ivanova and Stoletova (1990). They used this character to distinguish a subspecies, *indicum* Stolet. Plants of this origin have only one or two basal leaves, a low degree of foliation and a short vegetation period. Their fruits are lengthened, but the weight of 1000 fruits falls within the range of variation located in the middle of the distribution (8.2-12.5 g). The plant presented in Figure 1 is typical of this geographic group.

The weight of 1000 fruits is a character of great agronomic importance. It has a wide range of variation. A Georgian accession had the smallest fruits, with a weight of 1000 fruits of 4.3 g. In 1994, a year with unfavourable weather conditions, the same accessions had a minimum weight of 2.5 g/1000 fruits. The largest fruits had a weight of 20 g/1000 fruits. Figure 6 shows that in the genepool studied, large fruits are more exceptional, and 75% of the accessions had a weight of 1000 fruits lower than 12.5 g. The positive correlation between size, i.e. diameter, and weight of the fruits (r=0.92) has been reported (Diederichsen and Hammer 1994). The weight of the fruits is negatively correlated with the following characters: number of basal leaves (r=–0.466); length of the longest basal leaf (r=–0.459); the degree to which the longest basal leaf (r=–0.460) and the upper stem leaves (r=–0.357) are pinnate; foliation of the plant (r=–0.435); branching of the plant (r=–0.580); height of the plant (r=–0.519); essential oil content (r=–0.423); fatty oil content (r=–0.414, investigated in 1994), and length of the vegetation period.

The type of coriander with large fruits always has only one, two, or occasionally

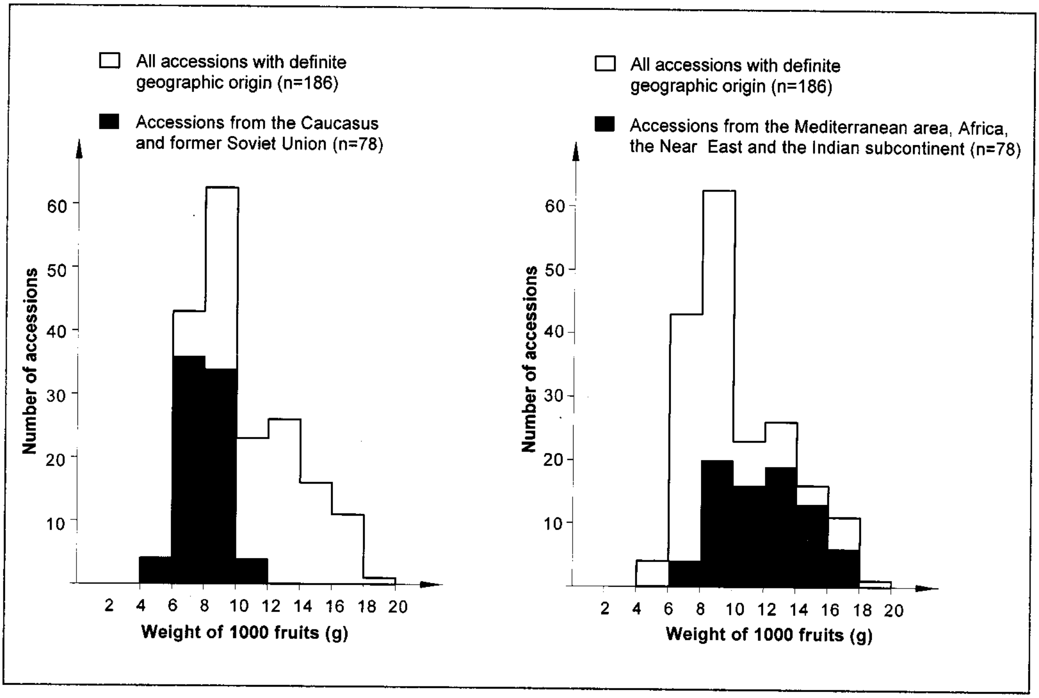

Fig. 13. Histograms for the geographic distribution of the character 'weight of 1000 fruits'.

Table 9. Weight (in g/1000 fruits) of the fruits of coriander in different umbels of the same plant

Character	Accession no./origin:	
	CORI 186/Germany	CORI 194/Chile
random sample	8.00	15.6
primary umbels	9.2	18.1
umbels of last order	6.5	13.2
Difference: primary umbel – umbel of last order	2.7	4.9

three basal leaves which are not pinnate to a high degree. The vegetation period is usually relatively short. Geographically, the distribution of the accessions according to this character is very similar to that of the number of basal leaves (see Figs. 7 and 13). Coriander of different origin from the two groups mentioned above usually has fruits of medium size, but the accessions from the Americas have large fruits too. Figure 14 summarizes the geographic distribution of the character 'weight of 1000 fruits'.

Weight of the fruits is an important trait and should be recorded for all accessions in *ex situ* collections. It should be noted that the weight of the single fruits of one plant is dependent on the relative position of the umbel from which these fruits are taken. The primary umbels produce the largest fruits, while the umbels of higher order have smaller fruits, and the difference is a notable one. Table 9 shows that this difference in fruit weight is about one-third of the mean fruit weight in those types of the plant with small fruits (var. *microcarpum*, e.g. accession CORI 186 from Germany) and also in types with large fruits (var. *sativum*, e.g. accession CORI 194 from Chile), and is important to notice for agronomic reasons. If the plants are sown with wide distances, the number of higher-order umbels will increase, because the plants will produce more branches. If the plants have less space, the branching is reduced and there are more primary umbels contributing to the harvested fruits.

The low essential and fatty oil content of the accessions with large fruits is noteworthy. These accessions originate in areas with a subtropical climate. That these accessions have a short juvenile stage seems to be due to their adaptation to arid environments. The primary umbel of accessions with this origin usually finishes flowering quickly. The vegetative parts of these plants do not have the plasticity of the leafy types of different origin, and the leaves are often largely concealed by the flowers.

The agronomic importance of the weight of the fruits and the correlation with many other characters justify classification by the infraspecific taxa var. *microcarpum* and var. *sativum* described above (Section 6.1).

The tendency of the plants to shatter the fruits, and the tendency of the fruits themselves to split into mericarps, is different in the accessions too. The observations at Gatersleben showed that these differences are difficult to judge. A few accessions have fruits with a tendency to split very easily. This character was used by Stoletova (1931) and Ivanova and Stoletova (1990) for the infraspecific differentiation between the groups that they named. Further observations need to be made to clarify the variation of this agronomically important trait which is also of interest for research in the evolution of coriander. Shattering or splitting of fruits is a typical weedy character and is unwelcome in cultivated plants. Popovcev (1973) showed that the tendency of genotypes to possess this weedy character can be detected from the anatomical structure of the stems of young plants with four nodes. This is important to the agronomic improvement of coriander by selection and breeding.

6.3.3 Variation of the phenological characters

The phenological characters of the plant are important for agronomic purposes. All the noted phenological characters are positively correlated with each other and are therefore discussed together. Number of days until stem elongation shows the widest range of variation. Plants with few basal leaves have a short juvenile period, and the stems become visible 42 days after sowing. The accessions forming large rosettes needed 33 more days until the stems became visible. In 1994, a summer that was cooler at the beginning than that of 1995, the difference was as great as 43 days. The extremely late types are the Syrian, Caucasian, Central Asian and Ethiopian accessions with large rosettes. If it is taken into account that the emergence of the plants forming rosettes was on average several days earlier than of the accessions with few basal leaves and large fruits, the difference between the accessions is even more striking.

