**2021 Food Legume Crop Vulnerability Statement**

**Summary of key points**

*Chickpea*

• Collections of genetic resources need to be made from the primary (*Cicer reticulum*) and secondary (*Cicer echinospermum*) gene pools of the crop wild relatives. Currently there are 253 accessions of *C. reticulum* and 79 of *C. echinospermum*.

• Determine genetic resources and genes/QTLs associated with resistance to Ascochyta blight, Pythium seed and seedling blight, and Fusarium root rot and wilt species.

• Evaluate accessions for herbicide tolerance/resistance to herbicides used to manage critical weeds limiting chickpea production.

• Determine genetic resources and genes/QTL associated with resistance to drought, cold and low soil pH tolerance.

• Determine accessions with high protein content and yield and associated genes/QTL.

• Based on Table 2 of this document, accessions need to be identified that increase concentrations of critical human nutrients (iron, zinc, Vitamin A) classified as low or moderate sources, to being moderate or high sources, respectively, while keeping the level of other nutrients the same or higher.

*Lentil*

• Collections of genetic resources need to be made from the primary (*Lens culinaris* subsp. *tomentosus*) and secondary (*Lens odemensis* and *Lens lamottei*) gene pools of the crop wild relatives. Currently there are zero collections of *L. culinaris* subsp. *tomentosus* and *L. lamottei* and only 8 accessions of *Lens odemensis*.

• Identify genetic resources and genes/QTLs associated with Aphanomyces and Fusarium root rot and wilt resistance.

• Determine sources of genetic resistance and genes/QTL associated with the major viruses such as PEMV, BLRV and PSbMV and foliar diseases such as anthracnose, Stemphylium blight and white mold.

• Evaluate genetic resources for resistance to aphids, lygus bugs and wireworms and associated genes/QTL.

• Evaluate accessions for resistance to chalky spot caused by lygus bug feeding.

• Increase the height and harvestability

• Evaluate accessions for herbicide tolerance/resistance to herbicides used to manage critical weeds limiting lentil production.

• Determination of genetic resources and genes/QTL associated with resistance to drought, cold and low soil pH tolerance.

• Determine accessions with high protein content and yield and associated genes/QTL.

• Based on Table 2 of this document, accessions need to be identified that increase concentrations of critical human nutrients classified as low or moderate sources, to being moderate or high sources, respectively, while keeping the level of other nutrients the same or higher.

*Faba bean*

• Collections of genetic resources need to be made from the *Vicia faba* vars. *faba*, *minuta*, and *equina* and from the secondary [*Vicia cappadocica* and *Vicia johannis* (sometimes considered tertiary)] gene pools of the crop wild relatives. Currently there are 10, 7 and 5 accessions of the *V. faba* varieties *faba*, *minuta* and *equina*, respectively, and zero accessions of *V. cappadocica*.

• Determine sources of genetic resistance and genes/QTLs associated with Chocolate spot caused by *Botrytis cinerea* and *Botrytis fabae.*

• Evaluate genetic resources for resistance to pea leaf weevil and associated genes/QTL.

• Determine genetic resources and genes/QTL associated with cold tolerance to enhance winterhardiness of autumn-sown faba beans and drought and salt tolerance.

• Determine accessions with high protein content and yield and associated genes/QTL.

• Determine covicine, vicine and tannins in accessions and associated genes/QTL.

• Based on Table 2 of this document, accessions need to be identified that increase concentrations of critical human nutrients classified as low or moderate sources, to being moderate or high sources, respectively, while keeping the level of other nutrients the same or higher.

*Lupine*

• Collections of genetic resources need to be made from the primary (*Lupinus albus* var. *graecus*) gene pool of the crop wild relatives. Currently there are 4 accessions of *L. albus* var *graecus* in the collection.

• Identify sources of genetic resistance to brown spot caused by *Pleiochaeta setosa* and associated genes/QTL.

• Determine cold, high pH (above 7.5), and water-logging resistance/tolerance and associated genes/QTL.

• Determine accessions with high protein content and yield and associated genes/QTL.

• Evaluate accessions for alkaloid content and associated genes/QTL.

• Based on Table 2 of this document, accessions need to be identified that increase concentrations of critical human nutrients classified as low or moderate sources, to being moderate or high sources, respectively, while keeping the level of other nutrients the same or higher.

**Introduction to the crops** Cool season food legumes such as chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), faba bean (*Vicia faba*), and lupine (*Lupinus albus*) are either major commercially important legume crops in the US (chickpea and lentil) or small acreage crops (faba bean and lupine) that could be grown on dryland in the mid-west to western US. The most important of these crops based on 2019 farmgate values and acreage is chickpea which is annually grown on approximately 451,400 acres in the US with Washington (110,000 acres), North Dakota (41,000 acres) and California (13,400 acres) growing the greatest acreages. Lentil is second in importance and is grown on 486,000 acres in the US with Montana (295,000 acres), North Dakota (95,000 acres), Washington (62,000 acres) and Idaho (34,000) growing the greatest acreages (Statistics provided by Nass.usda.gov). Faba bean and lupine acreages are insignificant in the US. All these food legumes are, or could potentially, be grown in the arid west where they can be grown in rotation with cereals. As a group, these crops can tolerate cool, dry conditions and low fertility. They often are grown in marginal areas that are unsuited to other crops. All these leguminous crops are valuable to dryland growers since they can be rotated with wheat or other drought tolerant cereals to break disease cycles, and they form symbiotic relationships with nitrogen fixing bacteria that provide nitrogen to the legume crop and residual nitrogen for the crop that follows in rotation. To the consumer, these legumes are, or are potentially incredible sources of plant-based protein. Food legumes combined with cereals provides all the essential amino acids needed for a healthy human diet. Other potential cool season food legumes that could be investigated and studied but will only be addressed in specific sections of this statement include *Lathyrus* species known as grasspeas, primarily *L. sativus*, and *Trigonella* species, primarily *T. foenum-graecum* known as fenugreek.

**1.1 Biological features**

The primary plants of concern in the Food Legume crop germplasm are chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), faba bean (*Vicia faba*) and lupine (*Lupinus albus).*

*Chickpea*

There are 43 species of *Cicer* reported, 9 annuals (including the cultivated *Cicer arientum*, 33

perennials and 1 unspecified (van der Maesen 1987). Annual chickpeas come in two types,

“desi” and “kabuli”. These types are based on seed size, color, and the thickness and shape of

the seed coat. Desi types are usually smaller, angular seeds with thick seed coats that range in

color from white to pale cream-color to tan. Kabuli types are large-seeded with thin seed coats that are cream-colored. Chickpea plants are erect with primary, secondary, and tertiary branching, resembling a small bush. They flower profusely and have an indeterminate growth habit, continuing to flower and set pods as long as conditions are favorable. Pod set occurs on the primary and secondary branches and on the main stem. The individual round pods generally contain one seed in kabuli types and often two seeds in desi types. Chickpeas have a deeper taproot than peas and lentils, which gives them an advantage in moisture-deficient areas. Chickpea is a self-pollinating plant. The seedling is hypogeal. The growth of the plumule produces an erect shoot. The plant has a deep tap root that produces lateral roots. Leaves are born singly at each node arranged in alternate phyllotaxy and are generally unipennate compound. All external surfaces of the plant, minus the corolla are covered by glandular and aglandular hairs. Plants have five growth habits based on the angle of branches: erect, semi-erect, semi-spreading, spreading and prostate (Pundir et al. 1985). In general plants are usually 20 to 100 cm tall. They are usually borne singly in axillary racemes, but twin flowers may also be found. Flowers of desi-types and kabuli-types are generally purple and white in color, respectively. Chickpea has inflated pods, that can range from a few to over 1000 pods per plant. Pod shape is rhomboid oblong or ovate. The seed is beaked, angular and often wrinkled. Twenty-one different colors and shades of seed are recognized. The plant is diploid with 2n equal to sixteen chromosomes.

