Lentil

Lentil

An Ancient Crop for Modern Times

Edited by

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FOREWORD

On behalf of the United States Department of Agriculture, I am pleased to introduce the book *Lentil: An Ancient Crop for Modern Times*. The articles and essays in this volume, submitted by nearly 100 researchers, educators, and other experts, contain comprehensive information on a variety of topics of significance for lentil growers, researchers, and consumers worldwide.

Cultivated lentils (*Lens culinars*), an annual legume crop, have been grown as an important food source for over 8,000 years. They come in two main varieties: macrosperma (with large seeds and little pigmentation), and microsperma (with small seeds and some pigmentation). Depending on their variety and breed, however, lentil seeds can range in color from red-orange, to yellow, green, brown, or black. They are cultivated and consumed throughout the world, with Canada, Turkey and India being the top producers.

Although the production of lentils and other pulse legume crops lags far behind cereal production in most nations, including the United States, production remains highly important because of its benefits for producers and consumers alike. Lentil seeds provide high levels of protein and, when consumed in combination with cereals, they provide adequate amounts of essential amino acids for the human diet. Their relatively short cooking time provides an additional advantage. Lentil production is equally beneficial for producers, as lentils have a high tolerance for extreme environmental conditions such as drought and hot temperatures, and can be grown in semiarid regions without irrigation. Moreover, the crop can be grown in rotation with cereal crops to reduce soil erosion, improve disease and weed control, and reduce demand for nitrogen fertilizers. Beyond their longstanding food and agronomic attributes, there is increasing interest in using lentils as a biomass energy crop and for other industrial non-food uses.

USDA scientists are among many participants in a global effort to enhance lentil quality and promote its growth as a crop. The Agricultural Research Service partners with university researchers and other cooperators worldwide to improve crop disease resistance, develop effective insect and weed control practices, and identify other effective crop production strategies for lentils. This effort also includes international-scale lentil breeding and improvement programs to collect, introduce, maintain, and exchange germplasm. These programs are essential for improving lentils' genetic diversity, which, in turn, is important for increasing the yield and crop quality of the legume as well as for limiting the impact that diseases, weeds, and insect pests have on lentil crops. Although lentils tend to suffer less from disease than do other legume crops, they are still impacted by root rots and wilts, rusts, blights, and viruses. Lentils are also susceptible to damage from weeds, which can reduce yields by up to 75 percent, as well as from aphids, beetles, maggots, wireworms, grasshoppers, and other insects. Ongoing efforts to develop improved technologies to manage these threats as well as to enhance the end-use attributes of lentils for food, nutrition, and industrial uses will be critical to ensuring the long-term sustainability of these crops.

Lentil, edited by Shyam S. Yadav, David McNeil, and Philip C. Stevenson, provides a valuable overview of the history and background behind lentils as well as a detailed analysis of the research that has been conducted on lentil breeding and production strategies. As such, it will be useful to breeders, producers, researchers, educators, nutritionists, and anyone interested in obtaining an insight into the world of lentils.

Edward B. Knipling
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ABOUT THE EDITORS

Dr. Shyam Singh Yadav

Shyam Singh Yadav is a principal legume breeder at Division of Genetics, Indian Agricultural Research Institute, New Delhi, India. He received his B Sc degree in agricultural sciences from University of Agra, UP, his M Sc degree in plant breeding from University of Meerut, UP, before completing his PhD in Genetics & Plant Breeding from the Indian Agricultural Research Institute, New Delhi, India in 1986. During his PhD research program he worked on the genetic & physiological basis of plant architecture of chickpea (*Cicer arietinum* L.) He started his scientific journey as assistant wheat breeder in January 1969 at the Division of Genetics, Indian Agricultural Research Institute (IARI) New Delhi, India. Since then he has worked on various breeding positions in India and abroad till April 2007. As Principal Legume Breeder he used different breeding options/approaches for genetic enhancement, varietal development, germplasm enrichment and participatory breeding etc. More than 20 high yielding, widely adapted multiple resistant chickpea varieties were released for commercial cultivation in different eco-geographical under his leadership. He has also developed excellent germplasm lines and distributed to many international legume breeders around the world. These lines are being utilized in many countries by legume breeders. Along with this, he worked on the development of integrated crop production and management technologies and its dissemination and popularization in farmers fields. Professional collaborations were also developed under his leadership with international organizations like ACIAR, Australia, USDA, ICRISAT, ICARDA etc. during this period. The post graduate school at IARI, New Delhi provides Graduate and Doctoral research programs to national and international students. During the last 30 years, Yadav has been a faculty member at post graduate school of IARI and taught various professional courses in Genetics and Plant Breeding at Graduate and Doctoral level. He has published more than 125 research papers in national and international journals and written 10 book chapters for international books. In March 2007, a book on chickpea breeding and management was published by CABI, UK for which Yadav was senior editor.