The effect of the high degree of branching of these plants is that many flowers are formed and the flowering period is lengthened. The highest-order umbels of these plants are still flowering when the primary umbel is ripe. This is a problem when deciding when to harvest. The expression of the phenological characters is highly dependent on environmental influences. Plants sown at the end of September 1994 could be harvested only 10 days earlier than the same accessions sown at the beginning of April 1995. Plants grown in greenhouses during the summer without artificial illumination, where temperatures were higher than outside, had a considerably prolonged period of vegetation, due to reduced light intensity. This behaviour shows that the amount of light as well as high temperatures are critical for the successful production of coriander fruits.

6.3.4 Chemical composition of the fruits

The essential oil content is of greatest importance, and Table 8 and Figure 6 show that there are accessions that have almost no essential oil and others with up to 2.60% of essential oil in the air-dried fruits. The extremely leafy types from Syria have a very low essential oil content in the fruits. Despite this, the essential oil content is positively correlated with the foliation of the plant (r=0.348). A high essential oil content of was found in all accessions from the Caucasus.

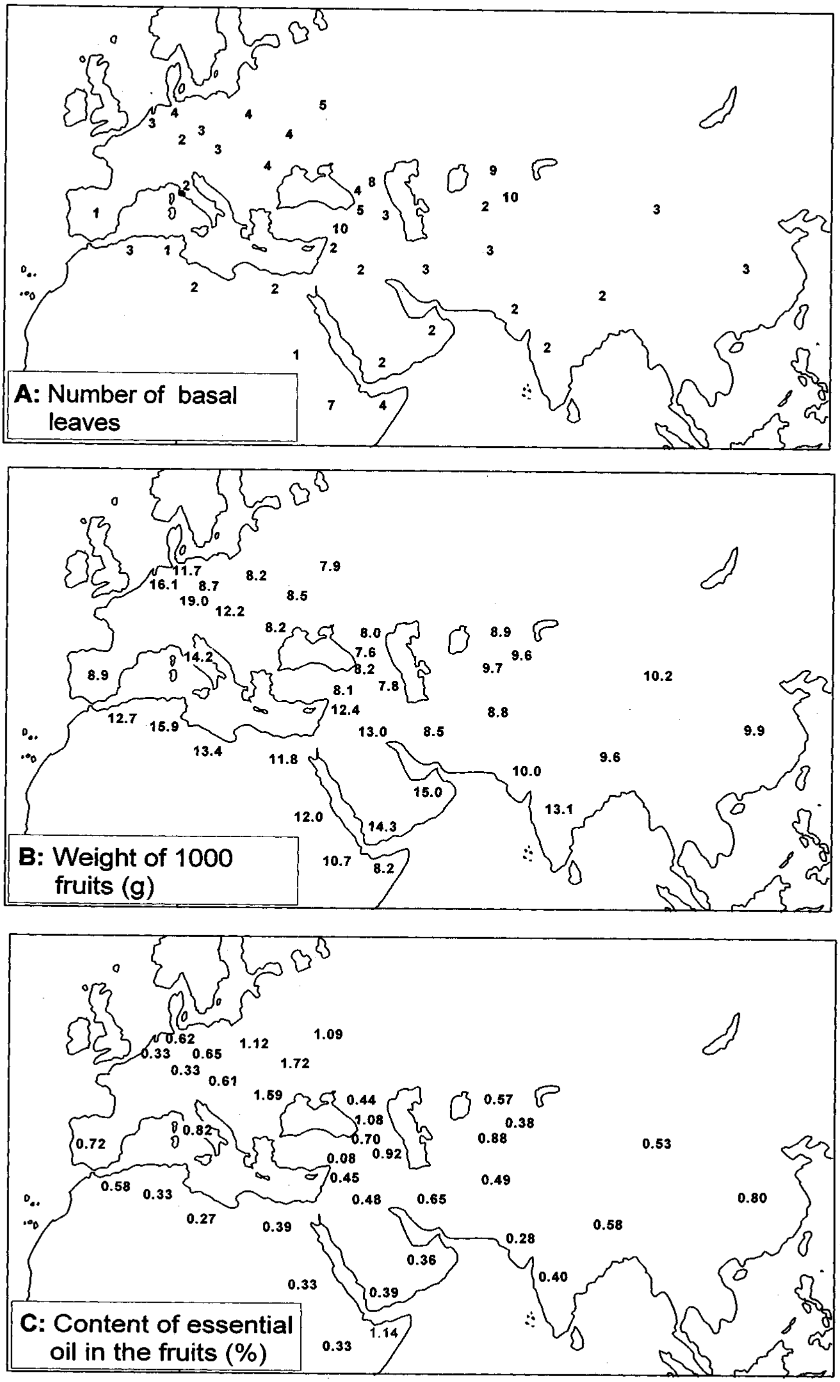

Fig. 14. Geographic distribution of important characters of coriander. A: number of basal leaves; B: weight of 1000 fruits (g); C: content of essential oil in the fruits (%). Mean values refer to coriander originating in the countries listed in Table 6.

The taste of the green leaves of the plant was more aromatic in the accessions that had a high essential oil content in the fruits. The Georgian types had leaves with a very spicy taste. The Syrian types must have been subject to a selection towards plants with a mild taste more suited to use in salads than as a spice. The Ethiopian accessions show the same tendency as the Syrian, but their flavour is more aromatic.

Usually, the plants with low foliation and large fruits have a low essential oil content. The Indian group with the lengthened fruits also belongs in this category. This fact has been known and described in literature for a long time (e.g. Luzina and Michelsson 1937). But the chemical composition of the essential oil of the plant is also important, as it affects its flavour. The organoleptic differences between coriander plants of different origin have been described by Purseglove *et al.* (1981). The linalool content of the essential oil does not show much variation. All accessions with less than 50% linalool in the essential oil belong to the Syrian leafy types. By this character, as well as by the low essential oil content, accessions can be clearly distinguished chemotaxononically. A further chemotaxonomical characteristic is that the relative content of α-pinene is high in these Syrian types. The coriander originating from the Caucasus and the former Soviet Union always has a relatively high linalool content, as has already been stated by Girenko *et al.* (1985).

Camphor is regarded as an unwelcome component of the essential oil. Its content in the accessions was 0-6.3% of the essential oil. The accessions originating in the Indian subcontinent always had a low camphor content, and this was invariably correlated with a low limonen content (*r*=0.873). The accessions from the Caucasus and former Soviet Union always contained both components, which together comprised up to 10% of the essential oil. These and some other correlations are also discussed by Černodubov and Berestovaja (1986).

Figure 14 summarizes the geographic distribution of the character ‘essential oil content of the fruits’. During the growing period, this character is particularly affected by climatic conditions. In 1994, a cooler summer than 1995, the maximum value for the essential oil content was only 1.02%. The mean value for the essential oil content of the fruits of the 176 accessions analyzed in 1994 was a mere 0.27%. If these figures are compared with the results of 1995 (Fig. 6), it is apparent that the climate during the growing season has an enormous influence on this character. Nevertheless, accessions with high essential oil content in 1994 also had a high essential oil content in 1995, and *vice versa*. Such behaviour was also reported by Ivanov *et al.* (1929).

The fatty oil content had a wide range of variation, and extremely high values of up to 27.7% were found in the leafy Syrian types. In general, the leafy types of coriander from the Caucasus had a high fatty oil content. The accessions of Mediterranean, African, Near Eastern and Indian origin, on the other hand, showed themselves not to be a homogeneous group with respect to this character. The composition of the fatty acids is quite constant in all accessions. Petroselinic acid is always the principal component, but the accessions with large fruits tend to have more petroselinic acid in their fatty oil than the others.

