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REVIEW ARTICLE

ORIGIN, DOMESTICATION, TAXONOMY, BOTANICAL DESCRIPTION, GENETICS AND CYTOGENETICS, GENETC DIVERSITY AND BREEDING OF LENTIL (*Lens culinaris* Medik.)

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ABSTRACT

Lentil belongs to the Family Fabacaeae, Genus Lens, Species Lens culinaris and Subspecies *culinaris.* Lentil (*Lens culinaris* Medik. ssp. *culinaris*) is one of the oldest cultivated plants that originated in the Near East arc and Asia Minor. This cool season legume crop is an excellent food source to provide energy, proteins and iron in the human diet. Cultivated lentil is a self-pollinated diploid plant with 2n = 2x = 14 chromosomes and a genome size of 4 Gbp. The lentil is an edible legume. It is an annual plant known for its lens-shaped seeds. It is about 40 cm tall, and the seeds grow in pods, usually with two seeds in each. As a food crop, the largest producer is Canada, producing 45% of the world's total lentils. Many different names in different parts of the world are used for the crop lentil. The first use of the word *lens* to designate a specific genus was in the 17th century by the botanist Tournefort. The word "lens" for the lentil is of classical Roman or Latin origin, possibly from a prominent Roman family named Lentulus, just as the family name "Cicero" was derived from the chickpea, *Cicer arietinum*, or "Fabia" (as in Quintus Fabius Maximus) from the fava bean (*Vicia faba*). Types can be classified according to their size, whether they are split or whole, or shelled or unshelled. Seed coats can range from light green to deep purple, as well as being tan, grey, brown, black or mottled. Shelled lentils show the colour of the cotyledon which can be yellow, orange, red, or green. Lentils are often categorized by their color, which can range from yellow and red to green, brown, or black. This species has been cultivated for 10,000 years in several regions worldwide, especially in West Asia, Australia, North and South America, Mediterranean basin, Middle East, and in the Indian sub-continent. It is a valuable human food, mostly consumed as dry seeds (whole decorticated, seed decorticated and split). In Indian sub-continent mostly consumed as 'Dal' by removal of outer skin and separation of cotyledons, snacks and soup preparation etc. It is easy to cook and easily digestible with high biological value, hence also referred to patient. Dry leaves, stems, empty and broken pods are used as valuable cattle feed. Lentils are a good source of protein, dietary fibre, vitamin B, iron, and phosphorus. Thus far, lentil breeders have been successful in improving some easily manageable monogenic traits using conventional breeding techniques of selection and recombination. However, these conventional techniques are insufficient to address economic traits like seed yield due to polygenic inheritance and genotype-environment interaction. Cultivated lentil (*Lens culinaris* Medikus ssp. *culinaris*) is the third most important cool-season grain legume in the world after chickpea (*Cicer arietinum* L.) and pea (*Pisum sativum* L.). In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Genetics and Cytogenetics, Breeding, Uses, Nutritional Value and Health Benefits of Chickpea are discussed.

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INTRODUCTION

Lens is a small Mediterranean genus which contains the cultivated lentil (*L. culinaris* Medikus subsp. *culinaris*) and six related taxa (Ferguson *et al*., 2000). Lentil is an ancient cool-season food legume that has been traditionally grown in the Middle East, South Asia, Ethiopia, North Africa and to a lesser extent, in southern Europe. More recently it has been introduced to the Americas and Australasia. Its ability to grow on poor soils under adverse environmental conditions yet produce a high quality protein has made it one of the principal pulse crops in the drier regions, particularly in the Middle East, South Asia and North Africa where it is a dietary mainstay. It is usually grown in rotation with cereals and in West Asia its straw is of great value as feed for small ruminants (Ferguson and Erskine, 2001).

Lentil belongs to the Family Fabacaeae, Genus *Lens*, *Species Lens culinaris and Subspecies culinaris* (Laskar *et al.,* 2019; BSMRAU, 2023). Lentil (*Lens culinaris* Medik. ssp. *culinaris*) is one of the oldest cultivated plants that originated in the Near East arc and Asia Minor (Laskar *et al.,* 2019). This cool season legume crop is an excellent food source to provide energy, proteins and iron in the human diet (Laskar *et al.,* 2019). Cultivated lentil is a self-pollinated diploid plant with 2n = 2x = 14 chromosomes and a genome size of 4 Gbp (Khazaei *et al.,* 2016; Mbasani-Mansi *et al*., 2019; Liber *et al*., 2021; Ahlawat, 2023). The lentil is an edible legume. It is an annual plant known for its lens-shaped seeds. It is about 40 cm tall, and the seeds grow in pods, usually with two seeds in each. As a food crop, the largest producer is Canada, producing 45% of the world's total lentils (Wikipedia, 2023). Lentil, red dahl [English]; lenteja [Spanish]; lentilha [Portuguese]; lentille [French]; Linse, Erve [German]; lenticchia [Italian]; mdengu [Swahili]; Linze [Dutch]; Mercimek [Turkish]; Đậu lăng [Vietnamese]; (Heuzé *et al*., 2021). Common Names for lentil are Lentil (English), Adas (Arabic), Mercimek (Turkey), Messer (Ethiopia), Masser (India), heramame (Japanese) (Muehlbauer and Tullu, 1997). Lentil is known as Masur, Malka (bold seeded) (Wikipedia, 2023). Masoor (also known as red lentil, Hindi: masoor, Gujarati: masoor) is a brown skinned lentil that is orange on the inside (Indiaphile, 2023). As a preferred food legume, lentil is known by as many as 30 different common names around the world including *masser* (India), das (Arabic), *mercimek* (Turkey), *messer* (Ethiopia), and *heramame* (Japanese), to name a few (Laskar *et al*., 2019).

Many different names in different parts of the world are used for the crop lentil. The first use of the word *lens* to designate a specific genus was in the 17th century by the botanist Tournefort. The word "lens" for the lentil is of classical Roman or Latin origin, possibly from a prominent Roman family named Lentulus, just as the family name "Cicero" was derived from the chickpea, *Cicer arietinum*, or "Fabia" (as in Quintus Fabius Maximus) from the fava bean (*Vicia faba*) (Wikipedia, 2023). Types can be classified according to their size, whether they are split or whole, or shelled or unshelled. Seed coats can range from light green to deep purple, as well as being tan, grey, brown, black or mottled. Shelled lentils show the colour of the cotyledon which can be yellow, orange, red, or green (Wikipedia, 2023). Black Chickpea (*Cicer arietinum*)- Desi chana, kala chana- Origin; Southeast Turkey, cultivated in Middle East' Other Names: Bengal Gram, Chana, Sanaga Pappu, Shimbra, Chana, Chole (Indiaphile, 2023). White chickpea (*Cicer arietinum*)- kabuli chana-- Origin; Southeast Turkey, cultivate maybe from Afghanistan (named "Kabuli"). Other Names: Chana, chole, chickpea, garbanzo bean (Indiaphile, 2023).

Lentils are often categorized by their color, which can range from yellow and red to green, brown, or black.

Here are some of the most common lentil types (Healthline, 2023):

Brown: These are the most widely eaten type. They have an earthy flavor, hold their shape well during cooking, and are great in stews and soups.

Puy: These come from the French region Le Puy. They're similar in color but about one-third of the size of green lentils and have a peppery taste.

Green: These can vary in size and are usually a less expensive substitute in recipes that call for Puy lentils.

Yellow and red: These lentils are split and cook quickly. They're great for making dal and have a somewhat sweet and nutty flavor.

Beluga: These are tiny black lentils that look almost like caviar. They make a great base for warm salads.

Products of lentil are cull lentils, culled lentils, surplus lentils, lentil screenings, lentil bran, lentil chuni, lentil hulls, lentil straw (Heuzé *et al.,* 2021). 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 (Sandhu and Singh, 2007). Lentil was one of the first domesticated grain legumes, originating from the Near East center of origin. Lentil subsequently spread to central Asia and the Mediterranean Basin (Khazaei *et al.,* 2016). It is a relatively new crop in North America, first introduced into northwest USA in the 1930s and into the northern temperate prairies of North America in the late 1960s. Globally today, lentil is grown in three major distinct agro-ecological zones: Mediterranean, sub-tropical savannah, and northern temperate. These zones each exhibit different day lengths and temperatures, which limits the exchange of germplasm between agro-ecological adaptation zones. Success in crop breeding is a function of heritability, genetic diversity, and selection. Natural agro-biodiversity stored in genebanks can be used to expand the diversity in crops. These collections are a vital source for discovering useful genes/alleles, which serve as a cornerstone for any pre-breeding program (Khazaei *et al.,* 2016). This species has been cultivated for 10,000 years in several regions worldwide, especially in West Asia, Australia, North and South America, Mediterranean basin, Middle East, and in the Indian sub-continent (Mbasani-Mansi *et al*., 2019). Lentil domestication and selection over thousands of years led to the low amount of genetic variation in the current cultivated species and this scarcity in genetic variability represents a major constraint for lentil breeding (Laskar *et al.,* 2019). Lentil (*Lens culinaris* Medik.) is an annual food legume and one of the four most important legume crop in the world (Mbasani-Mansi *et al*., 2019).

The lowly lentil, a type of legume, has been sustaining man for thousands of years. Although they may be relatively inexpensive, lentils are very nutritious, filling, and more importantly, arguably the most flavorful of all the legumes (Filippone, 2021) . Lentils, botanically-known as *Lens culinaris esculenta,* grow in pods that contain either one or two lentil seeds. Sometimes smaller than the tip of a pencil eraser, lentils can be round, oval, or heart-shaped disks. Known as *dal* or *dahl* in India, lentils are dried after harvesting and may be sold whole or split into halves, with the brown and green varieties being the best at retaining their shape after cooking. When halved, dried lentils resemble their split pea cousins (Filippone, 2021). They can be used for soups and stews, salads, and side dishes, and feature prominently in Indian cuisine, especially as the main ingredient in a dish known as *dal*. In the United States, they are frequently associated with vegetarian cooking as a non-meat protein source (Kreighbaum, 2023). Unlike many dried beans, you do not need to soak lentils before you cook them. Using the method similar to all beans and grains, simply cover them with liquid, bring the pot to a boil, then cover it and simmer until the lentils absorb the liquid and soften.

This takes about 20 to 40 minutes depending on the Variety (Kreighbaum, 2023). We can add dried lentils straight to a pot of brothy long-simmering soup, or add pre-cooked lentils to salads, protein bowls, casseroles, pasta, pilafs, and other sides. Season them as the non-meat base for a shepherd's pie or slip them into everything from meatloaf to tacos (Kreighbaum, 2023). The taste of lentils depends on the color, although all varieties might be described as earthy. Red lentils have a sweeter note while green or black lentils impart a bit of a peppery flavor to a dish. The mild flavor leaves plenty of room for seasoning (Kreighbaum, 2023). Inexpensive lentils add flavor and bulk at breakfast, lunch, and dinner to a wide range of dishes coming from cuisines that span the globe (Kreighbaum, 2023). Lentils can be purchased in bags like dried beans, but are also a popular offering in bulk bins. Because lentils are a staple food in most of the Middle East, India, and Asia, check those types of markets for a greater selection and lower prices. Most grocery stores stock the common brown, green, and red lentils, but you may need to go online for the French and black varieties. You can also purchase ready-to-eat canned lentils, but beware of the high sodium content; rinsing canned lentils before you use them washes away some of the salt (Kreighbaum, 2023). The seeds are used chiefly in soups and stews, and the herbage is used as fodder in some places (Britannica, 2023). It derives the name *Lens* from the lens shaped seeds. It is mostly eaten as '*dal*'. The *dal* is made by splitting the grain in 2 cotyledons, which are deep orange red or orange yellow in colour. The whole grain is also used in some of the dishes. It is also rich in calcium (560 ppm), iron, and niacin. It has the lowest content of lectins and trypsin inhibitors among legumes. Since it is a leguminous crop, it improves the fertility of soil biological nitrogen fixation. Lentil seeds also provide a source of starch for textiles and printing. Lentil residues form important livestock feed. Lentil floor is used for thickening of soups. It is mixed with wheat flour in bread and cake production (Ahlawat, 2023). Lentil, (*Lens culinaris*), small annual legume of the pea family (Fabaceae) and its edible seed. Lentils are widely cultivated throughout Europe, Asia, and North Africa but are little grown in the Western Hemisphere (Britannica, 2023). It is a valuable human food, mostly consumed as dry seeds (whole decorticated, seed decorticated and split). In Indian sub-continent mostly consumed as 'Dal' by removal of outer skin and separation of cotyledons, snacks and soup preparation etc. It is easy to cook and easily digestible with high biological value, hence also referred to patient. Dry leaves, stems, empty and broken pods are used as valuable cattle feed (DPD, 2023.).

Lentil seeds are a good source of human nutrient, containing proteins, carbohydrates, fibers, minerals and antioxidant compounds (Mbasani-Mansi *et al.,* 2019). Lentils are a good source of protein, dietary fibre, vitamin B, iron, and phosphorus (Britannica, 2023). Lentils can be an addition to a nutrient-rich diet. Their health benefits include fiber, protein, and key vitamins (Healthline, 2023). Moreover, lentil straw is used as high-quality animal feed. In addition, lentil provides interesting possibilities for sustainable agriculture due to its nitrogen fixing capacity that enable low use of fertilizers in cereal-based cropping system (Mbasani-Mansi *et al.,* 2019). Lentil cultivation increases soil fertility via nitrogen fixation (Liber *et al.*, 2021).

Assessments of genetic diversity and relationships among preserved germplasm have important implications both for facilitating reliable documentation of genetic resources and for identifying material with possible utility for specific breeding purposes, particularly in cultivated lentil and other species with a narrow genetic base (Khazaei *et al.,* 2016). Considerable genetic diversity has been reported in *Lens* genetic resources for agro-morphological and phenological characteristics (Khazaei *et al.,* 2016). The main aims of this study were to assess the population structure and genetic variation of a group of 352 lentil germplasm accessions of Canadian breeding lines (northern temperate adaptation) and *ex situ* germplasm collections of a diverse origin using a relatively large number of SNP markers spanning the genome (Khazaei *et al*., 2016).

There are currently 58,405 *Lens* accessions held in various genebanks worldwide. International Center for Agricultural Research in the Dry Areas (ICARDA) hosts the largest collection (19%) followed by the National Bureau of Plant Genetic Resources, India (17%) and the Australian temperate field crops collection (9%). Currently, the most accessible and accessed lentil collection is held by the USDA-ARS (Khazaei *et al.,* 2016). Thus far, lentil breeders have been successful in improving some easily manageable monogenic traits using conventional breeding techniques of selection and recombination. However, these conventional techniques are insufficient to address economic traits like seed yield due to polygenic inheritance and genotype-environment interaction (Laskar *et al.,* 2019). Other species of the genus *Lens* are important sources of genetic variation for breeding key traits into new lentil varieties (Laskar *et al.,* 2019). Induced mutagenesis is a powerful breeding tool and can greatly supplement the availability of lentil genomic resources (Laskar *et al.,* 2019). In Morocco, lentil is essentially produced in constraining environments, using landraces maintained by farmers. Landraces are characterized by specific and evolutionary adaptation as well as high nutritional and organoleptic qualities (Mbasani-Mansi *et al*., 2019). Thus, an assessment of plant genetic diversity for an efficient use in both breeding and conservation programs is worth carrying out (Mbasani-Mansi *et al*., 2019).

However, their low yield implies the development of novel cultivars with high yield potential and resistance to biotic and abiotic stresses. Breeding could therefore lead to reduction or loss of lentil genetic diversity over time (Mbasani-Mansi *et al*., 2019). Legumes are important components in farming systems, providing environmental and ecological benefits through crop rotation, especially by contributing to soil fertility and rhizosphere diversity through biological N_2 fixation (Khazaei *et al.,* 2016).