*Lentil*

Lentil plants are herbaceous, with slender stems and branches. Plant height ranges from 12 to 15 inches for most varieties but can vary from 8 to 30 inches depending on variety and environment. Plants have a slender taproot with fibrous lateral roots. Rooting patterns range from a many-branched, shallow root system to types that are less branched and more deeply rooted. Stems of lentil plants are square and ribbed and usually thin and weak. Branches arise directly from the main stem and may emerge from the cotyledonary node below ground or from nodes above ground. Leaves are relatively small compared to those of other large-seeded food legumes. Pods are oblong, laterally compressed, and approximately ¼ to ¾ inch long and 1/8 to 3/8 inch wide; they usually contain one or two lens-shaped seeds. Seed diameter of varieties commonly grown in the United States ranges from around 1/8 inch to a little over ¼ inch and colors range from light green or greenish red to gray, tan, brown, or black. Purple and black mottling and speckling of seeds are common in some varieties. Plants can have a single stem or branched, bushy form. Leaves are pinnate and have up to 14 sessile, ovate to lanceolate leaflets, each about 0.5 to 1.5 inches long. Leaves have two small stipules at the base and may terminate in a tendril. Flowers are usually double, or sometimes one to four on racemes, small (less than 0.5 inch long) and white to pale purple or dark purple. They bloom in sequences from the lower branches upwards (Cash et al. 2001). Flowers are self-pollinated and usually pollinate before opening. Occasionally cross-pollination can occur by thrips or other small insects. Flowers fade within 3 days of opening, and seed pods form 3 to 4 days later. Seed pods are flat, smooth, 0.5 to 0.75 inches long (Muehlbauer et al. 2002). Seeds are lens-shaped and have a seed coat which ranges in color from clear to green, pale tan, brown and black. Seed coats of some cultivars have purple or black mottles or speckles. A growing season of 80 to 100 days is required for growing a lentil crop, depending on the seed date, precipitation and heat units (Cash et al. 2001). The lentil is a true diploid (2n =14) (Muehlbauer 1991).

*Faba bean*

Faba bean is a cool season annual legume known as *Vicia faba* L. Winter type cultivars usually have 4 to 6 stems/plant and spring-type cultivars have 1 to 2 stems/plant. The root system is a tap root with secondary roots and bears nodules containing the nitrogen-fixing bacteria *Rhizobium leguminosarum* bv. *viciae*. Stem growth is indeterminate, and results from the growth of two orthostics which alternatively develop a node, carrying a leaf up to the 5th to 10th node and thereafter carrying a raceme of 2 to 12 flowers axillary to the leaf. The number of leaflets per leaf increases from two at the bottom of the plant to 6 to 8 leaflets at the top. Flowers, 2 to 3 cm long at anthesis, have a typically papilionaceous structure. They can be completely white, brown or violet. In most cases they concentrate their color on black or brown melanin spots on the wings. Pods are short and erected in minor and paucijuga types (3 to 4 ovules per pod) and long and hanging in major types (8 to 12 ovules per pod). *V. equina* types are intermediate having 4 to 8 ovules per pod. Seed color can be yellow, green, brown, black, or violet and the seed may sometimes carry punctuations, brown spots or stripes around the hilum. The hilum can be black or clear. Faba bean seed is about 25% protein and is higher in energy than soybean. For best production, faba bean crops should be grown on well-structured loam or clay soils with a pH of 6.5 to 9.0. They perform poorly on light sandy soils, and nodulation failures can occur on acidic soils. Faba bean is a long-day plant and requires a cool season for best development and can be seeded early. The crop is grown as a winter annual in warm temperate and subtropical areas; hardier cultivars in the Mediterranean region tolerate winter temperatures of -10 C without serious injury, whereas the hardiest European cultivars can tolerate up to -15 C. Growing seasons should have a little or no excessive heat, optimum temperatures for production range from 18 to 27 C. Faba bean are late maturing so they benefit from a longer growing season. The plants are erect, cultivars with both indeterminate and determinate growth are known, and those with determinate growth are between 2 and 7 feet tall (De Costa et al. 1997; Hickman and Canevari, 2012; Preston and Isely, 2012). Stems are square and hollow, there may be a single stem or several branching from the base to form a bushy habit. Leaves are compound 4 to 7 inches long with 3 to 7 leaflets and no tendrils. The leaf stipules have an extrafloral, purple nectary on the undersurface. Flowers are fragrant, borne in clusters on short stalks in the axils of the leaves, petals range from white to purple and may have black, dark brown or purple blotches. The flowers have 10 stamens, nine of these are fused and the tenth is free, the ovary is positioned above the stamens, and the style is angled upwards bearing a cluster of hairs near the stigma. The pod’s exterior is smooth, green, and cylindrical in shape with a wooly coated interior that can contain up to 10 seeds. Once the seed is mature, the pods dry to dark brown or black. Seeds vary greatly in size, and colors of mature seeds may vary from cream, brown, reddish, greenish and purple with a large dark-colored hilum. The root system consists of several lateral roots in addition to a broad and shallow taproot, though variation in root architecture among cultivars is known to exist. Faba bean cultivars with deeper root systems generally experience improved drought tolerance. (Ingram et al., 1997; Zhao et al., 2017). An association with the symbiotic nitrogen fixing bacteria, *Rhizobium leguminasarum bv. vicae*, develops nodules on the roots, which are variable in size, with a white exterior and reddish interior in actively fixing nodules (Jensen et al., 2010). Mycorrhizal associations develop on the roots of faba beans (Kopke and Nemecek. 2010). Chromosome number 2n=12, the genome size (~13 Gb) of faba bean is about double that of closely related species due to many repetitive sequences (Duc, 1997). Faba bean is a long day plant that is grown as a winter annual in warm temperate and subtropical areas, and as a warm season crop in cooler areas. Optimum soil temperatures for germination are between 60 and 65˚ F. Germination will not occur at temperatures below 40˚ F or above 76˚ F, though there are differences between cultivars (Jensen et al., 2010). Hardier cultivars from the Mediterranean can tolerate winter temperatures as low as 14˚ F and the hardiest European cultivars have a floor of 5˚ F. The optimum temperatures for growth range from 65-85˚ F while temperatures above 90˚ F will restrict growth and yields (Landry et al., 2015a; Jensen et al., 2010). For best production, faba bean crops should be grown on well-structured loam or clay soils with a pH of 6.5 to 9.0. They perform poorly on light sandy soils and nodulation failures can occur on acidic soils, especially if they are hard setting or prone to waterlogging. Plants are reasonably tolerant to waterlogging but are more prone to infection from foliar diseases such as Chocolate spot under waterlogged conditions.