The chemotaxonomical variation of coriander will be further investigated in Gatersleben.

6.4 A key for the determination of ecogeographical types of coriander

The fact that 186 accessions of the collection studied have a known origin recorded in the relevant passport data is fundamental to the geographic interpretation and the understanding of the evolution of coriander. It became obvious that some characters are particularly suitable for distinguishing geographic groups of coriander. Three of them are of special agronomic and taxonomic interest: (i) number of basal leaves; (ii) weight of 1000 fruits, and (iii) essential oil content of the fruits. Figure 14 presents the geographic distribution of these characters for the 178 accessions from the Old World with known geographic origin (Table 6).

The observations presented in this study need further discussion, also with respect to the domestication of coriander. This publication concentrates on presenting the diversity of the species, as this provides fundamental information for plant genetic resources work, as well as for plant breeding and molecular research. Further interpretation of these results awaits a later date. One conclusion which may be drawn is that the characters of the coriander leaves are of the greatest importance for infraspecific groupings. The leaves appear to differ in shape, size and flavour, and the foliation of the plants also differs. The leaf should be regarded as a very characteristic part of the coriander plant, whose traits are also connected to several characters of the fruit. Box 1 overleaf summarizes all the foregoing observations of single characters and presents a key for the determination of ecogeographical types of coriander. Such a classification is the classical approach to plant genetic resources work begun by N.I. Vavilov (Vavilov 1992; Hanelt and Hammer 1995).

The observations presented above make the diagnostic value of the characters used for distinguishing the named types clear. By using this key, it is possible to determine the ecogeographic type to which a single plant or a population of coriander belongs, and to give this group a name. The key makes use of the characters of the vegetative parts of the plant, because they have been demonstrated to be important. These allow determination of the ecogeographic type when coriander is found in fields or gardens (e.g. during expeditions). This classification needs to be formalized according to the International Code of Botanical Nomenclature (Greuter 1994) and the key presented in Box 1 is a step in this direction. It is recognized, however, that there is some imbalance in the collection studied (see Table 6), and secondly, that the recent transfer of seeds and also modern breeding have affected coriander. Formerly isolated geographic populations can occur in areas that are distant from their origin, and they may intercross with local varieties or be used in plant breeding. The groups identified by the study are nonetheless very typical; the morphological types are named after the area in which they clearly have their centre of

Box 1. Key for the determination of geographical types of coriander

1 Plants with one, two or occasionally three basal leaves, the longest of which are lobed and once pinnate; stems not longer than 70 cm and not branched to a high degree; stems with a few leaves only; change of blade shape from the first basal leaf or leaves to the upper stem leaves is very sudden; the juvenile stage and the period until ripening are short. **2**

1* Plants with at least three basal leaves, the longest of which are once or to a higher degree pinnate; stems often longer than 70 cm, with numerous side branches with many leaves; blade shape changes continuously from the first basal leaves to the upper stem leaves; the juvenile stage and the period until ripening is long. **3**

2 Fruits round or only very slightly ovate; weight of 1000 fruits greater than 10 g; fruits have a low essential oil content. Typical of the Near East and North Africa. Also occurring in the other Mediterranean areas, in Bhutan, the Americas and Europe. **Near Eastern type**

2* Fruits conspicuously ovate; weight of 1000 fruits often less than 10 g; fruits with a very low essential oil content. Typical of the Indian subcontinent. Also occurring in Pakistan. **Indian type**

3 Plants always have more than ten basal leaves forming a rosette; the period until ripening is very long. **4**

3* Plants never have more than ten basal leaves; the period until ripening is not long. **5**

4 Basal leaves prostrate, forming a flat rosette; leaves with aromatic taste, fruits of medium size and essential-oil content; plants with a long vegetation period. Typical of the countries of Central Asia. Also occurring in Daghestan, Georgia and Armenia. **Central Asian type**

4* Basal leaves curving, ascending; leaves almost without the typical aromatic flavour of coriander; fruits relatively small and nearly without essential oil but very rich in fatty oil; plants have a long vegetation period. Typical of Syria. **Syrian type**

5 Longest basal leaf once, seldom twice pinnate, with three or five lobed leaflets; leaflets emarginate; usually less than seven basal leaves; leaves have an aromatic flavour; weight of 1000 fruits between 4-10 g; stems and flowers contain anthocyans; fruits have high essential oil content. Typical of the countries of the Caucasian area. Also occurring in Eastern Europe, Russia, Mongolia and Germany. **Caucasian type**

5* Longest basal leaf twice pinnate; margins of the leaflets sawtoothed; at least seven basal leaves; flavour of the leaves not very aromatic; weight of 1000 fruits greater than 8 g; stems and flowers without anthocyans, or anthocyans not very obvious; fruits with low essential oil content. Typical of Ethiopia. **Ethiopian type**

origin.

6.5 Variation in the wild relatives of coriander

The wild species mentioned in Table 1 have never been subject to further investigation, and the taxonomy has not even been completely clarified at the species level. Several specimens of these species are documented in the herbarium of the Botanical Institute in St. Petersburg, and some accessions of *Bifora radians* are conserved at Gatersleben. The accessions do not contain any essential oils in the ripe fruit, but the smell of the green plant is to some degree similar to that of coriander. The flavour is undeniably unpleasant, however. In Georgia / Caucasus, the weed *B. radians* is sometimes called 'dikij coriandr', which means wild coriander. Care therefore needs to be taken that the species *Bifora radians* and *Coriandrum sativum* are not confused because of this.

The essential oil of the green plant of *B. radians* was studied by Pater (1925), who mentioned that at that time it was a very common weed in his area of Czechoslovakia. The accessions at Gatersleben proved to be winterhardy. There were differences in the shape of the petals and in the type of foliation, and the plants formed rosettes with about five leaves. The fruits shatter very easily when the plant is ripe, and always split into the mericarps. The weight of 1000 mericarps was 10.9 and 14.5 g respectively in the two accessions studied in more detail. Chemical analysis showed that they did not contain any essential oil.

Kleiman and Spencer (1982) showed that *B. radians* contains 49.5% fatty oil, with petroselinic acid comprising 74.9% of all fatty acids. The same authors showed that *B. testiculata* contains 41.5% fatty oil, with petroselinic acid comprising 81.1% of all fatty acids in the fruits. This is a much higher fatty oil content than in the coriander fruits. Chemical analysis of the accessions studied at Gatersleben showed that the relative composition of the fatty acids in *B. radians* is similar to that of coriander (see Table 4). If petroselinic acid becomes a raw material of interest, these plants will perhaps become secondary cultivated plants, and no longer have the status of a weed. The fruit-yielding potential of *B. radians* is similar to that of coriander, and the shattering of the fruits needs to be tested by plant breeding programmes. It will be difficult to find the *Bifora* species in future, because chemical weeding threatens their survival. This shows that genebanks should pay attention to weeds too.

7 Conservation techniques and methods used in *ex situ* collections

This chapter will concentrate on some basic methods for coriander reproduction without losing the genetic integrity of the accessions. Since cross-fertilization of coriander is possible (see Section 2), genebank accessions need to be isolated from each other for genetically identical reproduction. Coriander is usually pollinated by many different insect species, but wind pollination of the plant can also occur. If different accessions are cultivated simultaneously in the field, and the field is large enough, isolation can be achieved by keeping a distance of at least 80 m between different accessions. Fruit-setting is very good if the weather during the flowering period is more or less sunny and warm, because this also favours the insects which stimulate the seed-setting and isolation from insects will reduce the number of fruits (Baswana 1984).