Prof. David Leslie McNeil

David McNeil started his career in agricultural science in 1971 as a trainee crop physiologist with the New South Wales (NSW) Department of Agriculture followed by PhD on lupin physiology at the University of Western Australia. Since then he has swung between Departments of Agriculture and Universities with a strong involvement in pulse and grain legume crop research, development and extension. A key area of effort has been to expand scientific understanding of new crops and develop new productive, viable and sustainable industries around these new crops with pulses as a major area of effort. He has published well over 100 scientific papers as well as a similar number of extension publications. Professor McNeil's research publications have covered a wide range; from molecular mapping, GM, mutation and traditional breeding through crop/plant agronomy and physiology to market testing and consumer evaluation of new crops. David McNeil's work with legumes has included a period with NifTAL in Hawaii promoting N fixation world wide, including consulting for the UNEP program on N fixation. He has also developed super nodulation in soybeans as well as led major Australian breeding programs for a range of temperate pulses including lentils. Professor McNeil's career has included acting as researcher, lecturer, program manager and extension expert based at locations in the USA, New Zealand and Australia, usually with goals spanning both developing and developed country agricultural systems. Professor McNeil has worked at the Boyce Thompson Institute at Cornell, the University of Hawaii, the Australian National University, the WA Department of Agriculture, Lincoln University in New Zealand, the Victorian Department of Primary Industries, with the University of Melbourne in the Joint Centre for Crop Innovation. Presently he occupies the Chair of Agricultural Sciences in the School of Agricultural Science at the University of Tasmania. This school incorporates the Tasmanian Institute of Agricultural Sciences and as such is the predominant source of research in Tasmania for horticulture, dairy, vegetable, cropping and food safety. Professor McNeil's commitment to linking research and industry development continues with a strong interest in retaining pulses as a major component of a total cropping system particularly in high rainfall zone cropping. His interest in other areas of plant physiology, breeding and agronomic research continue including attempts to use biotechnological approaches in lentil, pea and chickpea breeding. Thus from his present position Professor McNeil continues his interest in combining detailed science with industry development of pulse, horticultural and other new crops in the Tasmanian, Australian and global environment.

Dr. Philip. C. Stevenson

Phil Stevenson is a Reader in Plant Chemistry at the Natural Resources Institute (NRI), University of Greenwich, UK, and holds a joint position between NRI and the Jodrell Laboratory at the Royal Botanic Gardens, Kew, UK. He received his B.Sc degree in Applied Biology from Brunel University of West London, before completing his PhD at University of London in 1992. During his PhD he worked on the chemical basis of resistance in wild species of groundnut (*Arachis* spp.) to the tobacco armyworm (*Spodoptera litura*) and so began a transformation from plant biologist to plant chemist. The compounds identified during this work were demonstrated to inhibit development of *S. litura* larvae and have subsequently been used as markers for breeding resistant groundnut cultivars in India. His interest in natural resistance in crop plants continued into his postdoctoral work at NRI when he studied Fusarium wilt and Botrytis grey mould of chickpea (*Cicer arietinum*) and extended this to other non-cultivated (wild) species of *Cicer*. He has also studied the chemistry of resistance in wild and cultivated pigeon pea and chickpeas to the pod borer (*Helicoverpa armigera*) and in *Cedrela odorata* to leaf weevils (*Exophthalmus* spp.). Much of this work has been in collaboration with the ICRISAT, India. He is working presently on the biological activity of pesticidal plants against storage insect pests developing ways to optimise their use, collection and even cultivation. He is also exploring resistance on Sweet potato (*Ipomoea batatas*) to sweetpotato weevils (*Cylas* spp). Phil has now published over 50 peer reviewed papers and book chapters on this work and other aspects of natural product chemistry and the role of plant compounds in biological systems, agriculture and medicine. He is a member of the Editorial Board of *Crop Protection*; the official journal of the International Association of Plant Protection Services.

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PREFACE

Lentils are believed to have originated and been consumed since pre-historic times. They are one of the first crops to have been cultivated. Lentil seeds dating back 8,000 years have been found at archeological sites in the Middle East. Lentils were mentioned in the Bible, both as the item that Jacob traded to Esau for his birthright and as a part of bread that was made during the Babylonian captivity of the Jewish people. In the modern and technologically advanced world, they are under cultivation in more than 35 countries of 5 different continents. It is this ancient origin and modern diversity that makes lentil an "ancient crop for modern times".