The major producer of lentils in the world is India, with about 1,160,000 hectares producing 850,000 MT in 1994; while World production was 2.875 million MT on about 3.36 million hectares during the same year (Muehlbauer and Tullu, 1997). Other important producers are USA, Australia, Canada, Pakistan, Syria, Argentina, Chile, Turkey, Ethiopia and Spain. In these countries, yields have ranged from 637 to 1263 kg/ha while the highest yield, 5000 kg/ha was recorded in Germany (Muehlbauer and Tullu, 1997). Global annual lentil production was around 5 million metric tons (Tg) from nearly 4.3 million ha in 2013. Canada was the largest producer, contributing 38% of the world's production, followed by India, Turkey, and Australia (Khazaei *et al*., 2016). Cultivated lentil (*Lens culinaris* Medikus ssp. *culinaris*) is the third most important cool-season grain legume in the world after chickpea (*Cicer arietinum* L.) and pea (*Pisum sativum* L.) (Khazaei *et al*., 2016). Most lentil-growing countries have a shared objective of higher and more stable seed yield, which often entails breeding for adaptation to abiotic and biotic stresses, which otherwise cause a substantial reduction in crop yield and production (Laskar *et al.,* 2019). There are hundreds of varieties of lentils, with as many as 50 or more cultivated for food. They come in a variety of colors, with red, brown, and green being the most popular. Lentils have an earthy, nutty flavor, and some varieties lend a slight peppery touch to the palate. Lentils grow best in cool weather (Filippone, 2021). In 2021, global production of lentils was 5.6 million tonnes, led by Canada with 29% and India with 27% of the world total (table). Saskatchewan is the most productive growing region in Canada, producing 95% of the national total. In India, Madhya Pradesh and Uttar Pradesh together produce more than 70% of the total. Lentils grow in pods, making them part of the legume family along with beans, peanuts, and peas. The dried seeds of legume plants, such as lentils, are also referred to as "pulses." (Kreighbaum, 2023). Lentils are edible seeds from the legume family. They're well known for their lens shape and sold with or without their outer husks intact. Though they're a common food staple in countries such as Turkey, Syria, Jordan, Morocco, and Tunisia, the greatest production of lentils nowadays is in Canada (Healthline, 2023). Lentils, small, lens-shaped legumes, range from yellow and red to green, brown, and even black. They are inexpensive and can be stored for a long time without refrigeration.

These features have made lentils a staple food in many cultures across the globe (Kreighbaum, 2023). Globally, it is grown in about 2 M ha with a production around 2.5 M t. Highest yields are obtained in Egypt (2.2 t ha^{-1}) followed by USA (1.0 t ha^{-1}) and Canada (0.8 t ha^{-1}). India accounts for about 40 per cent of the global production. In India, as per 2008-09 statistics, it is cultivated in 1.31 M ha with a production of 0.81 M t accounting for a productivity of 622 kg ha^{-1}. UP ranks first both in the area (0.51 M ha) and production (0.37 M t) followed by MP (area 0.48 M ha and production 0.21 M t). Productivity is highest (793 kg ha^{-1}) in Bihar followed by WB (763 kg ha^{-1}) (Pallavi, 2023).

The following lentil products and by-products are sometimes used for animal feeding: Surplus lentils and culled lentils unsuitable for human consumption are sometimes fed to livestock due to their low price. Lentil screenings are the by-products of cleaning lentil seeds. They may consist of whole and broken lentils, cereal grains, weed seeds, chaff and dust. Lentil bran (called chuni in India) or lentil hulls are the outer envelopes of lentils resulting from dehulling operations. Lentil straw is the crop residue of lentil harvesting from the threshing process. It includes broken branches, pod walls and leaflets. Lentil plants that cannot be harvested can also be used as forage (Heuzé *et al.,* 2021). Lentils are generally grown as a sole crop but do well when mixed with wheat, mustard or castor. Lentils can be intercropped with small grain cereals but rotations including other legumes, *Brassica* species (rape, cabbage), sunflower or potato should be avoided as they are all susceptible to the same diseases. Lentil seeds can be broadcast or sown in rows at a depth of 1-6 cm. Lentils are generally rainfed but do well under irrigation. Lentils are harvested when pods turn yellow. The plant can be hand-pulled or cut down, left to dry in the field and then threshed and winnowed. When harvesting is done mechanically, the plant is cut at a higher moisture content to avoid seed shattering. Lentil seed yield ranges from 0.4 to 4 t/ha. Fresh forage yield may be up to 7 t/ha (Heuzé *et al*., 2021).

Lentil flowers in 6-7 weeks after planting with early cultivars ready to harvest in 80-110 days, late cultivars reach maturity in 125-135 days. In traditional agricultural systems plants are cut to ground level or pulled by hand when they turn golden yellow and left to dry for 5-10 days before being threshed and winnowed. Low moisture is desirable at harvest. In the United States, lentils are harvested with swathers that cut and windrow the crop for drying. After a 5-10 day drying period, the lentil crop is harvested by combine (Muehlbauer and Tullu, 1997). Seed yields range from 450-675 kg/ha in dry areas, may increase to 2000 kg/ha with irrigation, and yields over 3,000 kg/ha have been recorded. The straw-to-seed ratio in one cultivar was about 1.2:1 and in studies conducted on 28 cultivars in New Delhi, India, pulse yields ranged from 558 to 1,750 kg/ha, while dry matter yields ranged from 2,667 to 3,550 kg/ha (Muehlbauer and Tullu, 1997). Lentil should be harvested when the plants dry up and pods are matured. The plants should not be allowed to become over ripe as large quantity of produce may be lost due to shattering. Threshing is done either by beating the plants with sticks or trampling by bullocks. After threshing, seed is cleaned and dried in sun to bring moisture content to 12% for safe storage (Ahlawat, 2023). A well-managed crop yields about 1.8-2.0 tonnes grain and 3.0-4.0 tonnes/ha of straw (Ahlawat, 2023). Crop become ready for harvest when leaves begin to fall, stem and pod turn brown or straw in colour and seeds are hard and rattle with 15% moisture inside them. Over ripening may lead to fall of pods as well as shattering and seed cracking if seed moisture fall below 10% due to delay in harvesting. The crop should be allowed to dry for 4-7 days on threshing floor and threshed by manually or bullock/power drawn thresher. The clean seed should be sun dried for 3-4 days to bring their moisture content at 9-10%. The seed should be safely stored in appropriate bins and fumigated to protect them from bruchids. A well mange crop yields about 15-20 quintals of grain per hectare (DPD, 2023). In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Chickpea are discussed.

ORIGIN AND DOMESTICATION

Lentils probably originated in the Near East and rapidly spread to Egypt, central and southern Europe, the Mediterranean basin, Ethiopia, Afghanistan, India and Pakistan, China and later to the New World including Latin America. It is probably the oldest of grain legumes to be domesticated. It is now cultivated in most subtropical and also in the Northern hemisphere such as Canada and Pacific Northwest regions (Muehlbauer and Tullu, 1997). Lentils are one the earliest known crops to be cultivated and archaeological evidence goes back at least 7000 years (Yadav *et al.,* 2007). 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 genepool. 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 gene banks 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 (Redden *et al.,* 2007).

Lentils are one of the oldest crops cultivated and domesticated by man. Carbonized small lentil seeds have been found in several archaeological remains starting from the Neolithic. It is probable, however, that the most ancient remains refer to wild lentils; this is difficult to ascertain since seed size was probably selected after the establishment of a domesticated lentil. It is general opinion that cultivation occurred before domestication, but for how long is still an open question. It is now well accepted that the domestication of lentils was accomplished in the Near East, in an area called "the cradle of agriculture". The genus *Lens* is very small, containing only 6 taxa. A wide range of morphological and molecular evidence supports the idea that the lentil wild progenitor is *Lens culinaris* ssp. *orientalis*. On the other hand, the most distantly related species within the genus appears to be *L. nigricans*, whose domestication was also attempted without success. The first characters involved in lentil domestication were pod dehiscence and seed dormancy. These traits are under a simple genetic control, and therefore mutants must have been fixed in a relatively short time. These and other morphological traits possibly involved in lentil domestication have been mapped in several linkage maps. However, generally these maps are not easily integrated since they are based on a limited number of markers. Newer maps, mainly built on different kinds of molecular markers, have been more recently produced. A consensus map is needed to fill the gap in lentil breeding and, at the same time, endow with deeper information on the genetics of lentil domestication, giving new insight into the origins of this crop, which present fragmented knowledge is unable (Sonnante *et al.,* 2009). Distribution of wild species and an overlap of both wild and cultivated lentils in the Turkey-Cyprus region has supported that Southwest Asia or Near East or Mediterranean area is primary center of diversity of the cultivated species *Lens culinaris*. Earlier, the eastern border of Southwest Asia (*i.e.,* region between Afghanistan, India, and Turkistan) was also considered as possible center of origin due to the presence of highest proportion of endemic varieties; later on, this region has been better explained as secondary center of diversity (Kumar *et al*., 2014).

L. orientalis is the progenitor species (Ladizinsky *et al*., 1984). The centre of origin for *L. culinaris* is the Near East and the species was first domesticated in the Near East. Lentil first spread to the Nile from the Near East, to Central Europe and then to the Indian subcontinent and the

Mediterranean Basin by the end of the Bronze Age. It was introduced to South and Central America in more recent times, presumably with the arrival of the Spanish. Subsequently, it was introduced into the United States before WW II and into Canada in 1969 (Inspection , 2014).

All crop wild relatives (CWR) co-occur in southeastern Turkey, Syria, Israel, Palestine, and Jordan (*i.e*., Levant); it is also there that the earliest archaeological evidence for lentil domestication can be found. The possibility that hybridization barriers might not have been strong enough to prevent different *Lens* CWR to contribute to the domesticated gene pool has not been thoroughly investigated. Lentil was one of the first plants domesticated by humans, in SWA, together with wheat and barley, although the precise location(s) where this could have happened is still uncertain. Wild lentils were gathered, by humans in the region, as early as the Upper Paleolithic, as attested by the Ohalo II (Israel, 23,000 BP), Abu Hureyra (Syria, 13,400–11.350 BP), and Mureybit (Syria, 11,800–11,300 BP) sites. Outside SWA, *L. nigricans* was probably gathered in Franchthi Cave (Greece, 15,500–8750 cal BP) and Grotta dell'Uzzo. There is evidence for pre-domestication cultivation of *orientalis* during the Pre-Pottery Neolithic A (PPNA; 11,600– 10,800 cal BP), in the sites of Jerf el Ahmar (Syria, 11,000 cal BP) and Netiv HaGdud In the Pre-Pottery Neolithic B (PPNB; 10,800-8,500BP) sites in the southern Levant, lentil is the most widespread legume. Seeds there were similar in size and shape to wild *orientalis*, but they were found in association with domesticated wheat and barley. Seed size is a trait that was slow to change but is traditionally used to indicate a domesticated status. At the site of Yiftah'el (Israel, 10,100–9,700 cal BP), a hoard of more than 1 million carbonized lentils was recovered contaminated with weed seeds, suggesting that lentil was by then widely cultivated. When agriculture spread outside the Fertile Crescent, lentils were part of the first set of crops introduced in Europe and Egypt. In the Indian subcontinent, it was a staple for the Harappan civilization. By the 5th millennium BCE, lentil was already adapted to the colder and more humid environments of Central Europe, being cultivated by farmers of the Neolithic Linear Pottery Culture. It is unknown if the adaptation of lentils to different environments was due to standing genetic variation in wild populations, the emergence of novel alleles, to epigenetic factors, or a combination of these. The routes by which lentils spread are assumed to have mimicked the appearance of the Neolithic package in different regions, but this is yet to be confirmed (Liber *et al.*, 2021).

Lentils originated from the Fertile Crescent (Eastern Mediterranean to the Persian Gulf) and then spread to Europe, the Middle East, Northern Africa and the Indo-Gangetic Plain. It is one of the earliest domesticated grain legume and was grown in Syria in association with wheat and barley as early as 8500-7500 BC. They are now cultivated in most subtropical and temperate areas, notably in low rainfall regions. Lentils are grown as a summer crop in temperate countries where winters are cold, and as a winter crop in subtropical areas. In the tropics, they can be cultivated at higher altitudes (above 1800 m) during the cool season. Lentils grow under a wide range of average temperatures (6-27°C) but does not do well in humid and hot tropical conditions. Intense or prolonged frost as well as temperatures above 27°C are deleterious to its growth. Lentils do well with below 750 mm annual rainfall and a marked dry period before harvest. Some cultivars can sustain periods of drought. Though it can stand a wide rainfall distribution (300 to 2400 mm), lentils cannot bear water logging and should be sown at the end of the rainy season in warmer areas, where they will grow on residual moisture. Lentils grow on many soil types, ranging from sandy to heavy clay soils, and on a large range of pH (4.5-9), provided that the soils are not saline, waterlogged or subject to flooding (Heuzé *et al*., 2021). Thought to have originated in the Near East or Mediterranean area, lentils have been a source of sustenance for our ancestors since prehistoric times. They are the oldest pulse crop known to man and one of the earliest domesticated crops. The word *lentil* comes from the Latin *lens,* and indeed, this bean cousin is shaped like the double convex optic lens that took its name from the lentil. Lentil artifacts have been found on archeological digs on the banks of the Euphrates River dating back to 8,000 B.C. and there is evidence of the Egyptians, Romans, and Hebrews eating this legume. Lentils are also mentioned several times in the Bible; one example is in the book of Genesis and the story of Esau, who gave up his birthright for a bowl of crimson lentils and a loaf of bread (Filippone, 2021). Lentil (*Lens culinaris* Medik. subsp. *culinaris*) was first cultivated in Southwest Asia (SWA) 8000-10,000 years ago but archeological evidence is unclear as to how many times it may have been independently domesticated, in which SWA region(s) this may have happened, and whether wild species within the *Lens* genus have contributed to the cultivated gene pool. In this study, we combined genotyping-by-sequencing (GBS) of 190 accessions from wild (67) and domesticated (123) lentils from the Old World with archeological information to explore the evolutionary history, domestication, and diffusion of lentils to different environments. GBS led to the discovery of 87,647 single-nucleotide polymorphisms (SNPs), which allowed us to infer the phylogeny of genus *Lens*. We confirmed previous studies proposing four groups within it. The only gene flow detected was between cultivated varieties and their progenitor (*L. culinaris* subsp. *orientalis*) albeit at very low levels. Nevertheless, a few putative hybrids or naturalized cultivars were identified. Within cultivated lentil, we found three geographic groups. Phylogenetics, population structure, and archeological data coincide in a scenario of protracted domestication of lentils, with two domesticated gene pools emerging in SWA. Admixed varieties are found throughout their range, suggesting a relaxed selection process. A small number of alleles involved in domestication and adaptation to climatic variables were identified. Both novel mutation and selection on standing variation are presumed to have played a role in adaptation of lentils to different environments (Liber *et al*., 2021).

Cultivated lentil is thought to have been originated and first domesticated in western Asia and then introduced into the Indo Gengetic plain around 2000 BC. Lentil has also been rapidly spread to Egypt, central and southern Europe, the Mediterranean basin, Ethiopia, Afghanistan, India, Pakistan, China and later to the new world including Latin America, Mexico chili, Argentina, Colombia and more recently Canada. Lentil was first spread to the Nile from the near east, to Central Europe and then to the Indian Subcontinent and the Mediterranean Basin by the end of Bronze Age. It is now cultivated in most subtropical and also in Northern hemisphere such as Canada and Pacific Northwest regions (Matny, 2015). Lentil is considered to have its primary area of diversity in south-west Asia and Mediterranean region. The archaeological proofs indicate near-east Arc as place of primary domestication (Ahlawat, 2023). The cultivated lentil is supposed to have originated in central Asia (India, Pakistan, USSR). Lentils are grown in Egypt since prehistoric times from where it spread to southern Europe, west Asia, India and China. The major lentil producing countries are Turkey, India, Canada, USA, Syria, Morocco and Ethiopia (Pallavi, 2023). Lentils are one of the most ancient of cultivated foods and were likely domesticated in the Near East. The lentil has been found in the lake dwellings of St. Peter's Island, Lake Biel, Switzerland, dating from the Bronze Age. The red pottage of lentils for which the Biblical Esau sold his birthright (Genesis 25:30–34) probably was made from the red Egyptian lentil. Lentils are cultivated in one or another variety in the Middle East, North Africa, and Europe along the Mediterranean coast and as far north as Germany, the Netherlands, and France. In Egypt, Syria, and other Middle Eastern countries, the parched seeds are widely sold in shops and are esteemed the best food to carry on long journeys (Britannica, 2023). Lentil ('*Lens culinaris* ') is a legume that has been grown in the Mediterranean region since ancient times**.** The centre of domestication and diversity is in the Fertile Crescent and West Asia, where it is still an important winter-sown crop. It has now spread globally, with production highest in Canada and in India, where consumption is largely domestic (CGIAR, 2023**).**

TAXONOMY

The genus *Lens* Mill. is a relatively small genus ofthe legume tribe Vicieae that includes four other genera: *Vicia* L., *Lathyrus* L., *Pisum* L. and *Vavilovia* Al. Fed. *Lens culinaris* Medik. is theonly cultivated species of the genus *Lens.* In 1787, the German botanist Medikus assigned lentil the scientific name *Lens culinaris* (Laskar *et al.*, 2019).

Lentil belongs to the genus *Lens* and tribe Vicieae. Cubero (1981) recognized five species in the genus *Lens (Lens culinaris*, *L. ervoides*, *L. montbretti*, *L. nigricans and L. orientalis*. Later another species *L. odomensis* was also included. Among these, *L. culinaris* Medik. has been regarded as the only cultivated species of lentil. The cultivated lentil (*L. culinaris*) was sub-divided in to two types, *macrosperma* and *microsperma,* primarily based on seed characters. The *macrosperma* types were characterized by large seeds (6–9 mm diameter), yellow cotyledons, poor pigmentation on flowers and vegetative parts, whereas, the *microsperma* types were have small seeds (2–4 mm diameter), orange (red)/yellow cotyledons and pigmentation on flowers and vegetative parts. Based on crossability behaviours, the genus *Lens* was classified in two biological species namely, *L. culinaris* and *L nigricans*. Based on cytogenetic and crossability studies have recognized two species within the genus *Lens: L. culinaris* and *L. nigricans*. It was concluded that the genus *Lens* is comprised of seven taxa (*Lens culinaris* ssp. *culinaris*, *L. culinaris* ssp. *orientalis*, *L. odemensis*, *L. ervoides*, *L. nigricans*, *L. tomentosus*, *L. lamottei*) (Mishra *et al*., 2007).