*Lupin*

This statement will focus on the white lupine *(Lupinus albus*) however other lupine species have been developed for various agricultural purposes such as the yellow lupine (*L. luteus*) for ornamental purposes and blue or narrow-leafed lupine (*L. angustifolius*) as animal feed, green manure and as a grain legume for animal and human consumption. White lupine is an annual legume that is mostly self-pollinating and does not need tripping. The average seed weight ranges from 70 mg to approximately 1 g. Seeds have a protein content ranging from 33 to 47%. Oil content varies from 6 to 13% with a high concentration of polyunsaturated fatty acids. The seeds contain no starch. The hulls are composed of cellulose, hemicellulose and lignin. The storage sugars are located in the cell walls of the cotyledons. Commercial varieties must be free of alkaloids. Turkish white lupine material collected on the Anatolian plateau are spring-sown, early flowering material with small seeds (200 mg/seed). When studied under Western European climatic conditions, they show an indeterminate growth habit with weak stems. Populations collected in the coastal zones are also early flowering but more vigorous and with larger seeds. When used in breeding, Turkish populations are good progenitors for flowering earliness. The populations from the Nile Valley are early flowering but tend to show reduced vegetative development, while materials collected in the South of Egypt tend to be more vigorous in initial field testings. Populations from the Balkans are traditionally autumn-sown materials with a limited frost tolerance, and good pod set. Wild populations of the subspecies *L. albus* ssp. *graecus* found in some areas of Greece are short with purple flowers, have shattering pods and they produce small, hard and marbled seeds. This subspecies considered as a potential ancestor of the cultivated white lupine is cross compatible with cultivated *L. albus* and their hybrids are fully fertile. Italian collections of white lupine are very diverse. Populations collected in the Apennines and Abruzzo region are very winter-hardy and interesting progenitors for frost resistance, whereas populations collected from coastal regions and in the South are very vigorous and frost susceptible. Among the Italian material, mean seed weight ranges from 200 mg to 1000 mg with populations used for human consumption having generally larger seeds than those used for green manuring or green forage production.

**1.2 Ecogeographical distribution**

*Chickpea*

Chickpea is considered to have originated from South-eastern Turkey and Syria and is grown in South Asia, West Asia, North Africa, East Africa, southern Europe, North and South America, and Australia. The wild progenitor of cultivated chickpea, *C. reticulatum*, is a rare species, currently reported from only 18 narrowly distributed locations (37.3-39.8 N, 38.3-43.6 E) in south-eastern Turkey. In 2003, Berger et al. used principal component analysis to summarize the habitat characteristics of the annual wild *Cicer* collection sites in terms of geography and climate and compared these with the range of habitats recorded for the species in regional floras. With few exceptions, the range of habitats sampled in ex situ collections is far smaller than that covered by the species distribution in the wild. As a consequence of low original accession numbers, and narrow collection site distribution, the world collection represents only a fraction of the potential diversity available in wild populations. It is suggested that targeted collection missions based on ecogeography data be implemented.

*Lentil*

Lentil is considered to have originated from central to southwest Asia. Three major regional groups have been identified in a world collection housed at ICARDA: 1) a levantine group (Egypt, Jordan, Lebanon and Syria, 2) a more northern group from South-East Europe and North-West Asia is composed of Greece, Iran, Turkey, and USSR, and 3) accessions from India and Ethiopia (Erskine et al. 1989). Lentils are a drought-tolerant, cool-season crop. They are usually grown in semi-arid climates without irrigation. A minimum of 10 inches of annual rainfall is required for lentil production (Cash et al. 2001). Lentils can tolerate low rainfall and high temperatures, however these stresses may negatively impact yield if they occur during flowering and seed set (Muehlbauer et al, 2002). Lentils are often planted in the spring in cool climates and in the fall or winter in warm climates. A few varieties are tolerant of extreme cold temperatures and can be planted in the winter in cool climates. Lentils grow best in deep, sandy loam soils, however they will grow in all soil types with good drainage (Oplinger et al. 1990; Elzebrok and Wind, 2008). They can tolerate moderate alkaline or saline conditions (Muehlbauer et al. 2002) and grow in soils with pH of 4.4 to 8.2 but are best adapted to soils with pH of 5.5 to 7 (Elzebrok and Wind, 2008).

 The following information is taken from Malhotra et al. 2019. The wild *Lens* taxa are widely distributed in the Mediterranean region, and it was thought that only the Aegean and Southwest of Turkey overlapped for the distribution of *Lens* taxa (Ferguson et al., 1996). The distribution of the subspecies, *L. culinaris* ssp. *orientalis*, has an Eastern spread from Turkey, and *L. culinaris* ssp. *odemensis* has restricted distribution in the East, spreading from Turkey southwards to Syria and Palestine. *L. culinaris* ssp. *tomentosus* is found in Southeastern Turkey (Ladizinsky, 1997; Ferguson et al., 1998b). However, the species *L. ervoides* has a wide distribution from Spain to Ukraine and south to Jordan. *L. nigricans* grows in diffused small patches on rocky hillsides (Zohary, 1999) and has a western distribution from Spain to Turkey and south to Morocco (Ferguson et al., 1996), while *L. lamottei* grows well in Morocco (Van Oss et al., 1997). Unfortunately, Turkey, like other Mediterranean countries, is suffering from the rapid loss of many of its invaluable genetic resources. These genetic resources, which have the potential to provide useful diversity for crop breeding efforts, are being eroded primarily due to habitat destruction (Solh and Erskine, 1981).