Lentils are an important cool season food legume. Traditionally they are a low input crop grown extensively for subsistence or local consumption in rainfed agro-ecosystems. However, in the last 20 years they have also increasingly been grown in extensive, export oriented, production systems in north America. The increasing world interest in legumes has stimulated the need to document what is known about them in order to develop efficient agronomic production systems and breed widely adapted multiple resistant cultivars for wider ecologies. This book provides a comprehensive review of current constraints, achievements and future prospects for lentil crop improvement, production, protection and management technologies. The chapters, each written by specialists help teachers, scientists, students, extension workers, farmers, consumers, traders and administrators in increasing their understanding of the lentil crop.

This book on lentil comprises 23 chapters. Chapters 1–6 present the history, origin, biodiversity, ecology, consumption pattern, nutritional value along with geographic distribution and world trade. Chapters 7–11 explain the role of lentils in the cropping system, rhizobium management and nitrogen fixation, nutrient, weed, irrigation management and profitability in cultivation. Chapters 12–17 explain genetics, cytogenetics, mutation breeding, wild relatives, breeding methods, varietal adaptation and new plant type, genomics and molecular approaches and quality seed production. Chapters 20–23 highlight biotic and abiotic stresses, insect-pest management, post harvest management and lentil growers around the world.

In the modern world knowledge tends to be interdisciplinary and global and lentil systems are no exception. Therefore, most chapters have involved collaboration of 3 or more diverse international authors. Thus the book represents a truly global perspective consistent with the nature of world production, trade and consumption. The book also stress the interactions that have arisen globally for lentil technologies for international marketing, breeding, production and protection approaches, domestic consumption and economic issues arising internationally. This book offers the latest reviews of lentil technologies and publications as well as presenting new findings direct from leading researchers for use by researchers, professionals, technologists, economists, students, traders, consumers and growers. We are certain you will find it both a timely, interesting and valuable addition to the literature on an extraordinary crop.

Shyam S. Yadav
David Mc Neil
Philip C. Stevenson

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The editorial team would like to express our sincere thanks to all the contributors for their valuable professional contributions, patience, efficiency, dedication and devotion. The editing of multi-author texts is not always easy. In this case, it was painless, encouraging and enjoyable. All the authors and co-authors responded speedily, effectively and efficiently to the collective pressure exerted by the editors, with the consequences that the manuscripts were delivered on time and without any difficulty. This made the job of the editors easier and the job of collecting the scripts and preparing the final text for the publisher relatively straight forward.

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The Editors would like to express their sincere thanks to Manav Yadav, who agreed to work as Project Manager for this book. He has been working for this project right from the beginning when it was just a proposal until the final stages of book publication. He worked and managed the communications with Editors, Springer, Authors, and Technical Editor Queries. His able leadership and sincerity helped everyone involved to work as a team and finish this daunting task in a timely manner.

The Editors would like to thank Pulse Canada, who agreed to provide the front cover photograph of Lentils. More information about Pulse Canada can be accessed by visiting *www.pulsecanada.com* or by calling (204) 925–4455. The Editors are thankful to Pulse Canada for their assistance and help provided in the completion of this book.

GENERAL NOTE

References to any chemical control products, uses and operations in this book should not be considered an endorsement of their use in areas for which they have not been approved. Their incorporation here is to provide information on research that has been carried out and not to propose their use where not registered.

CHAPTER 1

HISTORY AND ORIGIN

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Abstract: Lentil (*Lens culinaris* Medikus) is the oldest pulse crop with remains found alongside human habitation up to 13,000 years BC. Its domestication is equally old and was probably one of the earliest crops domesticated in the Old World. It is mainly grown in India, Bangladesh, Pakistan, Egypt, Greece, Italy, countries in the Mediterranean region and North America. It is also being cultivated in the Atlantic coast of Spain and Morocco. The crop has a high significance in cereal-based systems because of its nitrogen fixing ability, its high protein seeds for human diet and its straw for animal feed. It is widely used in a range of dishes and reputed to have many uses in traditional medicine. There are a range of wild lentils but *L. orientalis* is believed to be the progenitor of the cultivated lentil

1. INTRODUCTION

Lentil, the plant varies from 6 to 18 inches in height, and has many long ascending branches. The leaves are alternate, with six pairs of oblong-linear, obtuse, mucronate leaflets. The flowers, two to four in number, are of a pale blue colour, and are borne in the axils of the leaves, on a slender footstalk nearly equaling the leaves in length. The period are about 1.5 cm long, broadly oblong, slightly inflated, and contain two seeds, which are of the shape of a doubly convex lens, and about 0.5 cm in diameter.