The genus *Lens* consists of the species:

- *Lens culinaris* Medikus,
- its progenitor *L. orientalis* (Boiss.) Hand.-Maz.,
- *L. nigricans* (M. Bieb.) Grand.,
- *L. ervoides* (Bring.) Grand.,
- *L. odemensis* Ladiz.,
- *L. lamottei* Czefranova, and
- *L. tomentosus* Ladiz.

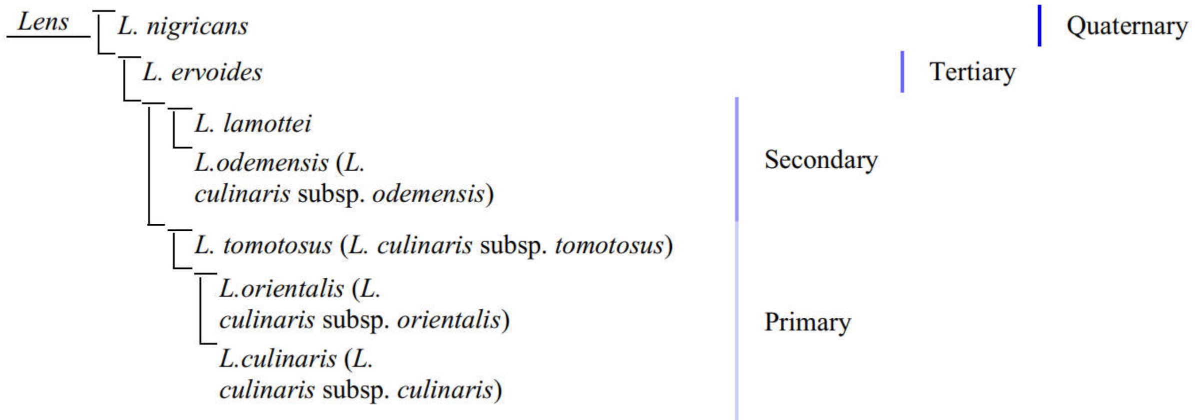
Most accessions of *L. orientalis* cross readily with *L. culinaris*, and both are genetically isolated from the other species. Crosses are possible between *L. culinaris* and the remaining species, but they are characterized by a high frequency of hybrid embryo abortion, albino seedlings and chromosomal rearrangements that result in hybrid sterility, if these seedlings reach maturity (Inspection , 2014).

Lentil belongs to the genus Lens of the Viceae tribe in the Legumnosae (Fabaceae) family, commonly known as the legume family. The plant was given the scientific name *Lens culinaris* in 1787 by Medikus, a German botanist and physician. The cultivated lentil, *Lens culinaris* spp. *culinaris*, has two varietal types: small seeded (*microsperma)* and large seeded (*macrosperma*) (Matny, 2015). Two main groups of domesticated lentils are recognized on the basis of seed size: *microsperma* and *macrosperma.* The weight of 100 seeds ranges from 1.5 g for the smallest *microsperma* varieties to 8.0 g for large *macrosperma* types (CGIAR, 2023). The genus *Lens* comprises the following species: *L. culinaris* with two subspecies: ssp. *culinaris* (the domesticated lentil) and ssp. *orientalis* (the wild form of ssp. *culinaris*), *L. tomentosus, L. odemensis, L. ervoides, L. nigricans*, and *L. lamottei*. Each of these species has its own morphological characteristics and shows specific ecological affinities and typical geographic distribution. Furthermore, they are reproductively isolated from one another by cross-incompatibility or by hybrid sterility. Chromosomically ssp. *orientalis* is the most variable of all the *Lens* taxa, as indicated by the occurrence of multivalent formations at meiosis or of bridges and fragments in intra-taxon hybrids. *Lens culinaris* and particularly its wild form comprise several crossability groups, one of which includes the domesticated lentil and most of its wild-form accessions. Based on characteristics that are monomorphic in ssp. *culinaris* but variable in ssp. *orientalis*, it was proposed that the wild genetic stock that gave rise to the domesticated lentil was the one of ssp. *orientalis* that shared them with the domesticated form. These characteristics are chromosome arrangement, crossability potential, and pattern of restriction-enzyme recognition sites of chloroplast DNA (cpDNA). Populations of ssp. *orientalis* possessing these characteristics were detected in northern Syria and southern Turkey. The effective wild gene pool of the cultigens includes members of ssp. *orientalis*, *L. odemensis, L. tomentosus,* and *L. ervoides*, the last two species can be exploited only by hybrid embryo rescue techniques (Ladizinsky and Abbo, 2015).

Lens morphology was described by Ladizinsky and Abbo (2015) is as follows: Annual; stems erect or climbing; leaves paripinnate; stipules lanceolate or semisagittate (semihastate); petioles mostly terminating in a tendril or awn; leaflets, 4−12; peduncles, 1−3 flowered, arista present or absent; pods short, rhomboid, glabrous, puberulent or tomentose, dehiscent in wild species, 1−2 seeded, compressed; seed compression lenticular, $2n = 14$. The morphological characters that can be used (though not as single traits) for identification of lentil species are the number of leaflets per leaf, the presence or absence of tendrils, stipule shape and orientation, and pod pubescence. Except in the case of pod hairiness, the traits are usually more pronounced on the middle parts of the plant.

Lentil is considered to be one of the oldest legumes used by humans, as attested by the remains of lentil seeds found in archaeological diggings as old as 10,000 years. Our findings indicate that lentil seeds formed only a negligible part of the pre-Neolithic diet. In nature, plants of ssp. *orientalis* grow in sparse stands and produce on average about 10 seeds per plant. To obtain 1 kg of wild lentil seeds, about 10,000 plants must be collected—not an attractive option in terms of input and output. Furthermore, because of seed-coat impermeability to water, only about 10 % of seed collected in spring will germinate in the following winter. As each of the resultant plants will produce 10 seeds, the expected yield is similar to the quantity of seeds sown. With regard to the question of how lentil cultivation began, it has been suggested that a germination-free mutant evolved in a natural stand of ssp. *orientalis*, resulting in the formation of a massive stand that attracted food gatherers, and when seeds collected from such populations were used in sowing experiments the yield was high enough for lentil cultivation to be continued (Ladizinsky and Abbo, 2015).

Lens is a genus of flowering plant in the legume family mostly known for its edible seeds, which are referred to as lentils. *Lens* contains four species of small, erect or climbing herbs with pinnate leaves, small inconspicuous white flowers, and small flattened pods. The lentil most commonly eaten is the seed of *Lens culinaris* (Wikipedia, 2023a). The genus *Lens* is generally divided into a few related "gene pool" groups that guide crossing. (Wikipedia, 2023a) reports a SNP-derived phylogeny as follows:



Lentil belongs to the Family Fabacaeae, Genus Lens, Species Lens culinaris Medikus and Subspecies *culinaris* (Wikipedia, 2023; BSMRAU, 2023).

Lens culinaris has the following subspecies (Wikipedia, 2023)

Lens culinaris subsp. *culinaris* – cultivated lentil
Lens culinaris subsp. *orientalis* (Boiss.) Ponert – wild progenitor
Lens culinaris subsp. *tomentosus* (Ladiz.) M. E. Ferguson et al.

Lens culinaris has the following synonyms (Wikipedia, 2023):

Cicer lens (L.) Willd.
Ervum lens L.
Lathyrus lens (L.) Bernh.
Lens esculenta Moench
Lens lens (L.) Huth
Lentilla lens (L.) W.Wight
Orobus lens (L.) Stokes
Vicia lens (L.) Coss. & Germ.

However, TPL (2013) reported only six synonyms as follows:

Ervum lens L.
Ervum lens Wall.
Lens culinaris subsp. *culinaris*
Lens esculenta Moench
Lens lens Huth
Vicia lens (L.) Coss. & Germ.

Heuzé *et al*. (2021) reported only four synonyms as follows:

Ervum lens L.,
Lens esculenta Moench,
Lens lens Huth,
Vicia lens (L.) Coss. & Germ.

The lentil species Lens culinaris has one cultivated subspecies (Lens culinaris Medik. subsp. culinaris) and 3 wild subspecies. The cultivated subspecies Lens culinaris subsp. culinaris is divided into two groups of cultivars: macrosperma (large seeds) lentils are mainly cultivated in Europe, North Africa and America, whereas microsperma (small seeds) lentils are grown in Asia, Egypt and Ethiopia. Both types are cultivated in Western Asia and South-Eastern Europe (Heuzé *et al*., 2021). There are two cultivated species of genus *Lens* i.e. *Lens esculenta* Moench and *Lens culinaris* Medik. The wild species include *L. orientalis* (Boiss) Hand-Mazz, *L. nigricans*, *L. erroids* and *L. montbretti*. The cultivated species *L. esculenta* are classified into 2 sub groups according to size of the seed (Ahlawat, 2023): Sub-species *microsperma*: They have small seed of 2-6 mm diameter and are produced in India, Africa and Asia. Pods are complex and small. Sub-species *macrosperma*: They have large seeds of 6-9 mm diameter and are grown in Mediterranean region and North America. Mostly pods are flat and large. Two types of lentils are known (Pallavi, 2023): *macrosperma* (masur or malkamasur) with large flat pods and large seeds (6.9 mm dia) found in Mediterranean, Africa and central Asia and *microsperma* (masuri) with small convex pods and small seed (3-6 mm dia), chiefly found in India, Pakistan and south and west Asia.

Lens culinaris is subdivided on the basis of seed size into two races: *macrosperma* and *microsperma*. The distinguishing characteristics of the two races are as follows (Laskar *et al*., 2019):\

Macrosperma Large pods (15–20 × 7.5–10.5 mm) generally flat enclosing large flattened seeds; 1000 seed weight is 25–50 g. Cotyledons yellow or orange. Flowers large (7–8 mm long), white with veins, rarely light blue, very light or no pigmenta-tion, 2–3 flowered peduncles. Long calyx teeth. Oval shaped large leaflets with dimensions 15–27 × 4–10 mm, length to width ratio range is 3–3.5. Height of plantis 25–75 cm.

Microsperma Pods small or medium (6–15 × 3.5–7 mm), convex. Seed flat- tened – subglobose, small or medium (3–6 mm diameter) with 1000 seeds weight up to 25 g. Cotyledons red, orange or yellow. Flowers white to violet, small (5–7 mm long),and 1–4 flowered peduncles. Elongated linear or lanceolate shaped small leaflets with dimensions 8–15 × 2–5 mm, length to width ratio is 4–5. Height of plant 15–35 cm.

The genus *Lens* belongs to the Fabaceae family and includes the wild subspecies *L. culinaris* subsp. *orientalis*, the presumed progenitors *L. culinaris* subsp. *tomentosus* and *L. culinaris* subsp. *odemensis*, along with three other wild species. The taxonomy of *Lens*, however, remains in debate. All species of lentil are self-pollinating annual diploids (2n=14) (CGIAR, 2023).

This species contains the following accepted infraspecific taxa/subspecies (TPL, 2013):

Lens culinaris subsp. *microsperma* (Baumg.) N.F.Mattos
Lens culinaris subsp. *odemensis* (Ladiz.) M.E.Ferguson & al.
Lens culinaris subsp. *orientalis* (Boiss.) Ponert
Lens culinaris subsp. *tomentosus* (Ladiz.) M.E.Ferguson & al.

Two broad varietal types of lentils are recognized based on morphological traits: the large- seeded *macrosperma* and the small-seeded *microsperma*; with a wide diversity of seed color and nutrient content. The taxonomy of the genus *Lens* has long been a matter of debate, with genetic, biochemical, morphological, plastid, and hybridization data providing conflicting results regarding its classification at the species and subspecies levels. The more widely accepted taxonomy recognizes four species: *L. culinaris* with four subspecies (subsp. *culinaris*, subsp. *orientalis*, subsp. *odemensis*, and subsp. *tomentosus*), *Lens lamottei, Lens ervoides,* and *Lens nigricans.* Cumulative evidence indicates that *L. c.* subsp. *orientalis* (henceforth referred as *orientalis*) is the wild progenitor of cultivated *L. c.* subsp. *culinaris* (henceforth referred to as *culinaris*). *Orientalis* presently occurs in Southwest Asia (SWA) and, occasionally, in Central Asia and Cyprus. The other wild species are distributed throughout the Mediterranean Basin: (i) *L. ervoides* is found in Israel, Syria, Turkey, the Adriatic Coast, Southern Italy, and, rarely, in Spain and Algeria; (ii) *L. nigricans* is found in Southern Europe from Spain to Turkey, the Crimean Peninsula, Georgia, and, occasionally, in Morocco and Algeria; (iii) *L. lamottei* is found predominantly in Morocco (Liber *et al.,* 2021).

According to the latest classification, the genus *Lens* consists of seven taxa in four species (Laskar *et al.*, 2019):

Lens culinaris Medik.ssp. *culinaris*
ssp. *orientalis* (Boiss.) Ponert
ssp. *tomentosus* (Ladiz.) M.E. Ferguson& al.ssp. *odemensis* (Ladiz.) M.E. Ferguson& al.
Lens ervoides (Brign.) Grande *Lens nigricans* (M. Bieb.) Godron*Lens lamottei* Czefr.

Lentil belongs to subfamilies Papilionoideae of legume. The species belonging to this subfamily are distributed into four clades: (1) the dalbergioid clade (it is more basal and mostly tropical), (2) the genistoid clade, (3) the haseoloids/millettioid clade, and (4) the galegoids/hologalegina clade. Lentil, which is a temperate or cool season legume, is the member of inverted repeat loss subclade (i.e., presence of a lost copy of the inverted repeat in the chloroplast genome of most angiosperms) of galegoids/hologalegina clade. Other members of this subclade are alfalfa (*M. truncatula*), chickpea (*Cicer arietinum*), faba bean (*Vicia faba*), and pea (*Pisum sativum*). A relationship based on molecular markers showed high-level synteny of lentil genome with the genome of *Medicago truncatula* and pea. Traditionally, the relationship among species has been established on basis of morphological characters and crossability among the species. This helped to establish their species or subspecies status. Free crossability of *L. odemensis* with *L. culinaris* subsp. *culinaris* and *L. culinaris* subsp. *orientalis* was identified as separate taxa from *L. nigricans* and *L. nigricans* with two subspecies, *nigricans* and *ervoides*. However, pollen and pistil morphology established close relationship between *L. odemensis* and *L. nigricans*, and these two species showed relationship with *L. culinaris* subsp. *orientalis. L. ervoides* was loosely related to all these taxa. The specific status of *L. tomentosus* is still debatable because this species only separated from *L. culinaris* subsp. *orientalis* on the basis of tomentose as opposed to glabrous pods and by the presence of a small, asymmetrical minutely satellited chromosome. *L. orientalis* is clearly the wild progenitor of cultivated species, and hence this was considered as subspecies of the cultivated species *L. culinaris*. Based on morphological, biochemical, and molecular markers, *L. odemensis* and *L. tomentosus* have also been considered as the subspecies of *L. culinaris* (Kumar *et al*., 2014).

BOTANICAL DESCRIPTION

All *Lens* species are annual, herbaceous diploids, 2N = 14. The lentil plant has a fine stem, rarely grows more than 45 cm tall and has an indeterminate growth habit. The first two nodes are vestigial and occur at or below the soil surface. If apical dominance is destroyed or if growing conditions are favourable, new shoots will arise from the dormant buds at the uppermost of these two nodes. The lentil plant may produce up to four basal branches and will produce up to five aerial branches at the five uppermost nodes just below the first flower. Under extremely favourable growing conditions, the aerial branches may also produce secondary branches. The first flower on the main stem is borne in the axis of the 11th to 13th node above the first two vestigial nodes. The leaves are pinnate with up to 10 pairs of leaflets. One or two small lens-shaped seeds are borne in small, flattened pods (one or two) on a short pedicel arising in the leaf axils above the 11th to 13th node. The seed coat colour ranges from white (zero tannin) to pale green to gray to brown to black, often with purplish flecks of varying sizes. Seed weight ranges from 30 to 70 g/1000 seeds in Canadian cultivars, but is much lower in Indian cultivars and in the wild species (Inspection , 2014).