Isolation of the populations from each other in the field can also be achieved by using technical tools, such as pergamin bags, but the microclimatic conditions in these bags considerably reduce the fruit-setting. This technique was successfully used at Gatersleben when single plants from a population growing on an experimental plot had to be isolated because they manifested some special properties.

Isolation cabins provide favourable conditions for the successful reproduction of coriander populations. If there are only a few seeds available from an accession that is to be multiplied, isolation cabins are the best way to achieve this. In such cases, the fruits can be split into the two mericarps, and these should be sown in single pots, which are transferred to the isolation cabins before flowering. The cabins should contain insects, but it is also possible to use paintbrushes to replace pollinating insects.

Harvesting of the fruits should be carried out when the primary umbel is completely ripe, or not much later, because the fruits tend to shatter. Threshing needs to be done very carefully, in order that the schizocarps do not split, because otherwise the seed is exposed to mechanical damage, as the pericarp is pellicular on the concave side of the mericarps (Fig. 5). After harvesting, the fruits are dried until they reach a moisture content of about 8-9%. It is important that the fruits be completely ripe before they are stored, otherwise the germination rate will be reduced. Coriander has orthodox seeds (Ellis and Hong 1996). The fruits (seeds) of coriander have a remarkable resistance to high temperatures (Toben *et al.* 1994), but for long-term storage the drying temperature should not exceed 40°C. Drying is especially important if the weather conditions during the period of ripening were unfavourable (Luk'janov and Reznikov 1976). The process of ripening can be assisted by exposing the harvested fruits to warm temperatures for some days, e.g. by spreading them on sheets in the sun. Such a treatment was successfully used in coriander seed production in the former Soviet Union. The vigour of the seedlings is strengthened by repeating this procedure short before sowing (Heeger 1989).

The fruits are physiologically ripe when the typical smell of the green plant, caused by several aldehydic components, has more or less disappeared and the green colour is gone (Fig. 11f). Before this stage is reached, the germination rate of the seeds will be reduced, despite their viability. This phenomenon is due to either immaturity or primary dormancy of coriander. Warm air treatment can also be used for artificial ripening of harvested fruits. Secondary dormancy of coriander seeds has not been observed at Gatersleben or mentioned in the literature, but some techniques for enhancement of the germination rate are reported. Stratification of the fruits for a period of 15-20 days will improve the germination rate and the vigour of the seedlings (Tjurina 1957), but the observations at Gatersleben showed that stratification is not as important as complete ripeness.

The fruits can be stored for 2-3 years in a dry atmosphere, at room temperature, without losing much viability, but longer storage will reduce the germination rate. The long-term storage of coriander should be done under cold and dry conditions, as is commonly practised in germplasm collections with other orthodox seeds, e.g. cereals. According to Jethani (1982), germination testing needs to occur at a temperature of 15°C. Temperatures higher than 20°C reduce the germination rate of coriander, and 20°C has been suggested for germination tests (Tjurina 1957).

Before sowing coriander, heat treatment of the fruits is recommended. Tjurina (1957) stated that this enhances the germination. If they are dry, the fruits of coriander are very resistant to hot temperatures. At Gatersleben, seeds of all accessions were exposed to a temperature of 65°C for 6 days to disinfect a bacteriose before sowing, as recommended by Toben *et al.* (1994). This treatment did not reduce the germination rate. Tjurina (1957) also mentions that the germination of coriander is enhanced if the fruits are split into the mericarps artificially. The reason for this could be better access of the seeds to water. The splitting of the fruits into the mericarps is sometimes practised in agriculture before sowing (Purseglove *et al.* 1981). It is important that curators of genebank accessions and breeders note that it is possible to split the fruits without loss of viability. This is because sometimes only a few fruits are available, and the two seeds of one fruit can receive optimal growth conditions if they are split before sowing.

Nikolaeva *et al.* (1985) mention that the germination rate of coriander can be enhanced by treatment with 0.0001% $CuSO_4$ and 0.0001% $KMnO_4$ solution, or phytohormones. Further tips on reproduction are given in Sections 2 and 9. Work with passport and management data also belongs to conservation techniques in a broad sense. These aspects are described by Knüpffer (1993).

8 Breeding

The breeding methods suitable for coriander depend on the pollination biology. Coriander is a facultative cross-pollinator and after selfing the studied plants did not show obvious inbreeding depression. Thus the species behaves similarly to rape (*Brassica napus* L.), and the described breeding techniques for rape, which are well-known, can be applied to coriander too. A considerable amount of breeding work in coriander has been done in the former Soviet Union. These activities started in the area of Voronež and involved close cooperation with the germplasm collection of the Vavilov Institute (VIR). The VIR has had a department for essential oil plants until 1938, and a number of the fundamental results from their ecogeographical and chemical investigations have been published (e.g. Stoletova 1931; Lusina and Michelsson 1937).

The Caucasian centre of diversity was the main source for selecting interesting types from the landraces, which have been famous cultivars for many years in the Soviet Union (Luk'janov and Reznikov 1976). The selection work itself was done close to the town of Alekseevka, 150 km south of Voronež. Later, research on essential oil plants was based in the town of Simferopol' on the Crimea. The institute in Simferopol' still exists and now belongs to the Ukraine; in 1995, a breeding variety of coriander for autumn sowing that the institute had developed was put on the Ukrainian and Russian markets (Sil'čenko 1995). The research and breeding work in this institute concentrated on the quality of the essential oil of the fruits (Černodubov and Berestovaja 1986), winter hardiness (Moskalenko 1972; Sergeeva and Sil'čenko 1984; Romanenko and Nevkrytaja 1988), resistance to *Ramularia coriandri* (Sil'čenko *et al.* 1984; Čislova 1988; Romanenko *et al.* 1990b) and drought resistance (Karpov *et al.* 1990), as well as on the breeding techniques themselves (Sil'čenko 1969, 1980a, 1980b; Romanenko *et al.* 1992). A cytoplasmatic and a nuclear type of male sterility in coriander have been found by researchers of this institute, which can be used in breeding (Romanenko and Svečnikova 1988).

In the former Soviet Union, the coriander for vegetable use has not been subject to breeding programmes, but the characterization data of the germplasm collection of the VIR in St. Petersburg have been published for a total of 139 accessions (Girenko and Cytovič 1980; Girenko 1992). Cooperation between the genebank collection and breeding has always been close, and has resulted in the forementioned evaluation programmes for the germplasm collection. Breeding and screening for essential oil use was done by the VNIIEMK[4], and the VIR concentrated on genetic resources and also on aspects of the vegetable's use (Alborišvili 1971, 1984; Girenko 1980). Today, both institutes involved belong to different states, i.e. the Ukraine and Russia, and the future of both institutes seems to be uncertain. At present the situation is problematic because the breeding experts and optimal environmental con-

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[4] Vsësojuznyj naučno-issledovatel'skij institut efirnomasličnych kul'tur=All-Union Research Institute for Volatile Oil Crops.

ditions for coriander are located in the Ukraine, while the factories for processing are located in Russia. The cooperation between these facilities has become difficult after the crash of the former Soviet Union (Sil'čenko 1996, pers. comm.).