There are several cultivated varieties of the plant, differing in size, hairiness and colour of the leaves, flowers and seeds (Figure 1). The last may be more or less compressed in shape, and in colour may vary from yellow or grey to dark brown; they are also sometimes mottled or speckled. In English commerce two kinds of lentils are principally met with, French and Egyptian. The former are usually sold entire, and are of an ash-grey colour externally and of a yellow tint within; the latter are usually sold like split peas, without the seed coat, and

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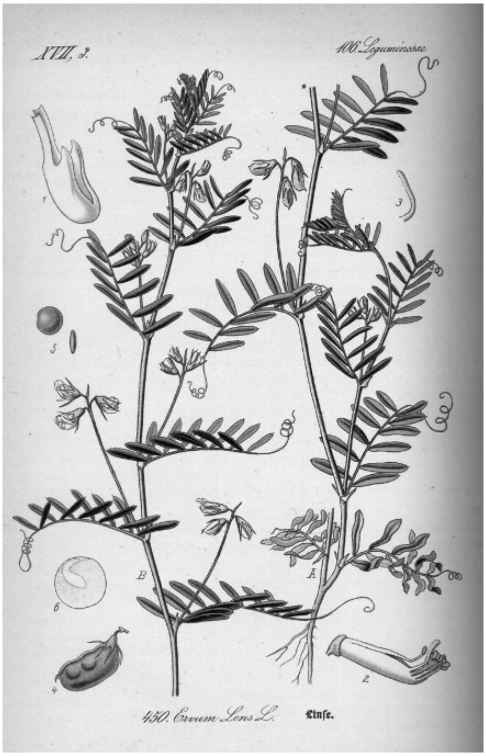

Figure 1. Illustration of the lentil plant, 1885

consist of the reddish-yellow cotyledons, which are smaller and rounder than those of the French lentil; the seed coat when present is of a dark brown colour. (www.1911encyclopedia.org,2006)

Popular in parts of Europe and a staple throughout much of the Middle East and India, this tiny, lens-shaped pulse has long been used as a meat substitute. There are three main varieties of lentils, the French or European lentil, sold with the seed coat on, has a grayish-brown exterior and a creamy yellow interior. The reddish orange Egyptian or red lentil is smaller, rounder and sans seed coat and yellow lentil. None of these varieties are used fresh but are dried as soon as they're ripe. The regular brown lentils are commonly found in supermarkets whereas the red and yellow lentils, though available in some supermarkets, must usually be purchased in Middle Eastern or East Indian markets. Lentils should be stored airtight at room temperature and will keep up to a year. They can be used as a side dish (puréed, whole and combined with vegetables), in salads, soups and stews. One of the most notable showcases for the lentil is the spicy Indian dhal. Lentils have a fair amount of calcium and vitamins A and B, and are a good source of iron and phosphorus.

2. COMMON NAMES

Lentil is known by various names in different parts of the world. The most common names are lentil (English), adas (Arabic), mercimek (Turkey), messer (Ethopia), masser or massur (India), heramame (Japanese). Other names mentioned in literature are mangu or margu (Persian), masura, renuka, mangalaya (Sanskrit).

3. USES

Lentil seeds are consumed as whole grains and as dehulled *dhal*. There are two types of lentil, the large seeded (*macrosperma*) and the small to medium sized seeded called (*microsperma*). The colour of seeds also varies with lines being brown, red, green or white. The lentil seeds are relatively higher in protein content (25%), carbohydrates and calories than other legumes (Muehlbauer *et al.* 1985). Its seeds are also a good source of essential minerals like calcium, phosphorous, iron and vitamin B. Lentil seeds are used for various cuisines worldwide and most commonly used as main dishes, side dishes, as sprouted grain in salads with *rotis* and rice. Seeds can be fried and seasoned for other uses. It is used as a staple of the diet in many Middle Eastern countries and India. Lentil flour can be used to prepare dishes such as soups, stews and purees. The flour can be mixed with cereals to make breads and cakes and as a food for infants (Williams and Singh 1988). Besides, being highly nutritious lentil seeds also contain anti-nutritional factors such as protease inhibitors, lectins or phytohaemoglutins and oligosaccharides that cause flatulence. These anti-nutritional factors can be minimized by heating, water soaking and germination (Jumbunathan *et al.* 1994). Williams *et al.* (1994) reported that lentils have the least while fababean generally have the highest concentrations of these anti-nutritional factors. Tannins are another set of anti-nutritional compounds found in the seed coat which is removed during dehulling while processing (Williams *et al.* 1994). Plant residues like dried leaves, stalks, husk, podwall etc. left after threshing are a good source of cattle feed. These residues contain about 10.2% moisture, 1.8% fat, 4.4% protein, 50% carbohydrate, 21.4% fibre and 12.2% ash (Muehlbauer *et al.* 1985). Lentil seeds are also used by industry as a source of commercial starch for textiles and printing (Kay 1979).