The botanical features of *Lens culinaris* (cultivated lentil) can be described as annual bushy herb, slender almost erect or suberect, much-branched, softly hairy; stems slender, angular, 15-75 cm height. Ten to sixteen leaflets are subtended on the rachis (40-50 mm); upper leaves have simple tendrils while lower leaves are mucronate. "The leaves are alternate, compound, pinnate, usually ending in a tendril or bristly; leaflets 4-7 pairs, alternate or opposite; oval, sessile, 1-2 cm long; stipules small, entire; stipules absent; pods oblong, flattened or compressed, smooth, to 1.3 cm long, 1-2-seeded; seed biconvex, rounded, small, 4-8 mm × 2.2-3 mm, lens-shaped, green, greenish-brown or light red speckled with black; the weight of 100 seeds range from 2 to 8 g; cotyledons red, orange, yellow, or green, bleaching to yellow, often showing through the testa, influencing its apparent color". Flowers are small, pale blue, purple, white or pink, in axillary 1-4-flowered racemes; 1-4 flowers are borne on a single peduncle and a single plant can produce upto 10-150 peduncles each being 2.5-5 cm long. Flowering proceeds acropetally. The size of seeds increase from the types grown in eastern regions to western types. Two types, namely; *macrosperma*, found mainly in the Mediterranean region and the New World (seed size ranging from 6 to 9 mm in diameter and yellow cotyledons with little or no pigmentation), and *microsperma* (2 to 6 mm with red orange or yellow cotyledons) found on the Indian subcontinent, Near East and East Africa, respectively, are known. The first one includes the Chilean or yellow cotyledon types while the latter includes the small seeded Persian or red cotyledon lentils. Germination is hypogeal and this keeps the developing seedlings below ground level which reduces the effects of freezing and other desiccating environmental conditions (Muehlbauer and Tullu, 1997).

It is an annual bushy herb with slender stem and having many branches with erect, semi-erect or spreading growth habit. Lentil plants are typically short, but can range from 20 to 75cm in height, depending on growing conditions. The cotyledons remain under ground after germination. The first two nodes on the stem develop below, or at the soil surface and are known as scale nodes. Plants can have single stems or many branches depending upon the population in the field. Lentil plants have an indeterminate growth habit. Flowering begins on the lowest branches, gradually moving up the plant and continuing until harvest. Lentil continue to flower until they encounter some form of stress, such as drought, heat, frost, nitrogen deficiency, mechanical damage, or chemical desiccation. This indeterminate growth habit is most predominant in late maturing varieties, but all current lentil varieties have indeterminate growth habit. Flowers of lentil are self-pollinated and first few flowers on the main stem may abort. This occurs if conditions favour excessive vegetative growth over seed production, such as good moisture combined with high nitrogen fertility (Matny, 2015).

Lens culinaris ssp. *culinaris* is a Cultivated, erect or ascending, height 20−40 cm, 8−14 leaflets per leaf. Upper leaves usually terminate in simple or branched tendrils, stipules entire, lanceolate. Peduncle 1−3 flowered, arista 2−4 mm. Corolla white, blue or pale, with all intergradations between them. Pod broadly rhomboid, glabrous; indehiscent at maturity, but some dehiscence may occur in old varieties and land races, particularly during late harvest. Weight per 100 seeds is 3−6 g, the lower value being typical of the cultivar group known as microsperma and the higher typical of the so-called macrosperma group of lentil varieties. In traditional farming systems, cultivated lentil may occasionally grow as volunteer plants in abandoned fields and plantations or next to arable land where the habitat is suitable. These volunteers usually have white flowers and can be confused with *L. culinaris* ssp. *orientalis.* The cultivated lentil is a traditional crop in the Mediterranean region, the Middle East, the Indian subcontinent, and Ethiopia and is grown as a modern crop in North and South America and Australia (Ladizinsky and Abbo, 2015).

Lentil is an annual herb, erect in growth form, much branched with a slender stem; leaves are alternate, compound, pinnate, usually ending in a tendril or bristly;leaflets alternate or opposite, stipules small and linear. Flowers are small, pale blue or purple, 1–4 flowers in axillary racemes. Pods are oblong, flattened or compressed, smooth containing 1–2 seeds; seeds lens shaped; greenish brown or light-red. The hypogeal germination found in lentil allows developing seedlings to grow below the ground level, which facilitates evading harsh environmental conditions at an early growing stage. Self-pollination is a common phenomenon in lentil, with cross-pollination reported usually <1–6.6%. Flowering takes place acropetally (upward) (Laskar *et al*., 2019).

Lentil (*Lens culinaris* Medik.) is a legume mainly grown for its edible seeds. It is an annual, bushy and herbaceous plant that can reach 60-75 cm high. The stems are hairy, slender and many-branched. The leaves are pinnately compound, ending in a tendril or bristle. The 5 to 16 leaflets are opposite, oblong to elliptical, 3-20 mm long x 2-8 mm broad. The papilionaceous flowers vary in colour from white to purple and are borne on 2-5 cm long axillary racemes. The fruits are small, laterally compressed pods that contain two or three lens-shaped, grey, green, brownish, pale red or black seeds, the size of which depends on cultivar type and ranges from 2-9 mm x 2-3 mm (Heuzé *et al*., 2021).

Lentil, *Lens culinaris*, is a a bushy, annual legume in the family Fabaceae grown for its edible seeds which are cooked and eaten. The lentil plant is slender and erect or sub-erect and has branching, hairy stems. The leaves of the plant are arranged alternately and are made up of 4–7 individual oval leaflets. The plant produces small blue, purple, white or pink flowers arranged on racemes with 1–4 flowers. The seeds, or lentils, are produced within rhomboidal pods and can range in size from 2-9 mm in diameter depending on the variety and can be red-orange, yellow, green or black in color. There are generally 1–2 lentils per pod. Lentil plants can reach 15–75 cm in height and as annuals, survive only one growing season. Lentil may also be referred to as red dhal or split pea and its origin is unknown although it is grown widely in Europe, Asia, and North Africa (Moncel, 2022).

The lentil plant is a short (20–50 cm), bushy annual with weakly upright to semi-vining growth. It has a restricted root system and tends to lodge at maturity because of its weak stem. It has many soft, hairy branches with pinnately compound leaves and numerous oval leaflets (CGIAR, 2023). The plant varies from 15 to 45 cm in height and has many long ascending branches. The compound leaves are alternate, with six pairs of oblong-linear leaflets about 15 mm long and ending in a spine. Two to four pale blue flowers are borne in the axils of the leaves in June or early July. The small pods are broadly oblong and slightly inflated and contain two seeds the shape of a doubly convex lens and about 4–6 mm in diameter. There are many cultivated varieties of the plant, differing in size, hairiness, and colour of the leaves, flowers, and seeds. The seeds may be more or less compressed in shape and can be white, yellow, orange, tan, green, gray, or dark brown in colour; they are also sometimes mottled or speckled (Britannica, 2023).

Lens is a small genus which consists of the cultivated *L. culinaris* and six related wild taxa. Among the different taxa of wild lentils, *L. orientalis* is considered to be the progenitor of the cultivated lentil and is now generally classified as *L. culinaris* subsp. *orientalis*. Lentil is hypogeal, which means the cotyledons of the germinating seed stay in the ground and inside the seed coat. Therefore, it is less vulnerable to frost, wind erosion, or insect attack. The plant is a diploid, annual, bushy herb of erect, semierect, or spreading and compact growth and normally varies from 30 to 50 centimetres in height. It has many hairy branches and its stem is slender and angular. The rachis bears 10 to 15 leaflets in five to eight pairs. The leaves are alternate, of oblong-linear and obtuse shape and from yellowish green to dark bluish green in colour. In general, the upper leaves are converted into tendrils, whereas the lower leaves are mucronate. If stipules are present, they are small. The flowers, one to four in number, are small, white, pink, purple, pale purple, or pale blue in colour. They arise from the axils of the leaves, on a slender footstalk almost as long as the leaves. The pods are oblong, slightly inflated, and about 1.5 centimetres long. Normally, each of them contains two seeds, about 0.5 centimetres in diameter, in the characteristic lens shape. The seeds can also be mottled and speckled. The several cultivated varieties of lentil differ in size, hairiness, and colour of the leaves, flowers, and seeds (Fig. 1, 2, 3) (Wikipedia, 2023).

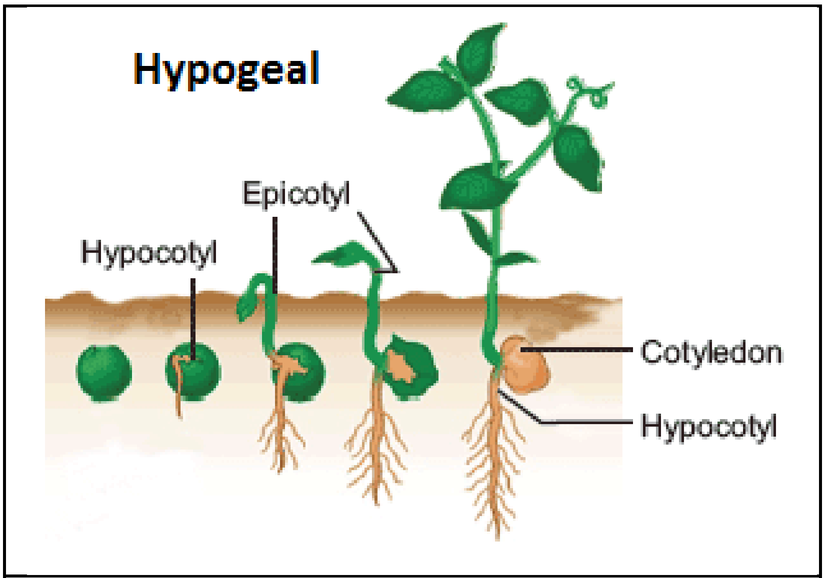


Fig. 1. Hypogeal germination in lentil

		
Lentil field	**Lentil plants**	**Lentil leaves**
		
Lentil flowers	**Lentil flowers**	**Immature pods of lentil**
		
Mature pods of lentil	**Lentil Seeds**	**Lentil plant**

Fig. 2 : Botanical description

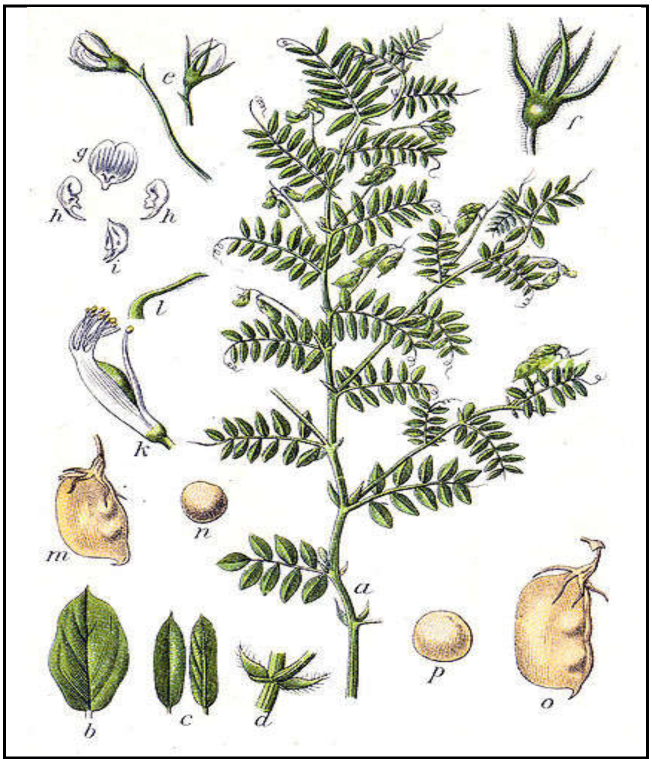


Fig. 3 : Botanical Description

Stem is Erect or sub-erect, slender, square cover with hairs. Leaf is Pinnate with four to eight pairs of leaf-let and usually ending in a tendril. Leaflets are obovate to lanceolate and arranged in a opposite to alternate. Flower is White, pink to bluish color and borne in axillary racemes up to four flowers together. Fruit is small, flattened pod and containing 1 or two seed **(**BSMRAU, 2023**).** Lentil is a herbaceous annual plant, mostly erect and bushy type with 4-6 primary branches. Lentil has well developed root system including a central tap root with several lateral branches spread out in all directions. The stem is weak and quadrangular. The leaves are small, compound and pinnate. The end of leaflets sometimes forms tendrils. The inflorescence is a receme of 2-4 flowers. Flowers are small, white tinged with blue violet or pink. Flowers consist of 5 sepals, 5 petals comprising of 1 standard, 2 wings and 2 keels, 10 stamens, 9 fused to form a staminal column. Ovary is short with 1 or 2 ovules, style curved and hairy on its inner surface. Pods are short, flattened, 1-1/2 cm long with curved beak. Pods contain mostly 2 seeds. Seeds are often light brown in colour and lens shaped. The crop is generally self-pollinated (Ahlawat, 2023).

Floral biology, Pollination, selfing and Crossing: Chickpea is a self pollinated species with normal out crossing limited to 1.58%. self pollination takes place one or two days before opening up of the flower. The flower open in the morning and close in the afternoon and each flower opens on two or three successive days. Time of anthesis is 3 AM to 9 AM. For hybridization crossing work should be started when the first pod on the selected plant is already formed. In Northern India, emasculation is done a day prior to pollination. The pollination is done in the morning hours give better setting. In south India, pollination immediately after emasculation give higher seed setting (Muehlbauer *et al*., 1980). Lentils are self-pollinating. The flowering begins from the lowermost buds and gradually moves upward, so-called acropetal flowering. About two weeks are needed for all the flowers to open on the single branch. At the end of the second day and on the third day after the opening of the flowers, they close completely and the color begins to fade. After three to four days, the setting of the pods takes place (Wikipedia, 2023).

Two crossing techniques for hybridization of chickpea have been reported and include pollination after emasculation and pollination without emasculation. Success of crossing with emasculation varied from 5 to 17%; while the success rate varied from 20 to 50% by pollination without emasculation. The important reason for the low success rate of the two procedures could be lack of detailed information on the flowering stages chosen for crossing together with the environment where plants grow. We describe a comprehensive method for chickpea crossing where two genotypes, ICCV96029 as female and PI503023 as male parent were used. Leaf shape and seed size were used as morphological markers to select hybrids. For crossing, incision was made along the central line of the keel petal for the removal of anthers and to expose the stigma for placement of pollen from donor parent on its surface. After pollination, style was inserted back gently inside the keel petal and covered by wing petals and standard petals to make a natural sac which prevents drying of internal organs. Alternatively, if the conditions are favorable there is no need to protect the pollinated flower and therefore petal removal method for cross-pollination can be used. Our method showed around 78% crossing success rate which is much higher than the previous results. We have shown that the crossing by keel petal incision or petal removal is an effective approach which significantly increases the crossing success rate. Furthermore, our detailed method shows that the flowering stage, selection of parents and temperature play crucial roles in crossing success (Kalve and Tadege, 2017).

Cross breeding techniques: Crossbreeding in lentil is a tiresome job and the success of the artificial hybridization has a range of 20–50%, depending upon the genotypes involved, and climatic condition such as temperature and humidity. Since lentil flowers are tiny and fragile, emasculation and pollination usually cause injury to the floral parts, thus reducing the success rate. To increase the success rate of hybridization the following actionsare recommended:

(1) Selection of appropriate size flower buds; (2) Selection of lateral buds rather than the terminal ones (Sindhu *et al.,* 1981); (3) During emasculation and pollination, proper care is required to avoid any mechanical injury to the floral parts.

Timing of pollination and fertilization is also vital in determining the success rate. Low temperatures, afternoon emasculation followed by pollination the fol-lowing morning gives better results. However, high temperatures, morning emasculation followed by immediate pollination are also reported to be successful (Laskar *et al.,* 2019).

A dissecting microscope, sharply pointed forceps, alcohol, and small tags are the only equipment needed for lentil hybridization. Emasculation of lentil flowers is necessary to prevent self-pollination.

GENETICS AND CYTOGENETICS

In the Indian sub continent, lentil (*Lens culinaris* Medik.) is a major rabi pulse crop with 2n = 2x = 14 chromosomes. Chromosomal studies were carried out on Indian lentils during the period of 1952 to 1991 employing orcein squash techniques by different authors but there was no unanimity on chromosome morphology and chromatin length. This is the first study conducted on two wild and 12 cultivated cultivars of Lens for detailed and comparative chromosomal analysis using enzymatic maceration and air drying (EMA) based Giemsa staining methods. Chromosomal analysis revealed chromosomal stability, uniform karyotype formula (3m + 1m (sat) + 2sm + 1st), one pair of interstitial sat in either chromosome number 3 or 4 and interesting variations in total chromatin length (53.6–121.2 µm) in all the studied cultivars (Jha *et al*., 2015) .

Studies of the relationships between *L. montbretti* and other *Lens* species in our possession at that time showed that this taxon differed considerably from the other *Lens* species according to morphological and chromosomal criteria **(Fig. 4)** and was cross-incompatible with them. Accordingly, we recommended returning it to the genus *Vicia*, where it was originally placed (Ladizinsky and Abbo, 2015).