The breeding of coriander has also long been practised in India (Dimri *et al.* 1976; Suthanthirapandian *et al.* 1980; Sethi 1981; Agrawal *et al.* 1990; Bhandari and Gupta 1991). Several studies of genetic diversity in coriander have been carried out, and coriander germplasm collections have been screened for resistance breeding. Several East European countries have bred varieties of coriander, but the interest in this crop has apparently diminished, as there are only few recent publications on this topic. In Egypt some breeding research on coriander was done by El-Ballal and El-Nasr (1987). This concentrated on the description of phenological earliness of the plants and the medicinal properties of the fatty oil in the fruits.

In Germany, two companies have been active in coriander breeding, who were mainly interested in the fatty oil (Meier zu Beerentrup and Röbbelen 1987; von der Schulenburg *et al.* 1991). At present only one of them is continuing this work, because the petroselinic acid of this crop is of little commercial interest. Breeding in Germany tries to combine fatty oil content with essential oil content and resistance to bacterial blight.

Biotechnology and genetic engineering have hitherto been unimportant for coriander breeding, but some techniques have been developed. Methods for tissue culture and micropropagation of coriander have been developed in India (Mujib *et al.* 1990) and in Russia (Kataeva and Popovic 1993). In China, somatic embryos of coriander have been used successfully in the creation of artificial seeds (Chen *et al.* 1992).

In the USA, genetic material from coriander has been successfully introduced in tobacco and has affected its fatty acid biosynthesis (Cahoon *et al.* 1992). In the United Kingdom, rape (*B. napus*) plants have been transformed with genetic material from coriander in order to obtain petroselinic acid from rape (Murphy *et al.* 1994).

9 Ecology and agronomy

The best descriptions of the agronomic needs of coriander cultivation for use of the fruits are given by Palamarja and Chotina (1953) and Luk'janov and Reznikov (1976). For Central Europe, the advice of Heeger (1989) is useful, and some more recent hints on cultivation are provided by Ebert (1982) and Dachler and Pelzmann (1989). Indian conditions have been reviewed by Singh and Gangwar (1991). Cultivation for production of coriander fruits is only possible if the sum of average temperatures of the days during the vegetation period is at least 1700-1800°C (Luk'janov and Reznikov 1976). The variation of the phenological characters (Table 8 and Figure 6) showed that the number of days until the plants were harvested depended very much on the ecogeographical type of coriander (see Box 1).

The soil should be sandy silt or soil of higher fertility. Especially during the juvenile period, coriander needs adequate moisture. After stem elongation, the plants are very resistant to drought, as the observations at Gatersleben showed. For this reason, coriander is grown in India and other countries with dry climates as a rain-fed crop, if irrigation is not possible. The introduction of coriander, even under irrigation, has recently been reported for Argentina (Luayza *et al*. 1995). High temperatures and sunny weather during the flowering period will favour the yield of fruits and the essential oil content. In tropical climates and in the areas not reaching the minimum sum of average temperatures of 1700°C, the production of coriander fruits is not possible. Under these conditions, the plant can only be grown for use as a spicy herb or vegetable. The extension of coriander cultivation for use of the fruits from the traditional production area of southern Russia and the Ukraine to northern Russia was successfully carried out by Kuzina (1973 and 1975).

The cultivation of coriander at Gatersleben showed that the plant is not sensitive to daylength. Plants reached the generative stage of ontogenesis when sown in spring, and in summer on the field, but also when sown in autumn, late autumn or winter in greenhouses. The vegetation period was always lengthened if the plants were grown in greenhouses, despite the fact that in summer the temperatures in the greenhouses were very high. This shows that the influence of light on ripening is important, and high temperatures alone are insufficient for successful cultivation of coriander. Another factor retarding the maturing of the fruits might be the high humidity in the greenhouses. The fact that coriander is sown in India at nearly any time of the year, and in some places in India has two growing seasons per year, also shows that the species has no, or only a slight, photosensitive adaptation to long days.

Observations during the winter 1994/95 at Gatersleben showed that coriander survives longer periods with temperatures below –15°C. Sergeeva and Sil'čenko (1984) showed that the roots of young coriander plants tolerate low temperatures down to –9°C. The results of field trials allow the conclusion that only the types forming rosettes tolerate these low temperatures. Autumn sowing is commonly practised in the Ukraine, and breeding in the former Soviet Union is concentrated on winter hardiness too, because sowing before winter increases the yields and is commonly practised in those areas with mild winters. To date, autumn sowing has not been practised in Western Europe.

Sowing in early April is possible, and the types without rosettes could also withstand some days with temperatures below 0°C. The plants become sensitive to lower temperatures after elongation of the stem. Therefore, this character, or the number of basal leaves, which is correlated with a long juvenile stage, can be used as a morphological indicator for frost resistance. The minimum temperatures necessary for emergence are 4-6°C, but only at temperatures of 15-17°C will emergence be as early as 2 weeks after sowing (Luk'janov and Reznikov 1976). A long period until emergence will allow weeds to take hold, and should be avoided. This is especially important if herbicides are not used. Mechanical weeding is only possible after emergence of the crop. Mechanical weeding needed to be carried out twice during the growing season at Gatersleben, and in India, two mechanical weedings are also common procedure (Husain 1994). Coriander is very sensitive to weeds during the juvenile stage, and the types not forming rosettes need particularly careful weeding.

The number of plants per square meter for optimum yield is between 50 and 100. The number of fruits sown per square meter should therefore be about 70. Depending on the weight of 1000 fruits, the quantity of fruits sown per hectare will be between 3 and 20 kg/ha. The branching ability of coriander allows a wide range of plants per square meter, without significant effect on the grain yield. The Caucasian types have an especially high plasticity and use the available space. These types can either be cultivated with wide distances, allowing mechanical or hand-hoeing between the plants, or with dense sowing and cultivation methods similar to those used for cereals. The Near Eastern and Indian types do not produce as many branches, and the number of plants per square meter is more important. In India, Rajasthan, Andhra Pradesh and Tamil Nadu are the major coriander-producing states. Both the bold round type (*C. sativum* var. *vulgare*) and the small-seeded type (*C. sativum* var. *microcarpum*) are under cultivation. Yield varies considerably: from a maximum of 1134 kg/ha in the Punjab to 2268 kg/ha in southern India when sown as a pure crop. When sown as a mixed crop, the yield is much lower: 800 kg/ha in Karntaka.

Pre-emergence application of herbicides in the field is possible, and herbicides exist for later chemical weeding. Phosphorus and potassium are nutrients which affect the grain yield of coriander. Applications of nitrogen did not affect the yield in the field trials of Dambroth and Bramm (1991), where the average yield was 2000 kg/ha. Heeger (1989) advised not to apply more than 20-40 kg N/ha, and Ebert (1982) stresses that more than 50 kg N/ha will favour fungal diseases. Nitrogen can retard ripening and cause lodging, and coriander is therefore regarded as a low-input crop. The harvest can be done with combine harvesters. Because fruits of different order do not ripen simultaneously, it is advantageous to cut the plants 1 week before threshing, and let them completely ripen on the field before threshing with the combine harvester. This ensures homogeneous ripening. Threshing can also be done immediately, but then artificial drying will often be necessary, owing to the high moisture content.

Experiments at Gatersleben showed that the essential oil content of the fruits is highest before the fruits are completely ripe. If artificial drying facilities are available, an early harvesting date can be chosen. In other cases, and for seed production, a later date should be chosen for the harvest. It needs to be appreciated nonetheless that the tendency of the fruits to shatter and split increases during ripening, and this may reduce yield and quality. The relative content of linalool is higher if the fruits are physiologically ripe. Only whole fruits that have not split into the mericarps are useable as a spice or for medicinal purposes.