*Faba bean*

Faba bean (also called broad beans or horse beans) is considered to have originated from the Near East and Mediterranean basin and is an important winter crop in warm temperate and subtropical areas. The ancestor plant of faba bean remains unknown. Faba bean are grown during winter in subtropical and warmer temperate climates on water remaining after crops such as maize and sorghum. Precipitation is often low and is a strongly limiting factor on the grain yield. The West Asia and North African regions have a Mediterranean-type climate with hot dry summers and wet mild winter-dominant rainfall patterns. Faba bean are grown under rainfed conditions during the winter and typically rotated with cereals, cotton or sugar beets in coastal regions. In China, faba bean is autumn-sown after rice or intercropped with cotton or maize in southern and Western provinces, where it is grown in rotation with winter wheat and also intercropped with cereals in the Northern provinces. In Northern parts of Europe, faba bean is primarily spring-sown in cropping systems with cereals, oilseed rape and sugar beets. Preceding crops to faba bean in rain-fed systems in Australia is usually wheat or barley. Faba bean is also used in rotation with irrigated cotton to some degree and in irrigated situations, cotton is the main crop before and after faba bean. There are large numbers of locally adapted cultivars and land races of faba bean due to its long history of domestication, and selection pressure in separated geographic areas. Some cross pollination occurs and falls between 4 to 84% (Torres et al., 2006). Faba beans can grow on heavier soils than vetch (*Vicia* spp.) and peas (*Pisum* spp.) (UCANR, 2019) and generally tolerate a variety of soil types but grow best on well-drained clay and silt soils in addition to sandy soils with adequate moisture. The pH range for faba bean growth is between 6.5 and 9. Poor performance on poorly drained and acidic soils is often attributed to failures in nodulation (Jensen et al., 2010). The relatively shallow root system means that faba bean depends on water availability in the top 12-18 inches of soil (Caracuta et al., 2015). Drought tolerance varies considerably between cultivars with those from northern Europe exhibiting less drought tolerance and shallower lateral roots compared to cultivars from southern Europe (Zhao et al., 2017). Sensitivity to drought is most severe at bloom and during pod fill (UCANR, 2019). Faba bean is a long day plant that is grown as a winter annual in warm temperate and subtropical areas, and as a warm season crop in cooler areas. Optimum soil temperatures for germination are between 60 and 65˚ F. Germination will not occur at temperatures below 40˚ F or above 76˚ F though there are differences between cultivars (Jensen et al., 2010). Hardier cultivars from the Mediterranean can tolerate winter temperatures as low as 14˚ F and the hardiest European cultivars have a floor of 5˚ F. Cold tolerance is a problem in some regions of the Continental United States and selection of cultivars to tolerate a wider temperature range is a goal of the USDA-ARS Faba Bean Research Program, along with selection of small-seeded cultivars that can be easily planted with corn and cover crop planters (Hu et al., 2009; Landry et al., 2015b). The optimum temperatures for growth range from 65-85˚ F while temperatures above 90˚ F will restrict growth and yields (Landry et al., 2015a; Jensen et al., 2010).

*Lupine*

White lupine is mainly found in the Mediterranean and along the Nile valley. Collections of white lupine have been made in the Iberian Peninsula, the Balkans, Turkey, Italy, Azores, Morocco and Egypt. Populations from the Sudan, Kenya, Ethiopia, Syria and Israel have also been collected. The possible locations for white lupines are the areas with neutral or acid soils and with a long-crop season and moderately high temperatures. The climate of Western Europe favors autumn-sown varieties and central Europe favors spring-sown varieties. Climates in North America that favor lupine production would be in the South East as a fall or winter cover crop or crop in double-crop systems, and in the North West to take advantage of winter rainfalls. White lupine has been used as a cover crop for cotton in Alabama, Georgia and South Carolina. Favorable climates in South America, where white lupines are currently grown include, Chile and to a lesser extent Argentina. South Africa where lupine acreage is increasing and Australia where spring-type varieties may be grown in areas with deep soils in Western Australia or in the Eastern United States. The white lupine collection of the Australian Lupine Collection was gathered from samples taken from the Ethiopian highlands, the Nile Valley, Mediterranean Basin and continental Europe (Berger et al. 2008). In the USDA White Lupine production guide (Clark 2014), the ideal conditions for lupine growth are mean monthly temperatures of 59-77 F. Higher temperatures and drought stress hinder flowering and pod setting. White lupine is cold-tolerant, but temperatures of 21 to 18 F are harmful at germination. Rainfall of 15 to 39 inches during the growing season is optimal. It shows good frost resistance, but this will vary by genotype and climate. White lupine prefers disturbed sites, poor soils, and areas with reduced competition. It grows well in acidic soils but tolerates mildly alkaline and slightly calcareous soils. Soil pH of 6.5 or less is suitable. Soil acidity is less critical for lupine production than for other legumes such as alfalfa and soybean. Growth is hampered on heavy clay, water-logged and alkaline soils. Some cultivars of white lupine are more tolerant to salinity and heavy soils than other crops.

**1.3 Plant breeding and its products**

*Chickpea*

Chickpeas come in two types, “desi” and “kabuli”. Desi type are small, wrinkled seeds, brown, light-brown colored, as well as orange, green or black. Desi seed are approximately 120 mg in weight and used as whole, split or as flour. Kabuli chickpeas are large, rounded seeds, white cream-colored and seed are around 400 mg. In North America, most kabuli chickpeas are marketed as whole seed, canned for salads or as hummus. Kabuli chickpeas are also marketed as dry chickpeas and ground flour.

*Lentil*

Lentils are divided into two major types: macrosperma (large-seeded, or Chilean types) and microsperma (small seeded, or Persian types) (Zohary, 1995; Cash et. al 2001). Large-seeded lentils have seeds up to 0.5 inches in diameter with yellow cotyledons and little pigmentation in the flowers or vegetative structures. Small-seeded lentils have seeds up to 0.25 inches in diameter with red, orange, or yellow cotyledons and more pigmentation in the plant tissue. Small-seeded lentils are generally shorter and have smaller leaves and pods (Muehlbauer et al. 2002). Numerous lentils are available for commercial production and fall within the following principal market classes: small reds, small green, medium green, large green, Spanish brown and zero tannin. Some lentils are sold and consumed with seed coats intact, and others with seed coats removed. Seeds are often consumed whole or split in soups, stews and salads, and can be ground into flour and used in cakes or infant food (Elzebrok and Wind, 2008). Lentils that do not meet food grade standards, #3 or below, are used for livestock feed (Oplinger et al. 1990). Plant residues are also sometimes fed to livestock. In the US, the Brewer variety is the most common grown with a large yellow cotyledon but recent niche markets for small Spanish brown lentils (Pardina variety) grown for sale to Spain and red lentils (Crimson variety) grown for sale to the Asian market have provided greater profitability (USApulses.org).

*Faba bean*

Faba bean is grown as a grain and green-manure legume. It can be used for food, feed, and fuel production. The nutritional value of dried faba beans is high, and it is used as feed for pigs, horses, poultry and pigeons. It may also be used as a component of the diet for cattle and sheep (Crepon et al., 2010; Jensen et al., 2010). As a green manure, faba bean can significantly enhance yields of cereals or other crops by providing nitrogen to the soil and helping to break disease cycles. Faba beans can be grown either as a cool or warm season cover crops depending on the location. Faba bean straw is used as a cash crop in Egypt and Sudan (Jensen et al., 2010). Some of the indeterminate cultivars of faba bean with an extremely high biomass production may be suited for use as biomass crops, possibly intercropped with high yielding, perennial monocots, to be used in biorefineries for biofuels, biogas, green chemicals, power and recycling of nutrients to agricultural lands. Two types of varieties are cultivated: (1) cultivars with large-flattened seeds, from 1 to 2 g dry matter per seed, named ‘‘*V. faba* major or broad beans’’, mainly grown in the southern regions of Europe and used for human food, either as fresh seeds or as dry seeds; (2) varieties with medium to relatively small and round seeds, from 0.4 to 0.8 g dry matter per seed, named ‘‘*V. faba* minor or field beans or horse beans’’), grown in a larger range of regions, mainly for dry seeds used for animal feed or for human food (Crepon et al. 2010). Three sub-species are recognized: *V. faba* var *faba*, broad bean or Windsor bean is a large-seeded form with one or two large pods, *V. faba* var *equina*, field bean or horse bean has more numerous pods and smaller seeds, and *V. faba* var *minuta,* bell bean or tick bean, has the smallest seeds with numerous pods in the leaf axils (UCANR, 2019; USDA Agriculture Research Service (ARS), 2018). The pods, beans, and shoots of the plant are edible, and the part(s) consumed depend on region and culture. Faba beans are a staple food around the Mediterranean area and across Eurasia, including Egypt, Syria, Iraq, Iran, Northern India, Pakistan, and Southern China. In Europe and the United States, the large seeded immature beans are eaten fresh with or without the seed coat. In Egypt and other Arab countries, small-seeded faba beans are used in the national dish, *ful medames*. In Southern Europe and Southeast Asia, beans are eaten fresh, dried in a variety of dishes, or roasted for use as a snack food. The fresh shoots and newly unfolded leaves are consumed fresh or in stir-fries in some Asian cultures. Faba bean makes excellent forage*,* the plants may be grazed or used for hay and silage (Jensen, 2010; UCANR, 2019). Analysis of nine faba bean lines grown under dryland conditions at the USDA-Natural Resources Conservation Service (NRCS) Bridger, Montana Plant Materials Center found crude protein ranged from 14 – 22% and the relative feed value (RFV) varied from 123-150%, which is comparable to the RFV of alfalfa (*Medicago sativa*) (Hensleigh, 2016; Tallman, 2016).