4. MEDICINAL VALUES

Lentil soups have a place in traditional medicines. They are claimed to improve digestion and are prescribed by traditional physicians during convalescence and also claimed to be as a blood purifier. An old traditional medicinal practice was the application of lentil paste to the skin to erase old skin disorders. It also said to alleviate peptic or duodenal ulceration and other intestinal afflictions that are seen in rice eating people. “In India, lentils are poulticed onto ulcers that follow smallpox and slow healing sores” (Duke 1981). In the sixth century, chickpeas were believed to be an aphrodisiac while lentils were considerd to have the opposite effect. Probably, this was the reason that lentil was a part of the diet of monasteries during seasons when there was a low availability of meat (van der Maesen 1972).

5. HISTORY

The history of lentil is as old as Agriculture (Helbaek 1963). The carbonized remains of lentil dated to 11,000 BC from Greece's Franchthi cave are the oldest known remains. Small seeded (2–3 mm) types were found at Tell Mureybit in Syria and have been dated to 8500–7500 BC (Van Zeist 1971, Zohary 1972, Hansen and Renfrew 1978). Lentil remains have been found in Neolithic, aceramic farming villages which were occupied in the 7th millennium BC in the near east arc (Helbaek 1959). The type of agriculture surround these lentils cannot be determined as during this period small seeded cultivated lentil could not be differentiated from wild lentil seeds. In an archaeological site in northern Israel the presence of a large storage of lentils clearly established that by 6800 BC lentil was a part of farming. Carbonized lentil seeds have been recovered from widely dispersed places such as Tell Ramand in Syria (6250–5950 BC), aceramic Beidha in Jordan, ceramic Hacilar in Turkey (5800–5000 BC) and Tepe Sabz in Iran (5500–5000 BC) (Van Zeist and Bottema 1971, Helbaek 1970). In Greece, lentils dating back to 6000–5000 BC have been found in Neolithic settlements such as Argissa-Magula Tessaly (Hopf 1962) and Nea Mikomedeia, Macedonia (Renfrew 1969, Van Zeist and Bottema 1971) and in the same period lentil remains were also seen in Egypt (Matmur, El Omari late 4th millennium, Helbaek 1963). The archaeobotanical remains of lentil have been found in the excavations of the Harappan civilization covering the period of 3300–1300 BC.

6. ORIGIN

Lens culinaris is indigenous to the near East and Central Asia. The putative progenitor of cultivated species *Lens culinaris* subsp. *orientalis* (Bioss.) Ponert is found in Turkey, Syria, Lebanon, Israel, Jordan, Iraq, Iran, Afghanistan, Greece, Uzbekistan (Ladizinsky 1979a, Cubero 1981, Zohary 1973). Most of the West Asian lentils have a flattened lens-like appearance while South Asian lentils have a convex shape on both sides. The electrophoretic studies of seed protein profiles in 22 lines comprising of 11 of *L. culinaris,* six of *L. orientalis,* four of *L. ervoides* and one line of *L. nigricans* belonging to different regions of distributions showed that *L. culinaris, L. orientalis* and *L. nigricans* were related to each other while *L. ervoides* was different (Ladizinsky 1979b). Further, Renfrew (1973) suggested that *L. nigricans* is the progenitor of the cultivated species *L. culinaris* based on his belief of the domestication of lentil in southern Europe. Other groups of workers more recently (Ladizinsky 1979a, Barulina 1930, Zohary 1972 and Williams *et al.* 1974) have claimed that *L. orientalis* is the progenitor of the cultivated species based on the fact that the wild species were found in the fields of the farmers where lentil crops were cultivated in the Middle East. Secondly, plant characteristics and pollen grain morphology were found to be quite close. Further, Ladizinsky (1979c) attempted the cross between *L. culinaris* and *L. orientalis* and studied the behaviour of F_1 and F_2 populations. He also concluded that pod indehiscence is governed by single recessive gene. Together these data gave a reason to believe that domestication of lentil might have started with selection of the variants from wild populations which were non-pod dehiscence (Ladizinsky 1979b). Non-pod dehiscence variants made the harvesting easy due to retention of pods till harvest. *L. orientalis* might have originated first from perennial species and at the secondary level become the progenitor of cultivated species (Singh 2001). According to Ladizinsky (1979a), *L. orientalis* is the progenitor of cultivated species based on the cytoplasmic studies. In the cytogenetic analysis of interspecific hybrids, three chromosome interchanges were found between the cultivated *L. culinaris* and *L. nigricans* while only one was found between the cultivated species and *L. orientalis*, which accentuates the concept that *L. orientalis* is the most probable progenitor of the domestic lentil. *Lens orientalis* is the presumed progenitor of *Lens culinaris* and the two species are crossable and produce fully fertile progeny (Muehlbauer *et al* 2006).