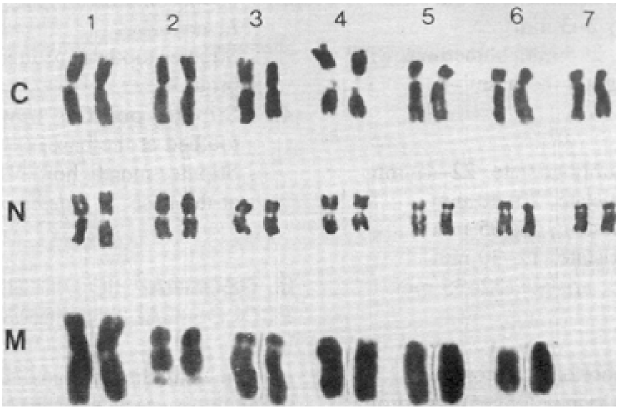


Fig. 4. Karyotypes of *L. culinaris* (C), *L. nigricans* (N), and *Vicia montbretii* (M)

All *Lens* species are diploid with 2*n* = 14. The standard karyotype of the genus consists of three pairs of submetacentric chromosomes, three pairs of acrocentric chromosomes, and a pair of metacentric chromosomes with a secondary constriction. The satellite is large and includes most of the arm(Ladizinsky and Abbo, 2015) **(Fig. 5).**

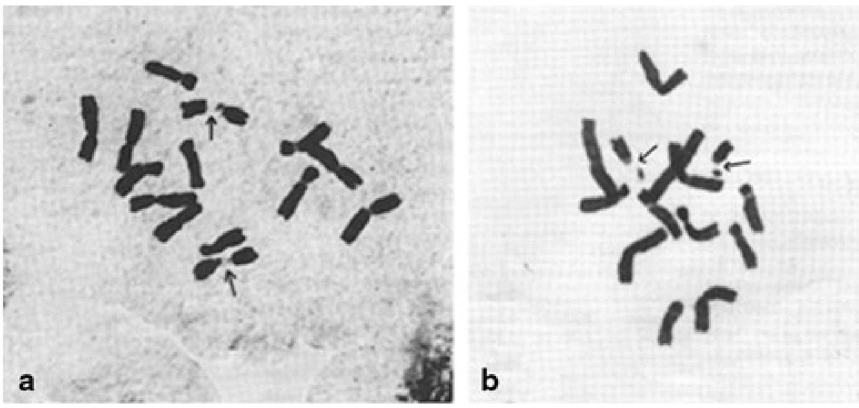


Fig. 5. Karyotypes of (a) *L. culinaris* and (b) *L. tomentosus*

Based on crossability assigned *Lens* species is divided into primary, secondary, and tertiary gene pools. GP-1: *Lens culinaris* ssp. *culinaris, orientalis, odemensis*; GP-2: *L. ervoides, L. nigricans;* GP-3; *L. lamottei, L. culinaris* ssp. *tomentosus*. *L. culinaris* ssp. *orientalis* exhibited resistance to cold, drought, wilt and *Aschochyta* blight. *Lens nigricans* and *L. culinaris* can form hybrids but with low seed set (Laskar *et al*., 2019).

GENETIC DIVERSITY

The seed coat colour ranges from white (zero tannin) to pale green to gray to brown to black, often with purplish flecks of varying sizes. Seed weight ranges from 30 to 70 g/1000 seeds (Inspection , 2014). Pods that contain two or three lens-shaped, grey, green, brownish, pale red or black seeds, the size of which depends on cultivar type and ranges from 2-9 mm x 2-3 mm (Heuzé et al., 2021). The seeds may be more or less compressed in shape and can be white, yellow, orange, tan, green, gray, or dark brown in colour; they are also sometimes mottled or speckled (Britannica, 2023). The flowers, one to four in number, are small, white, pink, purple, pale purple, or pale blue in colour. Seeds can range in size from 2-9 mm in diameter depending on the variety and can be red-orange, yellow, green or black in color. There are generally 1–2 lentils per pod. The hypogeal germination found in lentil allows developing seedlings to grow below the ground level, which facilitates evading harsh environmental conditions at an early growing stage. The plant is a diploid, annual, bushy herb of erect, semierect, or spreading and compact growth and normally varies from 30 to 50 centimetres in height. Splits of lentil are also in different color, shape and size **(Fig. 6, 7)** (Inspection, 2014; Heuzé et al., 2021; Britannica, 2023).

Fig. 6. Variability for seed coat color, shape and size of lentil

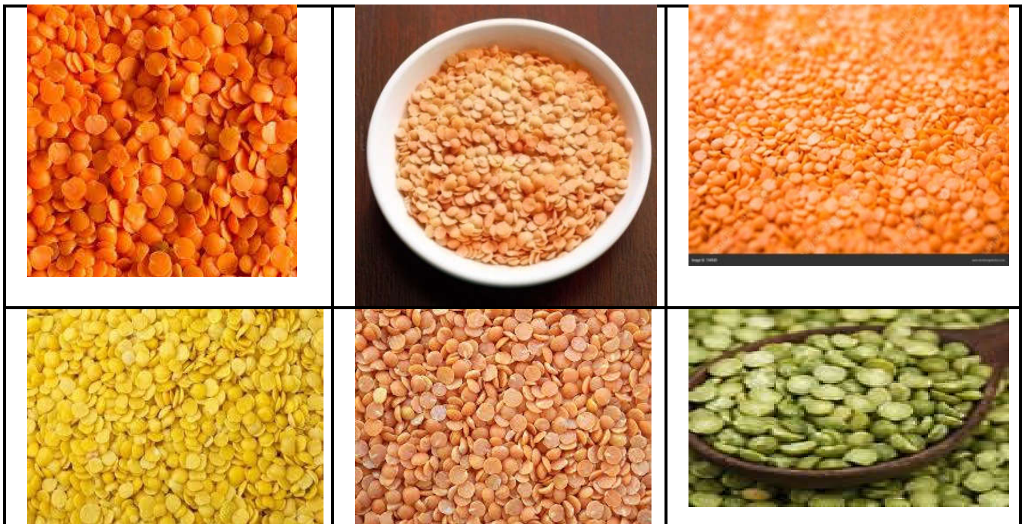


Fig. 7: Splits of lentil in different color, shape and size

When genetic variability is narrowed using traditional breeding methods for a long period, induced mutations are one of the most important approaches for broadening the genetic variation in lentil to circumvent the bottleneck conditions (Toker *et al.,* 2007). Assessment of genetic diversity and population structure of germplasm collections plays a critical role in supporting conservation and crop genetic enhancement strategies. We used a cultivated lentil (*Lens culinaris* Medik.) collection consisting of 352 accessions originating from 54 diverse countries to estimate genetic diversity and genetic structure using 1194 polymorphic single nucleotide polymorphism (SNP) markers which span the lentil genome. Using principal coordinate analysis, population structure analysis and UPGMA cluster analysis, the accessions were categorized into three major groups that prominently reflected geographical origin (world's agro-ecological zones). The three clusters complemented the origins, pedigrees, and breeding histories of the germplasm. The three groups were (a) South Asia (sub-tropical savannah), (b) Mediterranean, and (c) northern temperate. Based on the results from this study, it is also clear that breeding programs still have considerable genetic diversity to mine within the cultivated lentil, as surveyed South Asian and Canadian germplasm revealed narrow genetic diversity (Khazaei *et al.,* 2016). Global cultivated lentil germplasm selected for this study clustered primarily based on eco-geographical origin into three basic groups: subtropical savannah, Mediterranean, and northern temperate. The narrow genetic base of some groups of germplasm (*e.g.,* Canadian and South Asian) raises concern over the loss/penalty in yield due to biotic and abiotic stresses, particularly with the threat to global food security from climate change. This highlights the importance of harnessing the potential of lentil wild species in breeding programs by introgression of favorable genes from other regions. Based on the results from this study, it is also clear that breeding programs still have a lot of genetic diversity to mine within the cultivated species (Khazaei *et al*., 2016).

A total of 48 lentil genotypes were grouped into distinct groups for each character based on different forms of morphological characters. Almost all the genotypes have orange cotyledon except PL 6 which has yellowcotyledon and only local accession IC 201738 had black testa colour. For plant type 29%, 65% and 6% genotypes were classified into erect, semi-spreading and spreading, respectively. Based on rust scoring 67% genotypes were resistant type and only 33% genotypes were susceptible type. Three different groups *i.e.,* light green, medium green and dark green were formed and 15%, 69% and 17% genotypes were present in different groups, respectively. 79% genotypes were mottled type and 21% were non- mottled type. In conclusion, it can be said that plant breeders can use these genetic variations to make decision regarding the choice for selecting superior genotypes for improvement or to be utilized as parents for the development of future cultivars through hybridization. Furthermore, important morphological markers like, plant type, foliage colour, testa colour, testa pattern and cotyledon colours can also be used for testing hybridity and keeping genetic purity at genetic level (Choudhary *et al.,* 2017).

The genetic diversity of 96 genotypes of lentil comprising 34 cultivars, 46 advanced breeding lines, and 16 germplasm lines were studied using 260 SSR markers. These markers generated a total of 749 alleles. The alleles/locus ranged from 2 to 16 with an average value of 2.87. Polymorphic information content varied from 0.02 to 0.91 with a mean of 0.30. Major allelic frequency ranged from 0.14 to 0.99 with a mean of 0.77. Studied genotypes were clustered into two groups according to their breeding history. Advanced breeding lines derived from exotic lines were clustered in one group, while another group accommodated most of the cultivars and advanced breeding lines with common cultivars in parentage. The germplasm lines were sub-clustered within first group. Cumulatively, first three principal components contributed 21.2% to the total variability. Advanced breeding lines showed higher number of alleles/locus and gene diversity (*He*) than other sets of genetic materials. In present study, no significant differences were observed between cultivars developed in different decadal groups for both NA and *He*. Moreover, genetic diversity changes between small and large seeded lentil cultivars were also found non-significant in this study. These findings showed that the use of alien genes can help to diversify active genepool for developing improved new cultivars in lentil (Kumar *et al.,* 2018). The Greek lentil landrace ‘Eglouvis’ is cultivated continuously at the Lefkada island for more than 400 years. It has great taste, high nutritional value and high market price. In the present study, we used morphological and molecular markers to estimate genetic diversity within the landrace. Morphological analysis was based on characteristics of the seed. Molecular analysis was performed using simple sequence repeat (SSR) molecular markers in a high-resolution melting (HRM) approach. ‘Samos’ and ‘Demetra’, two of the most widely cultivated commercial lentil varieties in Greece, were used for comparisons. Morphological analysis was performed with 584 seeds randomly selected from a lot. Analysis of seed dimensions and colour distributed the samples in different categories and highlighted the phenotypic variability in ‘Eglouvis’ lentil seeds. Genetic variability was estimated from 91 individual DNA samples with 11 SSR markers using HRM analysis. Genotyping was based upon the shape of the melting curves and the difference plots; all polymerase chain reaction products were also run on agarose gels. Genetic distances of individuals and principal coordinates analysis suggested that ‘Eglouvis’ landrace has a unique genetic background that significantly differs from ‘Samos’ and ‘Demetra’ and no overlapping could be detected. Genetic variability within the ‘Eglouvis’ landrace can be considered in targeted breeding programs as a significant phytogenetic resource of lentils in Greece (Tsanakas *et al.,* 2018).

Knowledge of genetic diversity and population structure is a crucial step for an efficient use of available material in a plant breeding program and for germplasm conservation strategies. Current study undertakes an assessment of the genetic variations and population structure of Moroccan lentil including nine landraces and eight released varieties using sequence-related amplified polymorphism (SRAP) and random amplified polymorphism DNA (RAPD) markers. Results revealed that the two markers used have a good efficiency to assess genetic diversity in lentil. A total of 115 and 90 bands were respectively scored for SRAP and RAPD, of which 98.3% and 93.3% were polymorphic. The polymorphic information content values were 0.350 with SRAP and 0.326 with RAPD. Analysis of molecular variance based on the combined data sets of both markers revealed lower variations within (35%) than among (65%) landraces (PhiPT = 0.652), implying significant genetic differentiation between landraces. Principal coordinate analysis and the ascendant hierarchical classification clustered samples into groups that were consistent with the geographical origin of the cultivars. Population structure corroborated the main groups and confirmed the high differentiation among them. Moroccan lentil germplasm showed a wide genetic diversity that might be conserved and assessed for tolerance to biotic and abiotic stresses (Mbasani-Mansi *et al.,* 2019).

To evaluate the genetic variability of 90 lentil genotypes, two different molecular marker techniques namely CAAT Box Derived Polymorphism (CBDP) and Simple Sequence Repeat (SSR) markers were utilized. Average polymorphism information content (PIC) for SSR and CBDP markers were 0.63 and 0.45, respectively. The average genetic distance for CBDP and SSR markers were 0.50 and 0.49, respectively. Among markers tested, the average observed number of alleles (Na) for SSR markers were 4.83 and the average expected heterozygosity (He) for SSR marker was 0.64. The average of effective number of alleles (Ne) for SSR markers 3.01. The average resolving power (Rp) values ranged between 1.51 and 8.67 for SSR and CBDP markers, respectively. Overall, SSR80 showed maximum genetic diversity among the SSRs used. A total of 145 and 135 polymorphic bands were obtained using SSR and CBDP markers, respectively. CBDP and SSR markers showed different efficiency for evaluating DNA polymorphism in lentil. A positive significant correlation ($r = 0.89^{**}$) for similarity matrix was obtained between CBDP and SSR markers. Neighbor-joining cluster analysis for both markers (CBDP and SSR markers) grouped the genotypes into five distinct clusters. Our results suggested high efficacy for SSR and CBDP markers in fingerprinting of lentil genotypes. This is the first report of using CBDP for genetic diversity analysis in lentil and also a comparison between CBDP and SSR markers among lentil germplasm. Generally, our results are able to show the suitability of CBDP and SSR markers for genetic diversity analysis in lentil for their high rates of polymorphism and their potential for genome diversity and germplasm conservation (Saidi *et al.,* 2022). Lentil is an annual protein rich valuable edible crop with only one cultivated and six wild taxa. Keeping in mind its narrow gene pool, the genus deserves critical assessment of genomic diversity at the chromosomal level. Genetic diversity represents the heritable variation within and between populations of organisms. Over the decades classical and molecular cytogenetics have played an immense role in the field of crop improvement. Lentil, though grown in different countries, country-wise chromosomal information is inadequate. Critical evaluation of more than seven decades chromosomal information has revealed unique karyotype diversity within the landraces of different countries. Application of fluorescent banding and fluorescent in situ hybridization (FISH) has helped to segregate cultivars based on cultivar specific chromosomal markers and landmarks. Selection of cultivated and wild cultivars based on qualitative and diseases related morpho-traits and new information from this critical review especially on molecular cytogenetics may provide more options for crop improvement. More research in the field of molecular cytogenetics from country specific species and cultivars are needed to enrich the repository of gene pool. Alien gene introgression from extended gene pool through the advanced genomics and biotechnological tools could facilitate the path of sustainable improvement of this crop (Jha, 2022).

Wild relatives and exotic landraces have a repository of useful genes controlling the important traits. The wild species show large genetic diversity for morphological and seed traits (Fig.8 a, b) (Kumar *et al*., 2014).