The fruits can be stored when the moisture content is about 9%, and the essential oil losses are negligible for several years, if the fruits are not mechanically damaged. The maximum yields of coriander fruits reported are 3 t/ha, with an average of 1.5-2.0 t/ha. The extremely favourable conditions for coriander during the experimental year 1995 at Gatersleben showed that the crop has the potential for high fruit yields. The maximum value was 1235 g coriander fruits from 3 m^2 of experimental plot, and several accessions had a yield of more than 300 g from 1 m^2. In other years, remarkable losses have been observed, however, due to diseases or retarded development caused by cold weather. Experiments with the introduction of coriander as a field crop in German farms resulted in mean yields of 1220 kg/ha (Rottmann-Meyer 1993). Röbbelen (1990) reports yields of 2800 kg/ha.

From India, Jansen (1981) reported the possibility of intercropping coriander with cotton (*G. arboreum* L.) or black gram (*V. mungo* (L.) Hepper). Heeger (1989) stressed that cultivation of coriander in fruit tree gardens is dangerous because of the severe damage to trees caused by phytolexins. He mentioned that further research was needed on this subject, although this clearly has not been carried out.

Little advice exists on the cultivation of coriander for use as a herb. Alborišvili (1971) investigated 13 different types of coriander for their use as a herb, and the influence of sowing date on productivity under field conditions in Suchumi/Georgia. The same author (1984) mentions that leaf yields are maximized when the plants are cut four times and sown in autumn. In this case only the leaves are harvested. The entire plant is often harvested before flowering, and all parts of the plant are consumed. This is how ‘cilantro’ is normally used in the Americas. On behalf of European producers, Gimson (1985) conducted trials of coriander for use as a herb. He recommends a sowing density of 50-55 kg/ha, and the application of 100 kg nitrogen and the same amount of phosphorus per hectare. Sowing is possible from spring until late summer, as the plants are ready for harvesting 6 weeks after sowing. In the USA, Anderson and Jia (1995) presented studies of the greenhouse production of coriander for vegetable use. In the USA, the Caucasian type of coriander, i.e. the types with aromatic leaves, many basal leaves and a long period until stem elongation, were dubbed ‘slow bolt coriander’, because of their particular suitability for use as a vegetable (Simon 1990). In these types, the harvesting period is lengthened and the fresh matter yield increased.

It is important to note that either the entire young plant is harvested and used before flowering begins, or basal or stem leaves are plucked or cut from the plants. The possible combined use of coriander leaves and fruits has been investigated by Bhati (1988), who states that such a combination increases the economic benefits to producers of coriander. The combined use of leaves and fruits for small-scale production seems promising. In large-scale production, the wide range of leaf variation may be successfully exploited to allow concentration on one use of the plant.

10 Diseases and insect pests

Coriander is affected by some specialized and some general pathogens. An important disease is bacterial blight, caused by *Pseudomonas syringae* pv. *coriandricola*, which causes necroses and reduced number of fruits in the umbels and leaf spots. Since the application of antibiotic chemicals should be avoided, and the disease is systemic and thus spread by seeds, this bacteriose is discussed in greater detail. The disease has already been described by Palamarja and Chotina (1953), who noted that fruits harvested from affected plants will redistribute the bacteriose. The biology of this specific disease caused by *P. syringae* pv. *coriandricola* has been described at length by Toben (1995). Pollinating insects carry the bacteria and spread the disease, which can then become systemic. Awareness of the possibility of seed transmission is therefore needed when coriander fruits are transferred. The bacterium can persist in the field on volunteer plants, which can be other species of cultivated plants or weeds (Al-Shinawi, 1996, pers. comm.). Heat treatment of the ripe fruits before sowing (for 6 days=144 hours (!) at 65°C with dry heat) and other disinfection treatments have been developed (Toben *et al.* 1994). The accessions of the Gatersleben Genebank have been screened for resistance by Al-Shinawi, who also developed a method for screening at the early stages (Al-Shinawi 1993). Genetic resistance was found in accessions of different geographic origin.

Toben (1995) mentions other bacterial diseases affecting coriander caused by *Erwinia* and *Xanthomonas* species, which are not of great importance.

Several fungal diseases affect coriander. In Europe, *Ramularia coriandri* is of particular importance, and resistance breeding of this fungus has been carried out in the former Soviet Union (Sil'čenko *et al.* 1984; Čislova 1988). *Fusarium oxysporum* causes coriander wilt (Srivastava 1972), and resistance screenings of this disease were done by Prakasam *et al.* (1987). Stem galls are caused by *Protomyces macrosporus* (Das 1971). Grain mould diseases caused by *Helminthosporium* spp., *Fusarium* spp., *Curvularia* spp. and *Alternaria* spp. were studied by Rajan *et al.* (1990). Other fungal diseases are mildew (*Erisyphe polygoni*), and rust and leaf spots. The symptoms of several fungal diseases of the green plant are described by Palamarja and Chotina (1953). Fungicides for treatment of the seeds or application in the field exist.

Two virus diseases are mentioned for coriander. Alfalfa mosaic virus was isolated from coriander in Yemen (Alhubaishi *et al.* 1987) and the transfer and infection of celery mosaic virus in Brazil has been described by Oliveira and Kitajima (1981).

A specific insect pest of coriander is *Systole coriandri* (= *Systole albipennis* ?), whose larva damages the fruits and survives in them. Seeds of the affected fruits must not be used for sowing. A detailed account of this pest is given by Palamarja and Chotina (1953), who describe the biology of several mites, moths and beetles. Jansen (1981) describes the serious losses of fruits caused by the chalcid fly *Systole albipennis* in Ethiopia, and reports the possibility of their biological control by the parasites *Tetrastichus* spp. and *Liondontomerus* spp. Singh and Baswana (1984) screened coriander for resistance to this pest in India. The aphids *Myzus persicae* (de Araujo 1986) and *Hyadaphis coriandri* (Jain and Yadav 1988) have been mentioned for coriander.

Table 10. Production, export and import of coriander fruits in some countries (after Purseglove *et al*. 1981; Dachler and Pelzmann 1989; Ebert 1982, and Anonymous 1991-92, 1992)

Country	Production		Export		Import	
	tonnes	Year	tonnes	Year	tonnes	Year
Main producers						
Soviet Union	196 000	1976	nd		nd	
India	154 000	1984	2904	1977	48	1977
Morocco	13 380	1969/70	7674	1976	nd	
Mexico	24 486	1991				
Romania	nd		3000	1976	nd	
Argentina	nd		366	1976	nd	
Iran	nd		522	1973	nd	
Pakistan	3200	1991	15	1974	nd	
Main importers						
Germany (west)	nd		nd		1807	1979/80
USA	nd		nd		2507	1977
Sri Lanka	nd		nd		327	1976
Japan	nd		nd		1833	1975

nd = no data; the relevant statistics were not available.

Other insect pests and methods to combat them by sowing time or with pesticides are described by Jain and Yadav (1989).

Several insects damage coriander fruits during storage. One of them, the biscuit beetle, *Stegobium paniceum*, was also found in seed samples from genebanks. These insect pests can cause genetic erosion, and genebank curators need to ensure that the stored fruits are free of them. In India coriander has been screened several times for resistance to the nematodes *Meloidogyne incognita* (Midha and Trivedi 1988) and *Meloidogyne javanica* (Paruthi *et al.* 1987).