7. DOMESTICATION

Domestication is likely to have started with selection of plants from wild species that retain their seeds in pods before harvesting and continuous selection for large seed size. Lentil is a self-pollinated crop species and this would have helped greatly in maintaining line identity in the process of domestication. Archaeological studies, presented above, have confirmed the presence of lentil in the Turkey-Syria-Iraq region as far back as 8500–600 BC. This region probably played an important role in lentil domestication and starting the further spread to the Nile, Greece, Central Europe and eastwards to South Asia (Nene 2006). At the same time, lentil also spread to Ethopia, Afghanistan, India, Pakistan, China and later to the New World including the Latin America (Cubero 1981, Duke 1981, Ladizinsky 1979a). Bahl et al. (1993) suggested that probably lentil's domestication was the oldest among grain legumes. Lentil was thus an important part right from the start of the agricultural revolution in the Old World alongside the domestication of wheat, barley, pea, flax, einkorn and emmer wheats (Zohary 1976). The crop was part of the assemblage of Near Eastern grain crops introduced to Ethopia by the invaders of the Hamites. From the Bronze age onward, lentils were grown wherever wheat and barley were cultivated throughout the expanding realm of Mediterranean-type agriculture (Erskine 1989). This indicates a specific demand for lentil in the social system as the yield of lentil was quite low in comparison to wheat and barley. Thus along with other grain crops, lentil cultivation as part of a farming system was probably initiated in late 5th or early 4th millennia BC. The Harappan civilization (3300–1300 BC) remains are indicative of domestication of lentil starting prior to 2500 BC in India. De Candolle (1882) dated the start of lentil cultivation on linguistic grounds. "It may be supposed that the lentil was not in this country (India) before the invasion of the Sanskrit speaking race." This probably occurred before 2000 BC and is consistent with the other evidence presented above.

8. BOTANICAL DESCRIPTION

Lentil is annual bushy herb with erect, semi-erect or spreading and compact growth habit. It has many branches with soft hairs. Its stems are slender, angular, light green in colour about 15–75 cm in height (Duke 1981, Muehlbauer *et al.* 1985). The rachis is 4–5 cm in length bearing 10–15 leaflets in 5–8 pairs. Generally, the upper leaves are converted into tendrils or bristle, whereas the lower leaves are mucronate (Muehlbauer *et al.* 1985). The leaves are alternate, compound, pinnate and yellowish green, light yellow green, dull green, dark green or dark bluish green in colour. The stipules are small or absent. The axillary racemes generally bear 1–4 flowers on short peduncles having 2.5–5.0 cm length. The flowers are small, white, pink, purple, pale purple, pale blue in colour (Muehlbauer *et al.* 1985). The flowering proceeds acropetally. The lowermost buds open first and flowering proceeds upward and it takes about two weeks to complete opening of all the flowers on the single branch (Nezamudhin 1970). The opening of flower occurs between 8.00 to 10.00 hrs and continues till noon and each flower remains open for about 16–24 hrs. At the end of the second day and on the third day all the opened flowers close completely and the colour of the corolla begins to fade. The setting of pods occurs after 3–4 days. The flowers have small ovaries with one or two ovules. The style is covered with a hairy inner surface. The pods are oblong, flattened or compressed, smooth with 1–2 cm in length. Pods have a curved beak, persistent calyx and contain 1–3 seeds. The seeds are biconvex, round, small, lens-shaped and weigh between 2–8 g per 100 seeds. The colour of the testa varies from tan to brown black, purple and black. The mottling and speckling of seed is a common feature in some germplasm lines. The cotyledons are red, orange, yellow or green, bleaching to yellow (Kay 1979, Duke 1981, Muehlbauer *et al.* 1985). The germination of seed is hypogeal.

9. TAXONOMY

The genus *Lens* comprises six species (Ferguson 1998; Ferguson *et al.*, 2000) as *Lens orientalis* is generally now classified as *Lens culinaris* subsp *orientalis.* Only one species, *L. culinaris* Medikus is cultivated. Among the wild species namely *L. montbretii* (Fisch and Mey.) Davis and Plit., *L. ervoides* (Brign.) Grande; *L. nigricans* (Bieb.) Godr., and *L. orientalis* (Boiss.) M. Popov., the latter two species possess morphological similarities to the cultivated lentil (Ladizinsky 1979b). However, Ladizinsky and Sakar (1982) suggested that *L. montbretii* should be placed in the genus *Vicia* and named as *Vicia montbretii* (Fisch & Mey.) based on morphological and cytological data and breeding experiments. The cultivated lentil originated from *L. orientalis* (Barulina 1930) and chromosome number of cultivated lentil, its progenitor species, *L. orientalis* and