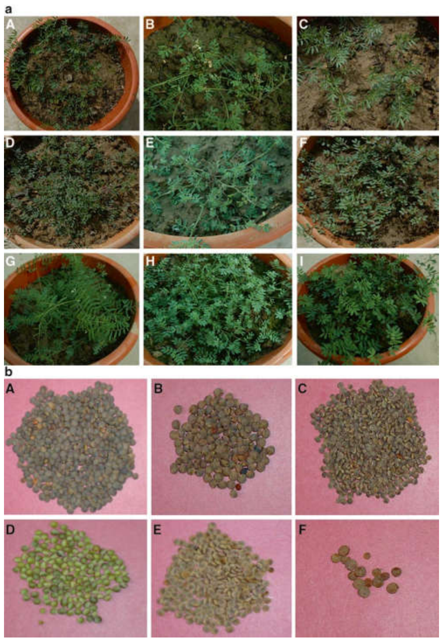


Fig.8 (a) Morphophysiological variation in wild accessions of lentil. (*A*) *L. ervoides*, *(B) L. culinaris* ssp. *odemensis*, *(C) L. nigricans*, *(D) L. culinaris* ssp. *odemensis*, *(E) L. culinaris* ssp. *orientalis*, *(F) L. nigricans*, *(G) L. culinaris* ssp. *odemensis*, *(H) L. culinaris* ssp. *orientalis*, *and (I) L. culinaris* ssp. *orientalis*. (b) Variation is seed shape and color in wild accessions of lentil. (*A*) *L.nigricans*, *B) L. Culinaris* ssp. *odemensis*, *(C) L. ervoides*, *(D) L. Culinaris* ssp. *odemensis*, *(E) L.lamottei*, *and (F) L. nigricans*

BREEDING

Germplasm: The most comprehensive collection of lentil germplasm (about 7407 accessions) is maintained by ICARDA located at Aleppo, Syria. The Regional Plant Introduction Station located at Pullman, USA has a collection of 2868 accessions. National programs of other countries also maintain a considerable number of germplasm accessions.Usually placed in two groups of subspecific rank: *Lens culinaris* ssp. *macrosperma* (Baumb.) Barulina include the large-seeded cultivars with large flattened seeds (6-9 mm diameter), flowers large, white or blue. The *macrosperma* types are important in the northern hemisphere. The smaller seeded *L. culinaris* ssp. *microsperma* (Baumb.) Barulina have small flowers that are violet-blue to white or pink convex pods and seeds that range from 2-6 mm. The *microsperma* are principally found in southwest and western Asia and Africa. One wild species of the Near East *Lens orientalis* (Boiss.) shows close morphological similarities and close genetic affinities to *L. culinaris*. It is occasionally interconnected to the cultivated lentil by a series of intermediate types and is completely interfertile with cultivated types. On the basis of combined archaeological, botanical, and genetic evidence, it is concluded that *L. orientalis* is the wild progenitor of cultivated lentil and that the domestication of this pulse took place in the Near East arc. Assigned to the Near Eastern center of diversity, lentil genotypes or cultivars from that center are reported to exhibit tolerance to alkali, disease, fungus, drought, high pH, heavy soil, heat, insects, low salinities, poor soil, slope, and virus. Some cultivars have high levels of cold tolerance. The passport data for various agronomically important traits including disease and pest resistance, adaptability, growth habit, resistance to lodging, and fruit dehiscence, tolerance to various abiotic stresses, and yielding and biomass production have been partly documented. The core collection comprising 287 accessions of lentil has been developed at the Regional Plant Introduction Station located at Pullman USDA-ARS and has been evaluated for resistance to several diseases (Muehlbauer and Tullu, 1997). The largest genebank collection is held by ICARDA. The Australian Grains Genebank also holds a large collections of *Lens* (CGIAR, 2023).

Worldwide, the leading 41 collections together hold 43,214 accessions of genus *Lens*. The major genebanks/institutes with more than 1000 *Lens* accessions are listed in Table 1. ICARDA, with 24% of the global *Lens* germplasm acces- sions, includes 583 wild accessions and is the largest such collection in the world. Assessment of genetic diversity within South Asian lentil germplasm, using RAPD markers, revealed the lowest narrow diversity in Pakistan, Afghanistan and India (Laskar *et al*., 2019).

Table 1. Major *Lens* spp. collections (>1000 accessions) in the world

Sl.No.	Country	Genebanks / institutes	Number of accessions
01	Global	ICARDA	10,822
02	Australia	Australian Temperate Field Crops Collection	5254
03	Iran	Seed and Plant Improvement Institute	3000
04	USA	USDA	2875
05	Russian Federation	N.I. Vavilov All-Russian Scientific Research	2556
06	India	National Bureau of Plant Genetic Resources	2285
07	Chile	Inst de Inv. Agropecuaria, Centro RegionaldeInvestigación Carillanca	1345
08	Canada	PGRC	1139

09	Turkey	Plant Genetic Resources Dept. AegeanAgricultural Research Inst.	1095
10	Syria	General Commission for Scientific AgriculturalResearch	1072
11	Hungary	Research Centre for Agrobotany	1061

Source: https://www.croptrust.org/

Breeding Objectives: Lentil breeding objectives usually differ depending on the problems and priorities of farmers and consumers of a specific region of the world. It was pointed out that the main breeding goals in the key exporting countries are higher and stable seed yield, disease resistance and better seed quality; while increased yield per hectare is the primary aim in the import-dependent countries like India. Ingeneral, lentil breeding with genetically diverse parents having traits of interest is carried out to generate new gene combinations to increase yield and stress resistance (Laskar *et al*., 2019).

Breeding: Lentil breeding has a relatively short history, however, since the inception of the ICARDA breeding program in 1977 substantial gains have been made in overcoming regional bottlenecks in germplasm diversity. This program has since been supplemented by breeding programs in both developing (*e.g.,* India) and developed countries (Australia and Canada). These programs have had substantial success in improving tolerance to both biotic (disease) and abiotic stress as well as improving regional adaptation. The Australian breeding program is detailed indicating differences and similarities with other programs. In recent years the need to concurrently develop agronomic approaches and breeding has lead to a greater collaboration among breeders and agronomists (Materne and McNeil, 2007). Lentil (*Lens culinaris* Medik subsp. *Culinaris*) is an important cool season food legume grown over a large area in the Indian subcontinent,west Asia, some parts of Africa and southern Europe. Keeping inview its great demand for its nutritious seeds, efforts are underway in different research institutes for development of improved plant types with high yielding ability, disease and insect pest resistance, and seed weight. Improvement of grain quality and nutrition are also among the import breeding objectives. While the cultivated germplasm is being utilized for addressing these objectives, even greater genetic variability has been observed in exotic germplasm and wild accessions. A better understanding of the pre- and post-fertilization barriers and use of *in vitro* techniques and hormonal manipulations has improved the possibilities of obtaining viable and fertile interspecific hybrids using these wild genetics resources. Consequently, efforts have been made to transfer alien genes from wild species, viz., *L. culinaris* ssp. *orientalis* and *L. ervoides* to cultivated species. Despite these developments, strategies still need to be developed to employ distant hybridization and alien gene introgression as a routing practice in genetic improvement of lentil. Further, a lot still requires to be done at molecular levels and gene transfer across genome boundaries through genetic transformation in lentil (Kumar et al., 2014). Genotyping-by-sequencing is an effective approach to study the domestication and spread of lentil. We confirmed the existence of four gene pools within the *Lens* genus, already revealed in previous studies. *Orientalis* was shown to be the sole wild progenitor of cultivated lentil (*culinaris*), with insignificant contribution from other wild species to the domesticated gene pool. Three groups were identified within cultivated lentils, and these correspond broadly to geographic regions. Lentil was likely domesticated from wild stands from somewhere between southern Turkey, to the north, and Jordan, to the south, in a protracted and incremental fashion. Two regional groups of cultivated lentils emerged in SW Asia, which further spreadinto different regions. A third group probably resulted fromlentil cultivation expanding into Central Europe. Introgression between cultivated lentil and its wild progenitor seems to have occurred at low levels. New mutations and selection from standing variation have probably resulted in local varieties becoming adapted to harsher environments in some areas, and these make a target for lentil breeding programs (Liber *et al.,* 2021). Although lentils have been an important crop for centuries, lentil breeding and genetic research have a relatively short history compared to that of many other crops. Since the inception of The International Center for Agriculture Research in the Dry Areas (ICARDA) breeding programme in 1977 significant gains have been made. It supplies landraces and breeding lines for countries around the world, supplemented by other programmes in both developing (*e.g.* India) and developed (*e.g.* Australia and Canada) countries. In recent years, such collaborations among breeders and agronomists are becoming increasingly important. The focus lies on high yielding and stable cultivars for diverse environments to match the demand of a growing population. In particular, progress in quantity and quality as well as in the resistance to disease and abiotic stresses are the major breeding aims. Several varieties have been developed applying conventional breeding methodologies. Serious genetic improvement for yield has been made, however, the full potential of production and productivity could not yet be tapped due to several biotic and abiotic stresses. Wild *Lens* species are a significant source of genetic variation for improving the relatively narrow genetic base of this crop. The wild species possess many diverse traits including disease resistances and abiotic stress tolerances. The above-mentioned *L. nigricans* and *L. orientalis* possess morphological similarities to the cultivated *L. culinaris*. But only *L. culinaris* and *L. culinaris* subsp. orientalis are crossable and produce fully fertile seed. Between the different related species hybridisation barriers exist. According to their inter-crossability *Lens* species can be divided into three gene pools: Primary gene pool*: L. culinaris* (and *L. culinaris* subsp. *orientalis*) and *L. odemensis*. Secondary gene pool: *L. ervoides* and *L. nigricans.* and Tertiary gene pool: *L. lamottei* and *L. tomentosus*. Crosses generally fail between members of different gene pools. However, plant growth regulators and/or embryo rescue allows the growth of viable hybrids between groups. Even if crosses are successful, many undesired genes may be introduced as well in addition to the desired ones. This can be resolved by using a backcrossing programme. Thus, mutagenesis is crucial to create new and desirable varieties (Wikipedia, 2023).

Breeding Methods (Laskar et al., 2019): The major goal of lentil breeding is the creation of varieties with higher and more stable yields, by exploiting genetic variability followed by the selection and evaluation of selected lines. Unlike other legume crops, lentil productivity is low with average yields of 570–766 kg/ha in Asia and 600–660 kg/ha in Africa. The success-ful outcome of conventional breeding depends on the degree of existing and accessible genetic variability. The main conventional breeding methods are discussed below.

Plant Introduction: Plant introduction is a method of obtaining high yield and wide adaptability of lentil cultivars from within or outside the country. The success of plant introduction depends on the introduced cultivar, as well as the soil and climatic conditions of thenew location. Homozygous pure lines are suitable plant material in plant introduction due to their better adaptability, compared to a heterozygous segregating population, which requires identification of a productive line with specific desirable traits. Even though plant introduction is employed at the initial phase of a breeding pro- gram, it is a discontinuous process but the cheapest and fastest way of developing cultivars. Hence, it becomes more important in a country where there is less area under crop cultivation, economic restraints or the absence of trained staff. Introduction is generally facilitated in the following ways: (1) Exchange of cultivars with other relevant plant breeders; (2) Area exploration showing higher species richness and evenness; (3) Obtaining plant genetic resources from national and international organization such as FAO, ICRISAT, ICARDA, NBPGR, India and theUSDA plant introduction stations. (Laskar *et al.,* 2019).

Hybridization: Hybridization is the process of combining desirable traits from two or more parentsinto a single cultivar. The main objective of hybridization is to increase the degree of genetic variation. (Laskar *et al.,* 2019). The selection of appropriate parents plays a crucial role in the success of hybridiza-tion. Depending on the objective, the choice of parents is made as follows: only oneparent is selected if the objective is to create a variety with higheryield and wider adaptability. The second parent must be chosen so that it complements the first parent. Diverse parents are selected, if creation of variation for the desired traits or broadening of the genetic base is the objective. To analyze the diversity and the combining ability of genotypes involved in hybridization, biometrical approaches are employed to ensure a rational and scientific basis in selection of the parents.

Mutation Breeding: The aim of this chapter is to review lentil breeding using induced mutations from the beginning of mutation breeding work to the present and to list the outcomes of mutagenesis works on lentils. The number of mutant varieties of all species officially released and recorded in the Food and Agricultural Organization/International Atomic Energy Agency (FAO/IAEA) Mutant Varieties Database is over 2300. From these mutant varieties, more than 265 grain legume cultivars have been developed using induced mutations and have subsequently been released. Gamma rays were the most frequently used technique to alter genes. Many mutant lentils have been mentioned in the available literature while seven mutants have been released for commercial production so far. Mutant lentils have now contributed several million dollars annually to global agriculture. Several specific regional problems in lentil production areas have been coped with using mutant lentil cultivars. Fundamental genetics, physiological and molecular studies will also be come to light using mutant lentils (Toker *et al.,* 2007).

Achievements: A listing of mutagenic lentil cultivars released globally is presentedin **Table 2**. Among these, two cultivars, Ranjan and Rajendra Masoor 1, have been released from India for different improved traits like high yield and spreading type, tolerance to low temperatures, early maturity and suitable for late sowing. India contributed 55 mutant legume varieties to the tally of 287 from Asia and 453 total worldwide **(Table 3)**. (Laskar *et al*., 2019)

Table 2. Lentil varieties developed through direct induced mutation

Variety Name	Country	Year	Mutagen used	Main improved attributes
S-256 (Ranjan)	India	1981	X-rays irradiation	High yield and spreading type
RajendraMasoor 1	India	1996	Gamma rays, 100Gy	Tolerance to low temperatures, earlymaturity and good for late sowing
NIAB Masoor-2006	Pakistan	2006	Gamma rays, 200Gy	Higher number of pods, resistance to lodging and resistance to blight and rust
Binamasur-1	Bangladesh	2001	extract of Datura seeds	High yield, tolerant to rust and blight, black seed coat
Binamasur-2	Bangladesh	2005	Gamma rays, 200Gy	High yield, early maturity, tolerant to rustand blight
Binamasur-3	Bangladesh	2005	EMS, 0.5%	High yield, early maturity, rust and blighttolerance
Mutant 17MM	Bulgaria	1999	Gamma rays,40 Gy	Vigorous growth habit, large leaflet, pods and seeds, resistance to anthracnose, stemohylium and viruses, high yield, drought tolerance and improved cooking quality
Zornitsa	Bulgaria	2000	EMS, 0.1%	High yield, high protein content (28.7%), good culinary and organoleptic quality, resistance to anthracnose, viruses and ascochyta blight
Djudje	Bulgaria	2000	Gamma rays,30Gy	High yield, dwarf bushy habit, suitable for mechanized harvesting, non-shattering, resistance to fusarium and botrytis, high protein content (27.9%), good culinary andorganoleptic quality
Elitsa	Bulgaria	2001	Gamma rays,40Gy	High yield (34.4%) and resistance to themajor disease
Verzuie	Moldova	2007	Gamma rays, 250Gy	Drought resistance, vegetative period (98 days), proteins26.7%, oils1.5%, fructose0.17%, glucose 0.08%, saharose1.23%, starch 45.30% and cellulose 7.16%
Aurie	Moldova,	2008	Gamma rays, 250 Gy	Drought resistance, high yields, earlymaturity, high protein content
NIAB Masoor-2002	Pakistan	2002	Recombinant	Erect growth habit, early maturity(120 days), black seed coat color, high grainyield, diseases resistance and synchronouspod maturity
Binamasur-6	Bangladesh	2011	Gamma rays, 250Gy	Higher yield (1.9 mt/ha and maximum yield 2.0 mt/ha), short maturity duration(105–110 days)
Binamasur-5	Bangladesh	2011	Gamma rays, 200Gy	Higher yield (2.1 mt/ha and maximum yield 2.2 mt/ha), short maturity duration(99–104 days)
Binamasur-8	Bangladesh	2014	Gamma rays, 200Gy	Higher yield (2.3 mt/ha and maximum yield 2.4 mt/ha),short maturity duration(95–100 days)
Binamasur-9	Bangladesh	2014	Gamma rays, 200Gy	Higher yield (2.1 mt/ha and Maximum yield 2.2 mt/ha),short maturity duration(99–104 days)
Binamasur-11	Bangladesh	2017	Gamma rays, 200Gy	Plants are erect, taller, many-branched and have green and violet colored flowers,higher yield (2.2 mt/ha and maximum yield 2.4 mt/ha),short duration (108–110 days)

Source: Joint FAO/IAEA, Vienna, Mutant Variety Database (MVD) 2018; http://mvgs.iaea.org

Table 3. Legume and lentil varieties developed through mutation breeding

Crop	Mutant Varieties		
	World	Asia	India
Lentil	18	12	02
Legume	453	287	55
Total	3281	1993	335

The annual productivity is low due to lentil's slow growth during the early phase, competitive weed infestation, and disease outbreaks during the crop growth period. Disease resistance breeding has been practiced for a long time to enhance resistance to various diseases. Often the sources of resistance are available in wild crop relatives. Thus, wide hybridization and the ovule rescue technique have helped to introgress the resistance trait into cultivated lentils. Besides hybridization, induced mutagenesis contributed immensely in creating variability for disease tolerance, and several disease-resistant mutant lines have been developed. However, to overcome the limitations of traditional breeding approaches, advancement in molecular marker technologies, and genomics has helped to develop disease-resistant and climate-resilient lentil varieties with more precision and efficiency (Roy *et al.,* 2023) (**Table 4).**

Growing countries: The important lentil-growing countries of the world are India, Canada, Turkey, Bangladesh, Iran, China, Nepal and Syria (Ahlawat, 2023) .India ranks first in the world in respect of production (0.99 m tonnes) as well as acreage (1.47 m ha). In India, lentil is mostly grown in northern plains, central and eastern parts of India. The major lentil producing areas are situated in Madhya Pradesh, Uttar Pradesh, Bihar and West Bengal.