11 Areas of production and consumption

World production of coriander fruits is difficult to estimate, since official statistics seldom contain figures relating to this crop. A considerable quantity of coriander is grown in home gardens or on a small scale, and is not recorded in any statistics. Taking the different observations on this subject into account, the world-wide production of coriander may be estimated at approximately 550 000 ha annually. The yearly production of coriander fruits may be estimated at about 600 000 t. The main producers of coriander fruits are the Ukraine, Russia, India, Morocco, Argentina, Mexico and Romania. Other countries that produce at least some coriander for use of the fruits, by geographical region, are:

- the Near East (Iran, Israel, Kuwait, Lebanon, Syria and Turkey)
- the Middle East (Bhutan, Kasachstan, Kirgysia, Pakistan and Tadjikistan)
- the Far East (Burma, China and Thailand)
- the Americas (Argentina, Chile, Costa Rica, Guatemala, Paraguay, USA and Canada)
- Africa (Algeria, Egypt, Ethiopia, Somalia and Tunisia)
- Europe (Bulgaria, Czechoslovakia, England, France, Hungary, Italy, the Netherlands, Poland and Yugoslavia).

As the list shows, coriander is grown in almost all agriculturally viable areas, with the exception of the tropics and the polar regions. The tropical climate is unfavourable for ripening of the fruits (see Section 9), and coriander is only cultivated for the use of the fruits in mountainous areas of the tropics. The plant is sometimes cultivated for use as a vegetable in tropical areas, e.g. in Cuba. The list provided is based on export figures presented by Purseglove *et al.* (1981).

India is a notable consumer of coriander, and in 1984, it produced 154 000 t of the crop, occupying an area of 349 000 ha. The average yield was about 442 kg/ha (Samba Murty and Subrahmanyam 1989). The International Trade Centre (1986) estimated that in 1986, the world production of coriander essential oil was 90-100 t/year. The main producer of coriander for export has always been the former Soviet Union, and Luk'janov and Reznikov reported in 1976 that 98% of the world's coriander essential oil was produced by the Soviet Union. The same authors estimated the total global area of land in coriander production to be 320 000 ha. The main production areas in the former Soviet Union are in the black soil regions of the Ukraine and in southern Russia. The average yield is about 1500 kg/ha. According to Dachler and Pelzmann (1989), in 1984, the world production of coriander essential oil was 25 t, only a quarter of the amount for 1976 (see above). The volatility of the market for this fruit is shown by these widely varying production figures.

The main exporters of coriander are the Ukraine, Russia, India and Morocco, and the main importers are the USA, Sri Lanka and Japan. Other countries importing coriander are Malaysia, Chile, Bolivia and some countries in the Middle East. Table 10 provides some figures on this subject.

The production of coriander for use as a vegetable is not of particular importance for world trade. Nevertheless, Luk’janov and Reznikov (1976) reported an annual area of 15 000-20 000 ha in cultivation for use of the green plant as a vegetable, much of it made up of home gardens, particularly in the Caucasus and Central Asia. The green plant is also widely used in Syria, India, China, Southeast Asia and in Central and South America. The national agricultural statistics of Chile mention 159 ha of ‘cilantro’ (coriander) for vegetable use in 1991 (Anonymous 1987-92), and the relevant statistics for Venezuela report 255 ha for this country in 1985 (Anonymous, no date). But it is certain that most of the production for this use is not recorded in any statistics. To some extent, coriander can be found in use as a vegetable in all areas in which it is cultivated. Recently, interest in this use of coriander has increased in western countries. The USA, for example, imports a considerable quantity of the crop from Mexico and produces some in Florida (Lamberts 1990) and California (Anderson and Jia 1995). England has also begun to produce the vegetable (Gimson 1985).

12 Prospects for research, conservation and development of coriander genetic resources

As mentioned above, until now no agreement exists on recommended descriptors for the characterization of coriander accessions in genebanks, or for the registration of breeding varieties (Schnock-Fricke, Bundessortenamt, 1994, pers. comm.). A tentative system for the basic descriptors of coriander is offered in Table 7 above, which lists the most important characters of the species. Description of the geographic distribution of the different types of coriander revealed that each of the four centres of diversity named by Ivanova and Stoletova (1990) (see Section 3) is the origin for characteristic types of coriander, morphologically and chemically. However, it needs to be established whether these different types have the same geographic origin or not, i.e. whether domestication occurred independently in different geographic areas.

Consideration of the geographic distribution of traits showed that some special characters occur simultaneously in geographically distinct areas:

- basal leaves pinnate to a high degree (a monogenic character occurring in Belorussia and in Kasachstan)
- plants not containing any anthocyans (a monogenic character distributed in several areas)
- plants with resistance to *Pseudomonas syringae* pv. *coriandricola* (found in several locations) (Al-Shinawi 1993)
- plants forming large rosettes (found in Central Asia and Syria)
- plants with large fruits (occurring in the Mediterranean area and the Near East, but also in Bhutan)
- plants with ovate fruits (observed in the Indian subcontinent, but also mentioned in Morocco and Northern Africa) (Hegi 1926; Ivanova and Stoletova 1990).

These characters are of interest to future research on the evolution of coriander. Some of them are monogenic, and they are caused either by mutations that occurred independently in the different areas or by germplasm transfer. Careful morphological observations might detect further characters of this kind, and molecular methods could provide further tools for the investigation of these interesting traits. Since coriander is not a crop of great commercial interest, there are still many landraces of this species in cultivation in home gardens, which may be able to provide the missing links between the widely differing types of coriander. The countries of the Near East, Turkey, Iran, Iraq, Afghanistan and Pakistan must have been either a barrier (if domestication started independently) or a bridge between the named centres of formation for different types. Collecting of coriander germplasm in these countries would allow interesting research in this direction. At present, coriander germplasm from Iran and Iraq is almost unavailable in the accessible *ex situ* collections. It can be assumed that interesting types of coriander occur in the area of Kurdistan, including the wild species *C. tordylium*.

Crossing experiments involving the species *C. tordylium* and *C. sativum* are of particular interest to studies of coriander’s evolution, and for breeding purposes too. The crossing of coriander with *B. radians* was not possible by conventional crossing methods including embryo rescue techniques (Meier zu Beerentrup, 1994, pers. comm.). Judging from the herbarium specimens studied in St. Petersburg, the other wild species from Central Asia (Table 1) seem to be doubtful genetic resources for coriander breeding because of their very different morphology. The taxonomy of the wild Central Asian species should be clarified, however.

The chemotaxonomical aspects of the plant are a very interesting subject for further research. The different organoleptic properties, which depend on the varying composition of the essential oils, must have been a selection criterion during the domestication of the species. Also, the differences in the flavour of the leaves are remarkable, and these have never been discussed in the literature. In Syria, the mild-tasting leafy types of coriander are used, while spicier types are favoured in the Caucasus and in South America. The South American plants belong to the Near Eastern type. The differences in flavour between the various types of coriander are considerable, and a thorough survey of this feature would be an important contribution to research, as well as being of interest to plant breeding.

Vavilov's law of homologous variation suggests that breeding of coriander might successfully create new types that form roots for use as a vegetable, as other umbelliferous plants do. Such breeding activities require access to coriander germplasm with a wide range of diversity. Research on the pollination biology of the species needs to be undertaken in order to obtain better information about the necessary requirements for reproduction and conservation of genetic integrity. In field reproduction, the distances used to isolate coriander populations from each other are only based on experience and speculation. Research in this field is also of entomological interest. In Section 6 it was shown that morphological markers are available in coriander, which are necessary for such investigations, and research in this area could be carried out using molecular methods.