L. nigricans are same, i.e. 2n = 14. The cultivated species, *L. culinaris* has been divided into two sub-species (Barulina 1930) namely *macrosperma* (seed diameter, 6–9 mm) and *microsperma* (seed diameter, 2–6 mm). The *macrosperma* type have yellow cotyledons and very light or no pigmentation in their flowers and other plant parts, whereas the *microsperma* types have red, orange or yellow cotyledons and pigmented flowers and other plant parts. Williams *et al.* (1974) classified *L. culinaris* in the order Rosales, sub-order Rosineae, family Leguminosae and sub-family Papilionaceae. The genus *Lens* occupies an intermediate position between *Vicia* and *Lathyrus*, the two other members of papilionaceae. However, it is more closely related to the genus *Vicia.* Of the annual *Lens* species, *L. nigricans* can be separated from *L. culinaris* and *L. orientalis* from the stipule shape (Barulina 1930, Ball 1968, Davis and Plitmann 1970, Williams *et al.* 1974). The stipules of *L. culinaris* and *L. orientalis* (*Lens culinaris* subsp *orientalis*) are oblong or elliptic, lanceolate, entire, whereas stipules of *L. nigricans* are semi-hastate, entire or dentate. The classical taxonomy is based on morphological characteristics, it does not necessarily represent biological entities. Hybridization within the genus indicates the classification of species based on morphology is not valid and accessions based on morphology classified in the same species sometimes turn out to be cross – incompatible. Due to this reason, *L. odemensis*, formerly a member of *L. nigricans*, has been described as a new species (Ladizinsky 1986). The stipules of *L. nigricans* are semi-hastate with up right position, whereas in *L. odemensis* the stipules are less dentate, semi-hastate with horizontal position. Both these species are cross incompatible (Ladizinsky 1993). The detailed characteristic features of various *Lens* species are as follows: The wild species *L. nigricans* is a slender, densely pilose having semi-hastate stipules, conspicuously aristate peduncles and mauve flowers. The pods are glabrous and small usually with two tiny lenticular seeds. It is morphologically more closely related to cultivated species *L. culinaris.* However, it can be differentiated from cultivated lentil by many characters like toothed semi-hastate stipules and the strong aristate peduncles. The wild species *L. ervoides* is very slender (10–30 cm tall), with semi-hastate stipules and long filiform penduncles. It has very small puberulent pods with lenticular seeds. Like *L. nigricans,* it is also morphologically closely related to cultivated lentil. However, it can be separated from cultivated lentil by traits like structure of stipules and peduncle, size of pod and seed and flower shape.

The wild species *L. orientalis* (*Lens culinaris* subsp *orientalis*) is slender, pilose (10–30 cm tall) and has a very strong resemblance to *L. culinaris* with respect to vegetative growth and structure of the flower and pod. The stipules are entire, obliquely lanceolate and unappendaged. The calyx is 4–6 mm long with teeth much longer than tube. The pods are glabrous with small lenticular seeds. Overall, *L. orientalis* (*Lens culinaris* subsp *orientalis*) looks like a miniature version of *L. culinaris* and morphological boundaries between both the species are occasionally intermixed. Some intergradation between the two species has been reported by Davis and Plitmann (1970) and some intermediates were also found in several localities in the Judean hills and in Galilee, Israel (Zohary 1972). The wild species

L. odemensis is decumbent-ascending with single or branched column. It has small rachis (8–20 mm) with 6–8 leaflets per leaf and ending in a tendril. The stipules are semi-hastate, slightly dentate at the base and horizontal to the stem. The calyx is 4–6 mm with long teeth. Pods are glabrous, rhomboid with 1–2 motted gray-brown small seeds.

Lentil is one of the oldest grain legumes. It is a short statured, annual, self-pollinated, high valued crop species. It is native to the Near East and Central Asia and rapidly spread to other parts of world. *L. orientalis* is the most probably a secondary level progenitor of the cultivated species *L. culinaris* Medikus. *L. orientalis* might had originated from the wild perennials through natural selection. The wild lentil species are potential resources yet to be tapped.