*Lupine*

Used for food because of high protein and oil content. Breeding for food is oriented towards the selection of dwarf determinate varieties that are sweet with low alkaloid content. Used as a green manure to improve soil structure, increase organic matter and improve nitrogen and phosphorous accumulation in poor soils. Lupine was an important cover crop in the southeastern United States from the late 1930s until the early 1950s until synthetic fertilizers became more available. Used as ruminant feed either as green forage in the areas of traditional cultivation or as protein supplements in the diets. The composition of the grain and especially the high protein content makes white lupine highly suitable for ruminant diets as a protein-rich product in intensive farming systems. The fiber-rich flour made from white lupine seeds are used by humans. The flour is a good source of macro- and micro-nutrients, protein, fat, carbohydrates, minerals, and vitamins (Yanez, 1996). It is used to enrich pastas, cake mixes, cereals, and other baked goods (Birk, 1993). Sweet white lupine flour also is added to emulsify meat products to increase nutritional value, aroma and to modify texture (Erbas et al., 2005).

**1.4 Primary crop products and their value** (Statistics from NASS.USDA.gov and Fao.org)

*Chickpea*

Gross production value of chickpea in the world in 2018 in millions of dollars was 11239.5 with the US accounting for 275.1 of that number. In 2018 in the US, the average price of chickpeas was $28.50 per 100 pounds, and 3,270,000 cwt of small chickpeas and 9,472,000 cwt of large chickpeas were produced.

*Lentil*

Gross production value of lentil in the world in 2018 in millions of dollars was 2739.0 with the US accounting for 139.6 of that number.

*Faba bean*

Gross production value of faba bean in the world in 2018 in millions of dollars was 1027.6. The US market size was so small no data was provided for it.

*Lupine*

Gross production value of lupine in the world in 2018 in millions of dollars was 340.1. The US market size was so small no data was provided for it.

**1.5 Domestic and international crop production**

**1.5.1 U.S. (regional geography)** (Statistics from NASS.USDA.gov)

*Chickpea*

In 2019, chickpeas were primarily produced in five states, California (13,400 acres, 355,000 cwt), Idaho (88,000 acres, 1,242,000 cwt), Montana (199,000 acres, 2,505,000), North Dakota (41,000 acres, 325,000 cwt) and Washington (110,000 acres, 1,810,000 cwt).

*Lentil*

In 2019, lentils were primarily produced in four states, Idaho (34,000 acres, 363,000 cwt), Montana (295,000 acres, 3,290,000 cwt), North Dakota (95,000 acres, 1,053,000 cwt), and Washington (62,000 acres, 682,000 cwt).

*Faba bean*

Minnesota and the lake states produce small acreages. In California, faba beans are grown on small acreages as a seed crop along the coast from Lompoc to Salinas and in the Northern Sacramento Valley, but in other areas of the state they are grown mostly as a cover crop or for green manure.

*Lupine*

Grown on small acreage in Minnesota and Wisconsin as dairy and livestock feed. Use to be grown extensively in the southern US as a green manure crop on cotton farms.

**1.5.2 International** (Statistics taken from Fao.org)

*Chickpea*

Chickpeas in 2018, were grown on 17,817,370 ha worldwide in at least 55 countries with the top eight countries as determined by area planted being India (11,899,185), Australia (1,075,136), Pakistan (976,580), Russian Federation (819,330), Turkey (514,102), Iran (500,854), Myanmar (368,390) and the United States of America (341,070). Additional countries in order of hectares planted include: Ethiopia (241,212), Mexico (194,370), Canada (176,000), Argentina (135,036), United Republic of Tanzania (113,480), Morocco (86,800), Spain (70,609), Bulgaria (59,841), Syrian Arab Republic (45,300), Algeria (32,065), Italy (26,024), Kazakhstan (24,470), Yemen (20,883), Greece (10,498), Nepal (9,882), Eritrea (9,112), Uganda (8,337), Israel (7,010), Sudan (6,716), Tunisia (5,509), Bangladesh (5,027), Kenya (3,690), Lebanon (3,185), China (2,870), Uzbekistan (2,773), Portugal (2,594), Malawi (2,166), Romania (2,086), Togo (1,733), Bosnia and Herzegovina (1,682), Egypt (1,253), Palestine (1,164), Peru (987), North Macedonia (888), Chile (780), Jordan (724), Republic of Moldova (699), Niger (444), Iraq (372), Libya (360), Slovakia (317), Bolivia (291), Hungary (272), Zimbabwe (221), Colombia (65), Cyprus (54), and Dominican Republic (2).

In 2018, US grown chickpeas were primarily consumed in Spain, Canada, Pakistan, India, Portugal, Peru, Algeria, Italy, Lebanon, Turkey, Jordan, United Kingdom, Sri Lanka, United Arab Emirates, Frances, New Zealand, Japan, Taiwan, Israel, Korea, Philippines, Egypt, China, Belgium, Dominican Republic, Colombia, Costa Rica, Trinidad and Tabogo, Netherlands, Hong Kong (Listed in order of greatest exports to these countries).