Communication between the existing *ex situ* collections of coriander is weak and should be improved. There only exist a few such collections (see Table 5), and it should be much easier to reach agreements on descriptors for coriander than for those of major crops. *In situ* conservation activities, especially on-farm conservation of coriander, should be supported by the genebanks and other institutions keeping germplasm collections. The tendency to create uniform environments for cultivated plants by the increased use of chemical fertilizers and pesticides makes uniform idiotypes of cultivated plants the most economic ones for farmers, as they respond to the standardized environments with high yields. Diversification of agriculture will go hand in hand with on-farm diversity of cultivated plants, and also with diversity of knowledge of how to cultivate and use plants.

It is therefore necessary to spread the information gathered about the species and accessions in germplasm collections not just within scientific circles, but also more widely, to all those who are concerned with biodiversity. Nongovernmental organizations (NGOs) as presented by Arrowsmith (1993) and Whealy (1993) are interesting partners for genebanks in this field. In the industrialized countries, agricultural diversification is necessary for ecological reasons. So-called ‘gene erosion’ has reduced the diversity of cultivated local varieties, which have been replaced by more or less genetically identical breeding varieties. Genebanks should feel responsible, not only for their collections, but also for genetic resources and agriculture in general.

13 Crop limitations and prospects

The fact that diversification of agriculture in industrialized countries is neccessary for ecological as well as economic reasons provides general scope for new crops. This argument has been made by Röbbelen (1993) in the case of coriander. The ecological role of coriander for the insect is very clear (see Section 2), but its economic aspects should also be considered. The successful cultivation of coriander for use of the fruits is limited by the climatic and soil conditions required. For developing countries with tropical climates, coriander is only produced successfully in the high-altitude areas. Therefore, the chances of these countries entering the international market for coriander fruits are negligible (International Trade Centre 1986). Importers have also preferred to buy their raw material from the former Soviet Union, where there is quality control of coriander fruit, owing to well-established production standards.

At present, the price for coriander essential oil is only US$12/kg, because the market has been flooded with exports from the Ukraine; the price was previously about US$50/kg. This illustrates the extreme volatility of international trading in essential oils. To avoid such price fluctuations and achieve stable coriander production, agreements should be established between the producers and the industry.

There are some new potential uses of the fruits for essential oil, however. In the production of washing powder, natural linalool could replace the oleochemically produced linalool, which is commonly used for fragrance today. Linalool can be obtained on a large scale from coriander, since it is the main component of the essential oil (see Tables 3 and 8,) and the content of essential oil in coriander is very high compared with other essential oil plants. Sil'čenko (1995) mentions that in southern Russia essential oil yields of 25-30 L/ha are obtained from coriander. The use of coriander as a source for linalool would moreover be a step towards greater independence from the petrochemical industry. It can be assumed that the use of this natural source for aromatic purposes in the non-food sector is ecologically more reasonable than the petrochemical processing of linalool. The demand for washing powder is considerable, and many consumers would prefer a natural fragrance. An economic study of this possible use of coriander should be undertaken.

The use of coriander as a fatty oil source is limited, because lauric acid is directly available from palm kernel oil. It makes ecological sense to use this source instead of chemically processing it from the petroselinic acid of coriander fruits. The economy of developing countries exporting palm kernel oil would suffer from its substitution by coriander. Another limiting factor is the fact that the fatty oil from coriander is strongly fixed in the endosperm of the seeds and is difficult to obtain by pressing (Meier zu Beerentrup, 1996, pers. comm.). The physicochemical properties of the coriander oil mentioned in Section 4.6 seem to be limited to some specific purposes, and the nutritional value of coriander fatty oil was shown to be lower than that of sunflower oil (Mironova *et al.* 1991). If petroselinic acid should become an important raw material for industry, the prospects for the species of the genus *Bifora* appear extremely good (Knapp 1990) (see Section 6.5). Only coriander allows the combined use of the fatty and the essential oils, however.

With the exception of curry powder, which contains coriander, the use of the fruits as spice is limited in industrialized countries, because the pure spice is relatively unknown. This situation could change if the awareness increases that in industrialized countries too there once existed a much greater range of cultivated plants, which were used for more purposes than at present. The literature reports many uses which have disappeared over the last three centuries (see Sections 4.2 and 4.3).

The use of coriander as a vegetable seems the most auspicious, and the market could grow if the potential producers manage to reach consumers in the same area. In the USA this market is already established, and a considerable quantity of cilantro is imported from Mexico (Lamberts 1990; Simon 1990). Cultivation of coriander as a vegetable is possible under all climatic conditions, and promotion of this use of the plant would open up completely new markets. The availability of new foods is being met with increasing interest in the industrialized countries, and as other markets are saturated, the production of coriander is also of interest to their agricultural sectors.

The production of plants for use as a herb needs to be located close to the consumer in order to deliver fresh herbs of high quality; this supports local horticulture and agriculture. It is also an opportunity to increase genetic diversity, as locally adapted or preferred varieties can be cultivated. Production on a large scale is possible too, since the leaves can be dried and enter the market in this form. The diversity of the species allows us to find several types, some of which have the character of a spicy herb, due to their strong aromatic taste, while other milder-tasting types are more salad-like.

Initial material with specific properties for all of the uses mentioned can be found in the existing collections of coriander germplasm. This study could not have been carried out without the germplasm exchange, also at an international level, which has been possible so far, and is necessary for further work with the plant genetic resources of coriander.

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Appendix 1. Addresses of individuals and institutes working with coriander. For addresses of genebanks see also Table 5

Name	Area of expertise	Address
Germany		
Dr H. Meier zu Beerentrup	Breeding	Pflanzenzuchtbetrieb W. von Borries-Eckendorf Hovedisser Str. 92, D-33818 Leopoldshöhe, Germany
T.A. Al-Shinawi Dr H.M. Toben	Diseases	Institut für Phytopathologie Universität Göttingen Griesebachstr. 6, D-37077 Göttingen, Germany
Prof. Dr K. Hammer A. Diederichsen	Genetic resources	Institut für Pflanzengenetik und Kulturpflanzenforschung (IPK) Genbank, Corrensstr. 3, D-06466 Gatersleben, Germany
Mrs. Chr. Reuter Prof. Dr W. Thies Dr P. Tillmann	Chemical analysis	Institut für Pflanzenbau und Pflanzenzüchtung Universität Göttingen Von-Siebold-Str. 8 D-37075 Göttingen, Germany
Dr H. Krüger	Chemical analysis	Bundesanstalt für Züchtungsforschung an Kulturpflanzen BAZ Neuer Weg 22/23,D-06484 Quedlinburg ,Germany
Ukraine		
kand. s.-ch. nauk V.M. Sil'čenko dr. s.-ch. nauk L.G. Romanenko	Breeding	Ukraina Crimea 333620Simferopol' ul. Kievskaja, 150 Institute for Volatile Oil Bearing and Medicine Crops
Russian Federation		
kand. biol. nauk M.M. Girenko	Genetic resources	Russian Federation 190000, Sankt-Peterburg Bol'saja Morskaja, 42, N. I. Vavilov All-Russian Research Institute of Plant Industry
India		
Dr K.V. Peter (Director) Dr S. Edison, Project Coordinator (Spices)		Indian Institute of Spices Research (ICAR) Calicut, 673 012 (Kerala)