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CHAPTER 2

LENS BIODIVERSITY

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Abstract: The *Lens* genus includes the cultivated *L. culinaris,* and wild subspecies *orientalis* - the progenitor, *tomentosus,* and *odemensis,* are in the primary genepool, while *L. ervoides, L. nigricans* and *L. lamottei* are in the secondary – tertiary gene pool. The Middle East is the primary centre of diversity for the primary genepool, with distribution of *L. orientalis* extending to central Asia, and of *L. ervoides* extending along the Mediterranean to Spain. The largest *Lens* collection is held at ICARDA. *In situ* reserves of *Lens* diversity are in Turkey and Syria. Documentation and storage of *Lens* germplasm is discussed. An evaluation database covering a number of genebanks has been developed for lentil germplasm. Core collections are discussed in the context of the generation Challenge program. Application of DNA characterisation is outlined, along with the potential for allele mining for variation in key traits, the study of relationships within *Lens* and the use of mapping populations. Reference is made to the International treaty for Plant Genetic Resources for Food and Agriculture

1. SOURCES OF GENETIC DIVERSITY

The genus *Lens* is a member of the legume tribe Vicieae which includes the major legume crops of the classical Mediterranean civilizations, faba bean, pea along with lentil. The precise generic boundaries between *Lens* and the related Vicieae genera (*Vicia* L., *Lathyrus* L., *Pisum* L. and *Vavilovia* A. Fedorov) have been much debated, but *Lens* appears most closely related to *Vicia* (Kupicha 1981). *Lens* is a small Mediterranean genus which contains the cultivated lentil (*L. culinaris* Medikus subsp. *culinaris*) and six related taxa (Ferguson 2000), as shown:

S.S. Yadav et al. (eds.), Lentil: An Ancient Crop for Modern Times, 11–22.

L. culinaris Medikus
subsp. *culinaris*
subsp. *orientalis* (Boiss.) Ponert
subsp. *tomentosus* (Ladizinsky) Ferguson, Maxted, van Slageren & Robertson
subsp. *odemensis* (Ladizinsky) Ferguson, Maxted, van Slageren & Robertson
L. ervoides (Brign.) Grande
L. nigricans (M.Bieb.) Godron
L. lamottei Czefr.

The cultivated taxon, *Lens culinaris* Medikus subsp. *culinaris*, includes two varietal types: small-seeded *microsperma* and large-seeded *macrosperma* (Barulina 1930).

Lens culinaris subsp. *orientalis,* in the primary genepool (Ladizinsky and Alder 1976), is fully cross compatible with cultivated lentil (Muehlbauer and Slinkard 1981, Robertson and Erskine 1997). *L. nigricans,* in the secondary genepool, can also cross with the cultigen, yet seed set in hybrids is considerably lower than a *L. culinaris* subsp. *culinaris* x *L. culinaris* subsp. *orientalis* cross (Muehlbauer and Slinkard 1981). *L. culinaris* subsp. *orientalis* accessions have been found to contain resistance to drought (Hamdi and Erskine 1996), cold (Hamdi *et al.* 1996, Robertson et al. 1996), wilt (Bayaa et al. 1995), and Ascochyta blight (Bayaa et al. 1994, Robertson et al. 1996).

The Middle East is the primary centre of diversity for both the domestic *L. culinaris* and its wild progenitor *L. culinaris subsp. orientalis* (Cubero 1981, Zohary 1972), but taxa are found from Spain to Tajikistan. Although Ferguson et al. (1998) showed that for *L. culinaris* subsp. *orientalis* two centres exist, (a) south-eastern Turkey and north-western Syria, and (b) southern Syria and northern Jordan. The southern centre overlaps with the centre of diversity for *L. culinaris* subsp.*odemensis*. A region of diversity exists for *L. ervoides* along the eastern Mediterranean coast and for *L. nigricans* in south-western Turkey. Ferguson et al. 1998 also showed that *L. culinaris* subsp. *orientalis* accessions from Iran, central Asia and northern Turkey are all very similar to each other, and correspond to the common cytotype identified by Ladizinsky et al. (1984). *L. ervoides* populations from the coastal region of the former Yugoslavia have a narrow genetic base, as do *L. nigricans* accessions from the same region as well as those from France and Spain. Maps illustrating the distribution of variation can be found in Ferguson and Erskine (2001).

Wild populations of *Lens* are generally poor competitors and highly palatable to grazing animals (Ferguson and Erskine 2001). They are found predominantly in primary, ungrazed habitats where they are not subject to competition by aggressive coloniser plants. They usually form small disjunct populations. The density of plants may vary dramatically between years apparently because of climatic conditions. *L. culinaris* subsp. *orientalis*, subsp. *tomentosus*, subsp. *odemensis* and *L. nigricans* are generally found in open or partially shaded habitats, on shallow stony soils originating from calcareous, metamorphic or basalt rocks. *L. nigricans* and *L. lamottei* have also been found in habitats showing signs of earlier human disturbance such as abandoned terraces or plantations and ruins. Both *L. nigricans* and *L. ervoides* have been found from sea level to over 1000 m.*L. culinaris* subsp. *orientalis* and