*Lentil*

Lentils in 2018 were grown on 6,167,985 ha worldwide in at least 52 countries with the top six countries based on area planted being India (2,215,397), Canada (1,499,400), Kazakhstan (294,574), United States (290,560), Turkey (259,374) and Russian Federation (247,885). Additional countries in order of hectares planted include Australia (228,918), Nepal (198,605), Bangladesh (154,678), Iran (146,821), Ethiopia (122,109), Syrian Arab republic (111,000), China (67,063), Morocco (44,101), France (36,634), Algeria (25,956), Ukraine (24,500), Pakistan (13,632), Argentina (13,032), Greece (9,664), Yemen (9,539), Mexico (8,080), Italy (5,417), Colombia (3,976), Ecuador (3,752), Bulgaria (3,179), Kenya (3,013), Peru (2,864), Chile (2,420), Tunisia (1,950), Martinique (1,787), Malawi (1,338), Myanmar (1,319), Madagascar (1,233), New Zealand (1,115), Eritrea (1,029), Uzbekistan (959), Azerbaijan (745), Lebanon (720), Palestine (636), Egypt (630), Tajikistan (588), Slovakia (372), Armenia (171), Jordan (130), Israel (110), North Macedonia (81), Croatia (25), Hungry (24), Cyprus (19) and Iraq (1).

In 2018, US grown lentils were primarily consumed in Spain, Sudan, Canada, Mexico, Peru, Colombia, India, China, Benin, Italy, Greece, Belgium-Luxembourg, Pakistan, Thailand, Dominican Republic, Turkey, Germany, French Pacific Islands, Netherlands, Leeward-Winward Islands, Korea, Philippines, United Arab Emirates, Ecuador, Bangladesh, France, Algeria, Laos, Mali, and Georgia.

*Faba bean*

Faba bean in 2018 were grown on 3,377,792 ha in 60 countries with the top six countries based on area being China (865,982), Ethiopia (464,313), Australia (218,544), United Kingdom (154,600), Morocco (137,032) and Sudan (64,988). Additional countries that grow faba bean in order of hectares planted include France (57,203), Germany (55,300), Tunisia (54,907), Peru (53,345), Italy (50,421), Egypt (40,298), Algeria (40,222), Brazil (36,061), Sweden (26,170), Paraguay (23,444), Spain (23,234), Guatemala (22,976), Mexico (21,166), Syrian Arab Republic (19,600), Bolivia (14,579), Dominican Republic (9,691), Iran (8,070), Austria (7,645), Russian Federation (6,620), Nepal (6,323), Turkey (4,772), Ukraine (3,500), Ecuador (2,543), Uzbekistan (2,312), Argentina (1,872), Yemen (1,868), Sierra Leone (1,506), Iraq (1,303), Colombia (1,151), Belgium (1,072), Greece (968), Czechia (932), Libya (899), Switzerland (748), Portugal (352), Uruguay (347), Netherlands (339), Slovakia (293), Cameroon (279), Malta (267), Jamaica (227), Poland (201), Eritrea (189), Lebanon (176), Palestine (171), Albania (169), Guyana (154), Japan (116), Hungary (112), Azerbaijan (62), Cyprus (62), Luxemburg (62), Bulgaria (46), and Slovenia (6).

*Lupine*

Lupines in 2018 were grown on 984,894 ha in 26 countries with the top six countries based on area planted being Australia (612,014), Poland (95,639), Morocco (88,941), Russian Federation (71,163) and Chile (24,968). Additional countries in order of hectares planted include Germany (23,400), Greece (17,480), Peru (11,706), Ukraine (9,100), South Africa (8,978), Belarus (4,059), Ecuador (3,615), Italy (3,343), Spain (2,984), France (2,928), Lithuania (2,553), Slovakia (935), Hungary (224), Egypt (201), Latvia (200), Austria (191), Argentina (115), Switzerland (87), Lebanon (53), Portugal (11) and Syrian Arab Republic (6). Lupine production is mostly non-existent in the US.

**2. Urgency and extent of crop vulnerabilities and threats to food security (4 pp. maximum)**

**2.1 Genetic uniformity in the “standing crops” and varietal life spans**

*Chickpea*

Due to the following reasons: 1) the scarcity and limited distribution of the wild progenitor, *C. reticulatum*, 2) the founder effect associated with domestication, 3) the shift, early in the crop’s history, from winter to spring sowing, and the attendant change from using rainfall as it occurs to a reliance on residual soil moisture, and 4) the replacement of locally evolving landraces by elite cultivars produced by modern plant breeding, the diversity in chickpea is considered to be limited compared to other legume crops. To widen the genetic base of cultivated chickpea, it is imperative to reintroduce traits from across the primary gene pool. An extensive collection of annual wild *Cicer* species, based on ecogeographic principles to maximize the probability of collecting diverse ecotypes, should provide a better understanding of the biology and adaptation in this crop to improve productivity.

A study genotyped part of the USDA chickpea core collection (Hannan et al 1994) with 20 microsatellite or simple sequence repeat (SSR) markers (Varshney et al. 2007). In addition, the genetic relationship was studied. A total of 376 accessions from the USDA chickpea core collection were genotyped. Twenty SSR markers revealed a total of 388 alleles among the 376 accessions. In the USDA core collection, the shared allele frequency (SAF) varied from 7.5% to 47.5% with an average of 21.6%. This suggests a higher level of genetic diversity present in the germplasm investigated. The structure of the population was determined using K=4 based on a model-based (Bayesian) clustering algorithm.

In Pakistan, thirty chickpea accessions were used to determine genetic diversity in chickpea, including 7 cultivars and 23 advanced lines (Ahmad et al. 2010). Five selected cultivars were collected from the Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan, while other genotypes (2 approved varieties and 23 advanced lines) of chickpea were collected from Ayub Agricultural Research Institute (AARI), Faisalabad, Pakistan. The low degree of similarity (monomorphic bands) indicated high divergence between the genotypes evaluated.

In Mexico, research was carried out to estimate the genetic variability of the main cultivars developed in Mexico, and others donated by International Centers (ICARDA and ICRISAT) (Valadez-Moctezuma et al. 2020). Fifty-seven accessions of *Cicer arietinum* were analyzed, including 19 cultivars and advanced lines obtained from breeding programs in Mexico, provided by CEVACU (from Spanish ‘‘Campo Experimental del Valle de Cualiaca´n’’) of the INIFAP (from Spanish ‘‘Centro de Investigaciones Forestales y Agropecuarias); 23 accessions were provided by ICARDA (Aleppo, Syria) and another 15 provided by ICRISAT (Patancheru, India). With the analysis of ten SSR markers, a total of 51 alleles were obtained, with individual values ranging from 3 to 9 alleles per locus. The average value of PIC was estimated at 0.70, while the average value of Shannon’s Information Index was 1.365, indicating the presence of a high level of genetic variability in the collection.

In Ethiopia, an investigation was designed to assess the extent of variability, genetic advance, heritability and interrelation of different traits of 100 chickpea genotypes using a triple lattice design in Takusa district, North Gondar, Ethiopia, during 2018/19 main cropping season (Tsehaye et al. 2020). The examined genotypes were highly significant for all studied traits. The magnitude of genotypic and phenotypic coefficient of variation indicated the presence of variability among advanced lines. The trait above ground biomass exhibited the highest range of variability followed by grain yield, number of pods per plant, hundred seed weight, days to flowering and days to maturity. The highest estimates of genotypic and phenotypic coefficient of variation were exhibited by grain yield followed by the number of pods per plant, number of secondary branches per plant, above ground biomass, and harvest index. The highest broad sense heritability coupled with high genetic advance were observed for grain yield, number of pods per plant, number of secondary branches per plant, above ground biomass and hundred seed weight. Inter distance (D2) values ranged from 81.6 to 874.5 with a total of 9 significant clusters. The first four principal components, with Eigen values greater than one, accounted for more than 81.5% of the total variation. Hence, the existence of huge variability infers, exploiting the existing variation is enough to improve chickpea grain yield only thorough simple selection by giving due attention for above ground biomass, number of secondary branches per plant, number of pods per plant and harvest index.