Table 4. Disease resistant lentil mutants developed

	Variety Name	Parent name	Mutagen	Dose	Local/National Registration Year	Character Improvement Details	Institute
1	Binamasur-1	L-5 (local genotype)	Extract of Dhatura seeds	NA	2001	High yield, tolerant to rust and blight, black seed coat	Bangladesh Institute of Nuclear Agriculture (BINA) & Bangladesh Agriculture University (BAU), Bangladesh
2	Binamasur-2	Utfala (local genotype)	Gamma rays	200 Gy	2005	High yield, early maturity, tolerant to rust and blight	BINA, Bangladesh
3	Binamasur-3	L-5 (local genotype)	EMS	0.50%	2005	High yield, early maturity, rust and blight tolerance	BINA, Bangladesh
4	Djudje	Tadjikskaya 95	Gamma rays	30 Gy	2000	High yield, dwarf bushy habit, suitable for mechanized harvesting, non-shattering, resistance to fusarium and botrytis, high protein content (27.9%), good culinary and organoleptic quality	Dobrudzha Agricultural Institute (DAI), General Toshevo, Bulgaria
5	Elitsa	Tadjikskaya 95	Gamma rays	40 Gy	2001	High yield (34.4%) and resistance to the major disease	DAI, General Toshevo, Bulgaria
6	Mutant 17 MM	NA	NA	NA	1999	Vigorous growth habit, large leaflet, pods and seeds, resistance to anthracnose, stemohylium and viruses, high yield, drought tolerance and improved cooking quality	DAI, General Toshevo, Bulgaria
7	NIAB MASOOR 2002	NA	Gamma rays	NA	2002	Erect growth habit, early maturity (120 days), black seed coat color, high grain yield, diseases recsistance and synchronous pod maturity	Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan
8	NIAB MASOOR-2006	ILL-2580	Gamma rays	200 Gy		Higher number of pods, resistance to lodging and resistance to blight and rust	NIAB, Faisalabad, Pakistan
9	Zornitsa	Tadjikskaya 95	EMS	0.10%	2000	High yield, high protein content (28.7%), good culinary and organoleptic quality, resistance to anthracnose, viruses and ascochyta blight	DAI, General Toshevo, Bulgaria

The bold and small seeded varieties suitable for different states/zones of India and their characteristicsare given in **Table 5-7** (Ahlawat, 2023).

Table 5. High yielding bold seeded varieties of lentil recommended for different states

Variety	Duration(days)	Yield (q/ha)	Recommended for	Special characteristics
Pant L 234	130-150	15-20	Uttar Pradesh	Tolerant to wilt and rust diseases
NFL 92 (NarendraMasoor 1)	120-130	15-20		Resistant to rust andtolerant to wilt
JLS 1	120-130	10-15	Central plateau region	Tolerant to wilt
Bombay 18	130-140	10-12	Maharashtra, Punjab and Haryana	
DPL 15 (Priya)	130-140	14-16	North-western plains zone	Resistant to rust and tolerant to wilt
DPL 62 (Sheri)	130-140	15-20	North-western plains zone	Resistant to rust and tolerant to wilt
L-4632			North western plains zone	Extra bold seeded variety
IPL 81(Noori)	110-120	10-15	Central zone	Tolerant to wilt and rust
K 75 (Malika)	120-125	14-16	North-eastern plains zone and central zone	
Pusa 4076(Shivalik)	130-135	25-28	North-western plains zone and central zone	Resistant to rust and lessaffected from drought incomparison to *deshi masoor*
Pusa 1	100-110	15-20	Bihar, Uttar Pradesh,Madhya Pradesh, Haryana and Orissa	
Pusa 4	130-140	20-25	Uttar Pradesh, Bihar and West Bengal	
Pusa 830	120-125	20-25	U.P. and Uttarakhand	Disease susceptible variety
LL56	150-160	12-13	Delhi	Good cooking quality
L-9		7-10		

Table 6. High yielding small seeded varieties of lentil recommended for different states

Variety	Duration(days)	Yield (q/ha)	Recommended for	Specialcharacteristics
BR 25	125-130	15-20	Bihar and Madhya Pradesh	
L 4147 (PusaVaibhav)	130-135	17.8	North-western plainszone	Resistant to rust and tolerant to podborer
T 36	130-140	16-18	Uttar Pradesh	Highly susceptible to wilt
Pusa 6	130-135	20-25	Delhi, UP, Haryana, Punjab, Bihar and West Bengal	
Pant L 406	125-130	20-25	UP, Bihar, Punjab, North-eastern hills and north-western plains	Resistant to rust and some races of wilt
L 4584			North-western plainszone	
L 830	120-125	8-12		
PL 81-17 (Pant Lentil4)	130-140	14-18		Resistant to rust and wilt
LH 84-8	130-140	14-16		Resistant to rust
VL 4	150-160	10-12	Hilly areas of northern, western andeastern states	Tolerant to wilt
Asha	125-130	14-16	West Bengal	
B-17	120-125	15-20		
B 177, S256, S177	125-130	15-20		
B-235, C31, Ranjan	116-120	16-18		
Pant L 639	130-140	18-20	North western plains Zone, north-eastern plains zone and central zone	Moderately resistant to shattering, resistant to rust and wiltcomplex
LH 82-6 (Garima)	130-140	12-15	Haryana	Tolerant to rust and blight
PL 77-12 (Arun)	125-130	12-15	Bihar	Tolerant to wilt
BR 26	125-130	20-25	North Bihar	
LL 147	135-140	12-16	Punjab	Resistant to rust
L-9-12	125-130	15-20		
VL-1	165	10-12	Hilly areas of UttarPradesh and other states	
VL-3	160-165	10-12	Uttar Pradesh	Tolerant to *Ascochyla* blight
T8	120-125	18-20		Susceptible to rust

Table 7. State –wise recommended varieties (DPD, 2023.)

States	Recommended Varieties
Bihar	Pant L 406, PL 639, Mallika (K-75), NDL 2, WBL 58, HUL 57, WBL 77, Arun (PL 777-12)
M. P. & C.G.	Malika (K-75), IPL-81 (Nuri), JL-3, IPL-406, L-4076, IPL- 316, DPL 62 (Sheri)
Gujarat	Malika (K-75), IPL-81 (Nuri), L-4076, JL-3
Haryana	Pant L-639, Pant L-4, DPL-15 (Priya), Sapna, L-4147, DPL-62 (Sheri), Pant L-406
Maharashtra	JL 3, IPL 81 (Nuri), Pant L 4
Punjab	PL-639, LL-147, LH-84-8, L-4147, IPL-406, LL-931, PL 7
Uttar Pradesh	PL-639, Malika (K-75), NDL-2, DPL-62, IPL-81, IPL-316, L-4076, HUL-57, DPL 15
Rajasthan	IPL 406 (Anguri), Pant L-8 (PL-063), DPL-62 (Sheri)
Uttarakhand	VL-103, PL-5, VL-507, PL-6, VL-129, VL-514, VL-133,
Jammu & Kashmir	VL 507, HUL 57, Pant L 406, Pant L 639, VL 125, VL 125

USES

Lentil is a nutritious food legume. It is cultivated for its seed and mostly eaten as dhal. Dhal is seed that is decorticated and split. The primary product is the seed which has a relatively higher contents of protein, carbohydrate and calories compared to other legumes and is the most desired crop because of its high average protein content and fast cooking characteristic in many lentil producing regions. It can be used as a main dish, side dish, or in salads. Seeds can be fried and seasoned for consumption; flour is used to make soups, stews, purees, and mixed with cereals to make bread and cakes; and as a food for infants. Even though lentils are considered to be highly nutritious, they contain antinutritional factors such as, trypsin inhibitors, hemagglutinins, and oligosaccharides that cause flatulence. Tannins are present in high concentrations in the seed coat; however tannins can be removed by processing, most often to remove the seedcoats. Husks, dried leaves, stems, fruit walls and bran (residues), can be fed to livestock. Lentil residues contain about 10.2% moisture, 1.8 % fat, 4.4% protein, 50% carbohydrate, 21.4% fiber, and 12.2% ash. When production of forage crops fall below the level required in the market, lentil residue commands an equal or a better price than lentil seeds in some MiddleEastern countries. Green plants make valuable green manure. Seeds are a source of commercial starch for textile and printing industries (Muehlbauer and Tullu, 1997). Lentils are supposed to remedy constipation and other intestinal afflictions. "In India, lentils are poulticed onto the ulcers that follow smallpox and other slow-healing sores". In the 6th century, chickpeas were believed to be an aphrodisiac; while curiously enough, lentils were considered to have the opposite effect, and this was probably the reason why the lentil was included in the diet in monasteries on meatless days (Muehlbauer and Tullu, 1997). They have been in constant use in different societies since then and their consumption has been widespread in developed and developing countries alike. It is consumed for its flavour, its versatility and its high nutritive value and other health benefits. In most of the Asian countries and particularly in the Indian subcontinent the major use for lentil is for making *dhal* for which the red lentils are preferred. The types of lentil soups prepared in different countries and regions throughout the world vary enormously depending on local tradition and palate from the spicy Indian *dhals* to the more aromatic north African lentil soups to the meat based European dishes and several recipes are included here. *Dhal* alone describes a whole group of dishes which vary enormously from the different regions of India and the other countries of the subcontinent. They are also used uncooked; either soaked crushed and moulded to make cakes or sprouted as an ingredient in salads in some parts of India and as such provide betternutrient value (Yadav *et al*., 2007).

Lentils rank 5th among the most important legume grains in the world and are extremely important in the diets of many people in India and the Middle East. Lentils are a highly valued food due to their good taste and nutritional quality, which makes them too expensive to be fed to livestock. They are eaten cooked, fried, spilt and ground in a wide range of dishes (soups, salads, stews, *etc*.). Lentil flour is used for pastry, bread and starch. Young pods and leaves are eaten as a vegetable. Lentils are an N-fixing legume that can be a valuable ley in cereal crop rotations (Heuzé *et al.,* 2021). Depending on location, lentils were either considered a necessity for people struggling with food insecurity or a delicacy for members of the upper class. While those Catholics who could not afford fish during the season of Lent substituted lentils, lentils graced the tables of peasants and kings alike as a tasty and plentiful source of protein. In Greece, this legume was favored by low-income communities while in Egypt it was fed to royalty. Today, however, lentils are a food for all and have taken a prominent place among edible legumes, for both farmers as well as restaurant and home chefs. While other legumes have fallen off of menus, the lentil has risen in popularity. Agriculturally, lentils are a solid crop when drought is likely and the soil conditions are not favorable. In the kitchen, lentils are welcome for their ability to cook quickly, offer delicious flavor, and provide plenty of nutrients, such as protein, iron, and Vitamins A and B (Filippone, 2021).

The lentil seeds can be eaten raw or are cooked and eaten in soups and other dishes. They are commonly eaten as dahl (lentils seeds which have had the husk removed and then split). Lentil seeds can be used as a source of starch for the textile industry or can be ground into flour. The youger pods are sometimes eaten as vegetables (Moncel, 2022). Most of the lentils are consumed as dhal or in soups. Unripe pods are used as green vegetable, dry leaves and stalks as cattle feed. In Kashmir valley, it is grown as green manure crop for rice crop (Pallavi, 2023). Lentils are used around the world for culinary purposes. In cuisines of the Indian subcontinent, where lentils are a staple, split lentils (often with their hulls removed) known as dal are often cooked into a thick curry that is usually eaten with rice or *rotis*. Lentils are commonly used in stews and soups (Wikipedia, 2023). Lentil is very nutritious. The husk, bran and dry haulms are good fodder. The young pod is used as vegetable. The leaves are acrid and bitter. Seeds are sweet and cooling, astringent to bowel, diuretic, improves appetite, removes cough and biliousness. Dry seeds contain 24% protein and 59% carbohydrate **(**BSMRAU, 2023**).** Lentils can be eaten soaked, germinated, fried, baked or boiled – the most common preparation method. The seeds require a cooking time of 10 to 40 minutes, depending on the variety; small varieties with the husk removed, such as the common red lentil, require shorter cooking times (and unlike most legumes don't require soaking). Most varieties have a distinctive, earthy flavor. Lentils with husks remain whole with moderate cooking, while those without husks tend to disintegrate into a thick purée, which may enable various dishes. The composition of lentils leads to a high emulsifying capacity which can be even increased by dough fermentation in bread making (Wikipedia, 2023).

Processing: A combination of gravity, screens and air flow is used to clean and sort lentils by shape and density. After destoning, they may be sorted by a color sorter and then packaged. A major part of the world's red lentil production undergoes a secondary processing step. These lentils are dehulled, split and polished. In the Indian subcontinent, this process is called dal milling. The moisture content of the lentils prior dehulling is crucial to guarantee a good dehulling efficiency. The hull of lentils usually accounts for 6 to 7 percent of the total seed weight, which is lower than most legumes. Lentil flour can be produced by milling the seeds, like cereals (Wikipedia, 2023).

Lentil dishes: Lentils are used worldwide in many different dishes. Lentil dishes are most widespread throughout South Asia, the Mediterranean regions, West Asia, and Latin America.

In the Indian subcontinent, Fiji, Mauritius, Singapore and the Caribbean, lentil curry is part of the everyday diet, eaten with both rice and roti. Boiled lentils and lentil stock are used to thicken most vegetarian curries. They are also used as stuffing in dal parathas and puri for breakfast or snacks. Lentils are also used in many regional varieties of sweets. Lentil flour is used to prepare several different bread varieties, such as papadam. They are frequently combined with rice, which has a similar cooking time. A lentil and rice dish is referred to in Levantine countries as mujaddara or mejadra. In Iran, rice and lentil is served with fried raisin; this dish is called adas polo. Rice and lentils are also cooked together in khichdi, a popular dish in the Indian subcontinent (India and Pakistan); a similar dish, kushari, made in Egypt, is considered one of two national dishes. Lentils are used to prepare an inexpensive and nutritious soup throughout Europe and North and South America, sometimes combined with chicken or pork. In Western countries, cooked lentils are often used in salads.[3] In Italy, the traditional dish for New Year's Eve is Cotechino served with lentils. Lentils are commonly eaten in Ethiopia in a stew-like dish called kik, or kik wot, one of the dishes people eat with Ethiopia's national food, injera flatbread. Yellow lentils are used to make a non-spicy stew, which is one of the first solid foods Ethiopians feed their babies. Lentils were a chief part of the diet of ancient Iranians, who consumed lentils daily in the form of a stew poured over rice (Wikipedia, 2023). Dried lentils have an extremely long shelf life. Store them in an airtight container away from light, heat, and moisture. An airtight container also keeps insects out, which easily infest improperly stored dried grains and legumes. Cooked lentils stay good when stored in an airtight container in the refrigerator for up to a week or in the freezer for up to three months, making them a good ingredient for a weekend meal prep plan (Kreighbaum, 2023).

Brown lentils hold their shape well but get mushy if you overcook them. This common variety cooks quickly (in about 20 minutes) and requires no soaking like most other beans. Use mild brown lentils in soups, stews, salads, pilafs, and more. Green lentils are quite large (about 1/4 inch in diameter) and tend to be slightly flatter than other varieties. Green lentils are flavorful, remain fairly firm, and retain their shape with cooking. This makes them ideal for salads, pilafs, and other dishes with ingredients that get tossed, mixed, or stirred together. French green lentils are smaller and darker than common green lentils and appear slightly speckled on the surface. This variety of lentil remains especially firm and requires an extended cooking time of approximately 40 minutes. Puy lentils are grown in a specific region of central France and have a notable mineral flavor. Yellow lentils are sweet and nutty and have a reddish interior flesh. These lentils break down when you cook them and work well in dips, purees such as Indian dal, and dishes that require thickening. Red lentils are yellow lentils that have been hulled and split. They are a light red to orange color, small in size, and create a very smooth puree when cooked. Because they have been hulled and split, red lentils are also the quickest cooking variety. Black/beluga lentils are small and quite round in shape. They are often called beluga lentils because they resemble beluga caviar when cooked. Although the hull is dark black in color, the flesh is light and creamy. Black lentils are available whole, hulled, or hulled and split (Kreighbaum, 2023).