In India, with a view to discern the genetic distance between the cultivated chickpea of the Indian subcontinent and that of Western Asian Mediterranean, Asian region and wild chickpea accessions, a molecular diversity study was undertaken with 50 accessions of chickpea obtained from ICARDA, Aleppo, Syria, ICRISAT, Hyderabad, India, NBPGR, New Delhi, India and IARI, New Delhi, India (Bharadwaj et al. 2011). All the ICARDA lines of Syrian, Turkey and those from Spain origin were falling in near vicinity to what was called subcluster IIB. This clearly brings out the distinctiveness of the Mediterranean group of lines from Syria and vicinity to be distinct from the Indian subcontinent lines. It is obvious as such because the ICRISAT germplasm has more than 60% accessions from Indian subcontinent and use of these accessions in developing advanced breeding lines and varieties by the breeders of Indian subcontinent repeatedly in their breeding programs would have narrowed the genetic base of the varieties released in this region. Further, adaptive selection from these lines by breeders in India, while developing varieties suitable for Indian subcontinent, would have led to development of Indian chickpea breeding materials with relatively narrower genetic base. The grouping of lines from Syria and wild species into a separate cluster indicates they are diverse to the Indian subcontinent type and can serve as good sources for genetic base broadening in chickpea.

*Lentil*:

Assessment of genetic diversity and population structure of germplasm collections plays a critical role in supporting conservation and crop genetic enhancement strategies. A cultivated lentil (*Lens culinaris* Medik.) collection consisting of 352 accessions originating from 54 diverse countries were collected from various sources including breeding lines obtained from the Crop Development Centre collection in Saskatoon, Canada, from ICARDA, and the USDA-ARS and were used to estimate genetic diversity and genetic structure using 1194 polymorphic single nucleotide polymorphism (SNP) markers which span the lentil genome (Khazaei et al. 2016). 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.

*Faba bean*:

Target region amplification polymorphism markers were used to assess the genetic diversity and relationship among 151 worldwide collected faba bean (Vicia faba L.) entries (137 accessions maintained at the USDA–ARS, Pullman, WA, 2 commercial varieties and 12 elite cultivars and advanced breeding lines obtained from Link of Georg-August University, Germany) (Kwon et al. 2010). Twelve primer combinations (six sets of polymerase chain reaction) amplified a total of 221 markers, of which 122 (55.2%) were polymorphic and could discriminate all the 151 entries. A high level of polymorphism was revealed among the accessions with an estimated average pairwise similarity of 63.2%, ranging from 36.9 to 90.2%. Cluster analysis divided the 151 accessions into five major groups with 2–101 entries each and revealed a substantial association between the molecular diversity and the geographic origin. All 101 accessions in Group V originated from China and 13 of the 15 accessions in Group II were from Afghanistan. Thirty-two individual plants were sampled from two entries to assess the intra-accession variation. It was found that the advanced inbred line (Hiverna/5-EP1) had very little variation (5.0%), while the original collection (PI 577746) possessed a very high amount of variation (47.1%). This is consistent with previous reports that faba bean landraces have a high level of outcrossing in production fields and thus contain larger amounts of variation within each landrace. One implication of this observation for germplasm management is that a relatively larger population is needed in regeneration to mitigate the possible loss of genetic variation due to genetic drift.

A study investigated the genetic variation in 22 faba bean genotypes, 18 of which were originated from International Center for Agricultural Research in the Dry Areas (ICARDA) and 4 of which were cultivated genotypes in Turkey, using SSR markers (Tufan and Erdogan 2016). Of 41 SSR markers used, 25 produced bands. As a result of SSR amplification, a total of 39 bands, 25 of which were polymorphic and 14 of which were monomorphic, were obtained. The mean gene diversity and polymorphism information content values were 0.27 and 0.24, respectively. The faba bean genotypes cultivated in Turkey had greater genetic diversity than those that originated from ICARDA. The faba bean genotypes FLIP10- and FLIP03- were successfully separated, using the un-weighted pair group method with arithmetic average dendrogram constructed via Jaccard similarity coefficients. These results were further supported by factor analysis substantially. The results indicated that there is sufficient genetic diversity among the tested faba bean genotypes (especially cultivated in Turkey) and could be used in faba bean breeding programs.

Genetic diversity of 20 Greek faba bean accessions were conducted (Terzopoulos and Bebeli 2008). The 20 lines were characterized as five minor types and 15 Mediterranean types. It was determined that the Mediterranean types could be divided into two different groups based on Inter-Simple Sequence Repeats and there were high levels of within population genetic variation observed.

In Ethiopia, a study was designed to determine the extent and pattern of genetic diversity and relationships among 48 Ethiopian faba bean genotypes using 37 SNPs loci based on Kompetitive allele specific PCR SNP markers (Mulugeta et al. 2021). Thirty-six SNPs were found polymorphic and revealed an average of 95.6% polymorphisms. The gene diversity ranged from 0.16 to 0.50 with a mean of 0.42 and the PIC value ranged from 0.14 to 0.38 with a mean of 0.33. The Bayesian clustering model grouped the genotypes into two genetically distinct clusters with certain degree of admixture, indicating the introduction of chromosomes of different ancestry and allele frequency. The result clearly showed the presence of relatively high genetic diversity among faba bean genotypes grown in Ethiopia. Thus, these genotypes can be used in faba bean breeding programs to develop farmer preferred cultivars with desirable traits.

In China, Faba bean evolved different types of cultivars due to its partial cross-pollination. The development of simple sequence repeat (SSR) markers from expressed sequence tags (EST) provided a useful tool for investigation of its genetic diversity (Gong et al. 2011). This study investigated the genetic diversity of faba bean from China and Europe using EST-SSR markers. 5,031 faba bean ESTs from the NCBI database were downloaded and assembled into 1,148 unigenes. A total of 107 microsatellites in 96 unigenes were identified, indicating that merely 8.36% of sequences contained SSRs. Based on these results, 11 EST-SSR markers were used to assess the genetic diversity of 29 faba bean cultivars from China and Europe with two to three alleles per locus. The polymorphism information content value ranged from 0.0644 to 0.4278 with an average of 0.2919. Principal coordinate analysis (PCA) and phylogenetic clustering based on these 11 EST-SSR markers distinguished these cultivars into different groups. The results indicated that faba bean in China had a narrow genetic basis, and the additional sources of genetic cultivars/accessions should be introduced to enhance the genetic variability. The results of this study proved that the EST-SSR marker is very effective in evaluation of faba bean germplasm.