NUTRITIONAL VALUE

Protein concentration of lentils reportedly range from 22-34.6%, and 100 g of dried seeds contain 340-346 g calories, 12% moisture, 20.2 g protein, 0.6 g fat, 65.0 g total carbohydrate, about 4 g fiber, 2.1 g ash, 68 mg Ca, 325 mg P, 7.0 mg Fe, 29 mg Na, 780 mg K, 0.46 mg thiamine, 0.33 mg riboflavin, 13 mg niacin. Among the cool season legume crops, lentil is the richest in the important amino acids (lysine, arginine, leucine, and sulpher containing amino acids). The starch content ranges from 35-53% in the seed and 42% in dry matter while amylose varies from 20.7 to 38.5% of the seed starch. "One hundred grams of decorticated lentil seed contain 344 calories, 9.9 % moisture, 25.8 g protein, 1.8 g fat, 58.8 g total carbohydrate, 0.9 g fiber, 3.7 g ash, 24 mg Ca, 271 mg P, 10.6 mg Fe, 0.47 mg thiamine, 0.21 mg riboflavin, and 1.5 mg niacin. Lentils are a good source of B vitamins, containing per 100 g: 0.26 mg thiamine, 0.21 mg riboflavin, 1.7 mg nicotinic acid, 223 mg choline, 107 mg folic acid, 130 mg inositol, 1.6 mg pantothenic acid, 13.2 mg biotin, and 0.49 mg pyridoxine. Vitamins, except folic and pantothenic acids, increase markedly during sprouting. Dry lentil husks contain 11.1% protein (1.3% digestible), 0.7% fat, 47.5% carbohydrate, 25.6% fiber, and 3.1% ash". "About 90% of lentil protein is found in the cotyledons with albumins and globulins being the major fractions. Digestibility coefficients for lentil are relatively high and range from 78-93%, while biological values range from 32-58%. Oleic, palmitic and linoleic are the dominant fatty acids" (Muehlbauer and Tullu, 1997). The importance of lentils as important dietary sources of macro and micronutrients essential for human welfare has been recognized since ancient times. Lentils provide sufficient amounts of most essential amino acids to meet the nutrient requirements, although they are deficient in sulfur-containing amino acids like most legumes. Lentils also contain fair amounts of other essential nutrients like minerals, vitamins and complex carbohydrates. In contrast, lentils exhibit a considerable amount of non-nutritional compounds like trypsin inhibitors, tannins or phytic acid that are able to interfere with the availability of several nutrients. Different processing conditions that range from the traditional soaking/cooking to germination, fermentation, or several thermal treatments, are usually employed to improve the organoleptic properties of lentil seed and its nutritional value through reducing the negative effect of the above mentioned non-nutritional components. In addition, technological treatments may significantly enhance the functional and beneficial health properties of the processed lentil food products, making consumption of this legume an appealing alternative for today's world (Urbano *et al.,* 2007).

Studies on human nutrition have shown that lentil consumption is healthy and eases oxidative stress, improves serum antioxidant capacity and reduces concentrations of total and low-density lipoprotein-cholesterol, triglycerides, adhesion molecules and inflammatory biomarkers that constrain the progress of cardiovascular diseases (Laskar *et al.,* 2019).

The nutritional value of lentil is presented in Table 8. The amino acid profile of lentil protein is deficient in the sulfur-containing amino acids methionine and cystine, and in tryptophan (Table 9) (Laskr *et al.,* 2019).

Table 8: Nutritional value of lentil, raw (dry weight) per100 g (3.5 oz) (Nutrient values and weights are for edible portion)

	Nutrient	Value
	Water	10.40 g
	Energy	343 kcal
	Protein	25.80 g
	Total lipid (fat)	1.06 g
	Carbohydrate	60.08 g
	Fiber, total dietary	30.50 g
	Sugars, total	2.03 g
Minerals		
	Calcium, Ca	56 mg
	Iron, Fe	7.54 mg
	Magnesium, Mg	122 mg
	Phosphorus, P	451 mg
	Potassium, K	955 mg
	Sodium, Na	6.00 mg
	Zinc, Zn	4.78 mg
Vitamins		
	Vitamin C, total ascorbic acid	4.40 mg
	Thiamin	0.873 mg
	Riboflavin	0.211 mg
	Niacin	2.605 mg
	Vitamin B-6	0.540 mg
	Folate, DFE	479 µg
	Vitamin A, RAE	2.00 µg
	Vitamin A, IU	39 IU
	Vitamin E (alpha-tocopherol)	0.49 mg
	Vitamin K (phylloquinone)	5.0 µg
Lipids		
	Fatty acids, total saturated	0.156 g
	Fatty acids, total monounsaturated	0.189 g
	Fatty acids, total polyunsaturated	0.516 g

Table 9. Amino acid composition of lentil

Amino Acid	Value g per 100g
Protein	24.63
Alanine	1.029
Arginine	1.903
Aspartic acid	2.725
Cystine	0.322
Glutamic acid	3.819
Glycine	1.002
Histidine	0.693
Isoleucine	1.065
Leucine	1.786
Lysine	1.720
Methionine	0.210
Phenylalanine	1.215
Proline	1.029
Serine	1.136
Threonine	0.882
Tryptophan	0.221
Tyrosine	0.658
Valine	1.223

Several studies have concluded that lentil straw has a lower NDF content, a better rumen degradability and a better whole tract digestibility than cereal straws. There are few studies on the nutritive value of lentil straw for ruminants. Four studies reported *in vivo* OM digestibility values comprised between 47 and 55%. However, a comparison of *in vitro* methods (enzymatic method defined by Aufrère and the two-stage method of Tilley and Terry), resulted in higher values comprised between 54 and 57% . Such differences may be explained by the variable leaf:stem ratio, which depends on the harvesting method. For instance, using *in vitro* gas production, a stem-rich lentil straw was found to have an ME of 6.7 MJ/kg DM *vs.* 8.3 MJ/kg DM for a leaf-rich lentil straw (Heuzé et al., 2021). Lentil seed contain protein 2.5 per cent, fat 1.5 per cent and carbohydrates 56.6 per cent. Calcium, iron and phosphorus contents (mg 100 g^{-1}) are 130, 6.0 and 250 respectively. Lentil has high saponin content (3.7-1.6 g kg^{-1} seed), which reduces the cholesterol levels in the blood. Lentils contain raffinose, which generate gas (flatulence). Lentils are recommended for treatment of diabetics, as they are good source of dietary fibre (Pallavi, 2023). According to DPD (2023) the nutritional value of lentil seeds are given in **Table 10.**

Table 10. Nutritional value of lentil seed

	Nutritional value		Nutritional value
Protein	24-26%	Carbohydrate	57 – 60%
Fat	1.3%	Fibre	3.2%
Phosphorus	300 mg/100 g	Iron	7 mg /100 g
Vitamin C	10-15 mg/100 g	Calcium	69 mg/100g
Calorific value	343 Kcal/100 g	Vitamin A	(450 IU)

According to Wikipedia (2023) the nutritional value of lentil seeds are given in Table 11.

Table 11 . Lentils, mature seeds, cooked, boiled, with salt

Nutritional value per 100 g	
Energy	477 kJ (114 kcal)
Carbohydrates	19.54 g
Sugars	1.8 g
Dietary fiber	7.9 g
Fat	0.38 g
Protein	9.02 g
Vitamins	**Quantity %DV†**
Thiamine (B1)	15% 0.169 mg
Riboflavin (B2)	6% 0.073 mg
Niacin (B3)	7% 1.06 mg
Pantothenic acid (B5)	13% 0.638 mg
Vitamin B6	14% 0.178 mg
Folate (B9)	45% 181 μg
Vitamin B12	0% 0 μg
Vitamin C	2% 1.5 mg
Vitamin D	0% 0 IU
Vitamin E	1% 0.11 mg
Vitamin K	2% 1.7 μg
Minerals	**Quantity %DV†**
Calcium	2% 19 mg
Copper	13% 0.251 mg
Iron	25% 3.3 mg
Magnesium	10% 36 mg
Manganese	24% 0.494 mg
Phosphorus	26% 180 mg
Potassium	8% 369 mg
Selenium	4% 2.8 μg
Sodium	16% 238 mg
Zinc	13%1.27 mg
Other constituents	**Quantity**
Water	69.64 g

Boiled lentils are 70% water, 20% carbohydrates, 9% protein, and 0.4% fat (table). In a reference amount of 100 grams (3+½ ounces), cooked lentils (boiled; variety unspecified) provide 114 calories, and are a rich source (20% or more of the Daily Value, DV) of folate (45% DV), iron (25% DV), manganese (24% DV), and phosphorus (26% DV). They are a good source (10% DV) of thiamine (15% DV), pantothenic acid (13% DV), vitamin B_6 (14% DV), magnesium (10% DV), copper (13% DV), and zinc (13%) (table). Lentils contain the carotenoids, lutein and zeaxanthin, and polyunsaturated fatty acids (Wikipedia, 2023). **NV** Lentils are often overlooked, even though they're an inexpensive way of getting a wide variety of nutrients. For example, they're packed with B vitamins, magnesium, zinc, and potassium. Lentils are made up of more than 25% protein, which makes them an excellent meat alternative. They're also a great source of iron, a mineral that is sometimes lacking in vegetarian diets (Healthline, 2023)

Though different types of lentils may vary slightly in their nutrient content, 1 cup (198 grams) of cooked lentils generally provides the following ((Healthline, 2023):

- **Calories:** 230
- **Carbs:** 39.9 grams
- **Protein:** 17.9 grams
- **Fat:** 0.8 grams
- **Fiber:** 15.6 grams
- **Thiamine:** 28% of the DV
- **Niacin:** 13% of the DV

- **Vitamin B6:** 21% of the DV
- **Folate:** 90% of the DV
- **Pantothenic acid:** 25% of the DV
- **Iron:** 37% of the DV
- **Magnesium:** 17% of the DV
- **Phosphorus:** 28% of the DV
- **Potassium:** 16% of the DV
- **Zinc:** 23% of the DV
- **Copper:** 55% of the DV
- **Manganese:** 43% of the DV

Lentils are high in fiber, which supports regular bowel movements and the growth of healthy gut bacteria. Eating lentils can increase your stool weight and improve your overall gut function. Furthermore, lentils contain a broad range of beneficial plant compounds called phytochemicals, many of which protect against chronic diseases such as heart disease and type 2 diabetes.

The nutritional value of lentil seeds are given in **Table 12** (Kreighbaum, 2023).

Table 12. Nutritional value of lentil seeds

Main analysis	Unit	Avg	SD	Min	Max	Nb	
Dry matter	% as fed	88.3	1.2	87.1	91.0	18	
Crude protein	% DM	26.9	1.8	24.6	30.0	23	
Crude fibre	% DM	4.9	1.1	2.9	7.7	18	
NDF	% DM	13.0	6.8	8.1	27.4	11	*
ADF	% DM	6.3	1.1	3.3	6.3	10	*
Lignin	% DM	1.6		1.2	2.0	2	
Ether extract	% DM	1.6	1.0	0.5	5.0	19	
Ash	% DM	3.8	1.2	2.7	6.8	19	
Starch (polarimetry)	% DM	45.7	5.3	29.7	53.6	18	
Gross energy	MJ/kg DM	18.5	1.2	16.6	18.9	3	*
Minerals	Unit	Avg	SD	Min	Max	Nb	
Calcium	g/kg DM	1.1	0.5	0.6	2.3	9	
Phosphorus	g/kg DM	4.5	1.1	3.1	6.6	11	
Potassium	g/kg DM	10.3	0.9	9.0	11.3	6	
Sodium	g/kg DM	0.4				1	
Magnesium	g/kg DM	1.3	0.2	1.0	1.5	6	
Manganese	mg/kg DM	18	4	14	24	5	
Zinc	mg/kg DM	38	7	29	44	5	
Copper	mg/kg DM	14	10	8	32	5	
Iron	mg/kg DM	88	22	73	126	5	
Amino acids	Unit	Avg	SD	Min	Max	Nb	
Alanine	% protein	3.9	0.7	2.4	4.3	7	
Arginine	% protein	7.3	1.4	3.9	8.8	9	
Aspartic acid	% protein	10.9	0.7	9.9	11.5	7	
Cystine	% protein	1.2	0.2	1.0	1.5	4	
Glutamic acid	% protein	15.3	0.6	14.7	16.3	7	
Glycine	% protein	4.0	0.2	3.8	4.4	8	
Histidine	% protein	2.6	0.7	1.3	3.8	9	
Isoleucine	% protein	4.5	0.8	3.4	6.3	8	
Leucine	% protein	7.6	1.3	6.8	10.9	9	
Lysine	% protein	6.5	0.9	4.3	8.0	11	
Methionine	% protein	0.9	0.2	0.7	1.1	5	
Phenylalanine	% protein	5.0	0.8	4.3	6.3	5	
Proline	% protein	3.6	0.5	2.6	4.0	7	
Serine	% protein	4.2	0.7	2.9	5.1	7	
Threonine	% protein	3.5	0.6	2.5	4.5	9	
Tryptophan	% protein	0.8	0.2	0.5	1.2	7	
Tyrosine	% protein	2.8	0.3	2.5	3.2	4	
Valine	% protein	4.6	0.6	4.0	5.4	5	
Secondary metabolites	Unit	Avg	SD	Min	Max	Nb	
Tannins (eq. tannic acid)	g/kg DM	6.6	2.9	1.8	11.4	7	
Tannins, condensed (eq. catechin)	g/kg DM	1.1				1	

Avg: average or predicted value; SD: standard deviation; Min: minimum value; Max: maximum value; Nb: number of values (samples) used

HEALTH BENEFITS

According to Torrens, (2023) the following are the health benefits of lentil seeds:

- **Reduces risk of certain chronic diseases**: Studies demonstrate that regularly eating lentils reduces your risk of chronic disease such as diabetes, obesity, cancer and heart disease. This is thanks to their rich content of protective plant compounds called phenols – lentils being amongst the top ranked legumes for phenolic content. It comes as no surprise then that lentils boast an antioxidant, antibacterial, anti-viral and anti-inflammatory effect and are cardio-protective.

- **Support the digestive system:** Lentils are especially rich in prebiotic fibre which promotes digestive function and 'fuels' the beneficial gut bacteria which are so important for our health. A diet rich in fibre is associated with a number of health benefits including a reduced risk of colorectal cancer.
- **Heart-healthy:** Lentils are rich in fibre, folate and potassium making them a great choice for the heart and for managing blood pressure and cholesterol. They are also a source of energising iron and vitamin Bl which helps maintain a steady heartbeat.
- **Helps to manage blood sugar levels:** Legumes, and lentils are no exception, have a low glycaemic index (GI) which slows the rate at which the energy they supply is released into the bloodstream. This helps improve blood sugar management. The high fibre content also makes them very filling which helps appetite control.
- **A source of plant protein:** Lentils are a rich source of protein making them a great alternative to meat or fish. As much as a third of the calories from lentils comes from protein, which makes lentils the third highest in protein, by weight, of any legume or nut. Like other legumes, lentils are low in a couple of the essential amino acids, namely methionine and cysteine. This is easily addressed by combining lentils with cereal grains such as rice or wheat.

According to Healthline (2023) the following are the health benefits of lentil seeds:

Polyphenols in lentils may have powerful health benefits: Lentils are rich in polyphenols, a category of health-promoting phytochemicals. Some of the polyphenols in lentils, such as procyanidin and flavanols, are known to have strong antioxidant, anti-inflammatory, and neuroprotective effects. When tested in the lab, the polyphenols in lentils were able to stop cancer cell growth, especially on cancerous skin cells. One animal study found that consuming lentils helped lower blood sugar levels and that the benefits were not solely due to the carb, protein, or fat content. It's also worth noting that the polyphenols in lentils don't appear to lose their health-promoting properties after cooking. This being said, these results are from laboratory and animal studies only. Human studies are needed before firm conclusions can be made about these health benefits.

May protect your heart: Eating lentils is associated with an overall lower risk of heart disease, as it has positive effects on several risk factors. One 8-week study in 39 people with overweight or obesity and type 2 diabetes found that eating 1/3 cup (60 grams) of lentils each day increased levels of HDL (good) cholesterol and significantly reduced levels of LDL (bad) cholesterol and triglycerides. Lentils may also help lower your blood pressure. A study in rats found that those eating lentils had greater reductions in blood pressure than those eating peas, chickpeas, or beans. Furthermore, proteins in lentils may be able to block angiotensin I-converting enzyme, which normally triggers blood vessel constriction and thereby increases blood pressure. High levels of homocysteine are another risk factor for heart disease. These can increase when your dietary folate intake is insufficient. Because lentils are a great source of folate, they may help prevent excess homocysteine from accumulating in your body. Having overweight or obesity increases the risk of heart disease. Eating lentils may help decrease your overall food intake, which could contribute to weight loss or maintenance. Lentils are very filling and appear to keep blood sugar levels steady.

Antinutrients may impair nutrient absorption: Lentils contain antinutrients, which can affect the absorption of other nutrients.

Trypsin inhibitors: Lentils contain trypsin inhibitors, which block the production of the enzyme that normally helps break down protein from your diet. However, lentils generally contain low amounts of these, and it's unlikely that trypsin from lentils will have a major effect on your protein digestion. Lectins can resist digestion and bind to other nutrients, preventing their absorption. Furthermore, lectins can bind to carbs on the gut wall. If they're consumed in excess, they may disturb the gut barrier and increase intestinal permeability, a condition also known as leaky gut. It's speculated that too many lectins in the diet may increase the risk of developing an autoimmune condition, but the evidence to support this is limited. Lectins may also possess anticancer and antibacterial properties. If you're trying to minimize the number of lectins in your diet, try soaking lentils overnight and discarding the water before cooking them. Lentils contain tannins, which can bind to proteins and prevent the absorption of certain nutrients. In particular, there are concerns that tannins may impair iron absorption. However, research indicates that iron levels are generally not impacted by dietary tannin intake. On the other hand, tannins are high in health-promoting antioxidants . Phytic acids, or phytates, can bind minerals such as iron, zinc, and calcium, reducing their absorption. However, phytic acid is also reported to have strong antioxidant and anticancer properties. Though lentils, like all legumes, contain some antinutrients, dehulling and cooking the seeds greatly reduces the presence of antinutrients.

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