*Lupine*

To explore the evolutionary relationship of *Lupinus*, preliminarily as well as to excavate and utilize lupine resources from the “Old and New World” effectively, the genetic diversity among the species under *Lupinus* genus was analyzed, which included lupine lines from the USDA-ARS germplasm collection (Zhang et al. 2020). Ninety-five polymorphic pairs of EST-SSR markers developed based on the transcriptome of narrow-leaved lupin (*Lupinus angustifolius* L.) were used to scan 133 lupin accessions from 22 species. A total of 1318 alleles were detected with 13.87 alleles per locus on average, ranging from 3 to 37 alleles; the polymorphism information content (PIC) ranged from 0.39 to 0.91 with the mean value of 0.63; the genetic diversity ranged from 0.41 to 0.92 with the mean value of 0.78. This study showed evolutionary relations among the 22 species under the *Lupinus* genus from the “Old World” and the “New World” based on the Neighbor-Joining (NJ) method, which is consistent with previous studies. Moreover, seventy-seven lupin accessions of seven *Lupinus* species from the “Old World” were divided into 4 groups; there was no overlap of accession from different species contained in each identified group, detected by all the three analysis methods like population structure, cluster analysis based on UPGMA and principal component analysis (PCA).

Some 121 white lupine entries representing 13 germplasm pools (11 landrace pools from European countries and from regions of North and East Africa, West Asia and Atlantic islands, and one winter-type and one spring-type variety pools) were evaluated in three major agroclimatic conditions, i.e., Mediterranean and subcontinental climate in Italy under autumn sowing and suboceanic climate in France under spring sowing, with the aim to assess: (i) the variation among and within germplasm pools for grain yield and 13 major morphophysiological traits; (ii) the impact of evaluation environments on entry characteristics; and (iii) the relation of wide- and specific-adaptation responses with morphophysiological traits (Annicchiarico et al. 2010). Indications on top-yielding genetic resources, entry morphophysiological traits and association of these traits with grain yield were largely environment-specific. Germplasm pools summarized a high portion of genotypic and genotype × environment (GE) interaction variation, indicating their usefulness as a criterion for locating genetic resources with specific characteristics. Adaptive responses of germplasm pools and individual entries, modeled through Additive Main effects and Multiplicative Interaction analysis, highlighted the outstanding agronomic value for specific agroclimatic conditions of a few landrace germplasm pools in comparison with variety pools. Overall, within-pool diversity for morphophysiological traits and adaptive response was largest in the landrace pools from Italy, Turkey, East Africa and West Asia. Only flowering time and individual seed weight exhibited high genetic correlations between environments for entry response, suggesting caution in inferring accession characteristics from evaluation data obtained in environments very different from those targeted by possible germplasm users. Optimal flowering time was early in the spring-sown environment, intermediate in the Mediterranean environment, and late (associated with winter survival) in the subcontinental-climate environment. Owing to the association of phenology with several other traits, germplasm ordination for adaptation pattern and for overall morphophysiological variation were very similar. Pod fertility emerged among the seed yield components because of its correlation with grain yield in each environment combined with low GE interaction. Beside contributing to the ecogeographic classification of landrace germplasm, results supported breeding programs of Europe and Mediterranean-climate regions in defining useful genetic resources, adaptation strategies and adaptive traits. Genetic resources from Madeira & Canaries (high-yielding across environments), Italy (featuring high adaptive and morphophysiological diversity) and a few other regions are of special interest for breeding in targeted definite agroclimatic conditions.

In Ethiopia, fifteen polymorphic simple sequence repeat (SSR) markers were used to assess the genetic diversity and population structure of 212 Ethiopian white lupin (*Lupinus albus*) landraces and two genotypes from different species (*Lupinus angustifolius* and *Lupinus mutabilis*) were used as an outgroup (Atnaf et al. 2017). The SSR markers revealed 108 different alleles, 98 of them from 212 landraces and 10 from out-group genotypes, with an average of 6.5 alleles per locus. The average gene diversity was 0.31. Twenty-eight landraces harbored one or more private alleles from the total of 28 private alleles identified in the 212 white lupin accessions. Seventy-seven rare alleles with a frequency of less than 5% were identified and accounted for 78.6% of the total alleles detected. Analysis of molecular variance (AMOVA) showed that 92% of allelic diversity was attributed to individual accessions within populations while only 8% was distributed among populations. At 70% similarity level, the UPGMA dendrogram resulted in the formation of 13 clusters comprised of 2 to 136 landraces, with the out-group genotypes and five landraces remaining distinct and ungrouped. Population differentiation and genetic distance were relatively high between Gondar and Ethiopian white lupin populations collected by Australians. A model-based population structure analysis divided the white lupin landraces into two populations. All Ethiopian white lupin landrace populations, except most of the landraces collected by Australians (77%) and about 44% from Awi, were grouped together with significant admixtures. The study also suggested that 34 accessions, as core collections, were sufficient to retain 100% of SSR diversity. These accessions (core G-34) represent 16% of the whole 212 Ethiopian white lupin accessions and populations from West Gojam, Awi and Australian collections contributed more accessions to the core collection.

**2.2 Threats of genetic erosion in situ. Current and emerging biotic, abiotic, production, dietary, and accessibility threats and needs.**

**2.2.1 Biotic (diseases, pests)** (Information for this section is mostly taken directly from the Pest Management Strategic Plan for Pulse Crops, O’Neal 2017).

**Plant Diseases**

**Anthracnose** (chickpea, lentil and lupine)

This foliar disease is caused by *Colletotrichum destructivum* species complex in lentil and

chickpea. Anthracnose is an important disease of lentil in some production regions. The disease causes leaf lesions, girdling of stems, lodging, premature plant mortality, and seed shriveling and discoloration. *Colletotricum* spp*.* are favored by temperatures of 68 to 75°F and 24 hours of leaf wetness. Where it occurs, Anthracnose can be a very serious disease. It can be severe in the Northern and High Plains but is a relatively minor pest in the Pacific Northwest. Anthracnose caused by *Colletotrichum gloeosporiodies* is also an issue on lupine. Two Polish accessions, PI 468128 (‘Kalina’) and a landrace known as ‘Byaly’, and an improved Ukranian variety, ‘Vladimir’, are the most promising white lupine accessions for potential anthracnose resistance. Research needed:

• Discern species diversity and aggressiveness within the *C. destructivum* complex on lentil and evaluate accessions for resistance.

• Rigorously assess seed-to-seedling transmissibility of pathogen in lentil and develop seed

thresholds.

**Aphanomyces Root Rot** (lentil)

Caused by the oomycete pathogen *Aphanomyces euteiches,* this is a major root rot pathogen in lentil. Infection can occur before or after the plant emerges, including in older established plants if the soil remains cool and moist. Symptoms include stunted, yellow plants with caramel-colored, infected roots. Highly prevalent in the PNW, emerging in the Northern and High Plains.

Research needed:

• Determine crop rotations (such as faba bean) for limiting this disease.

• Determine whether length of rotation has an impact in limiting the disease.

• Discern resistant varieties via marker-assisted selection.

• Develop a detection method such as a quantitative soil bioassay.

• Discern diversity of the pathogen.

• Develop disease forecasting model.

• Test the compounds, including biologicals and herbicides, including dinitroanilines to determine efficacy.

• Investigate cover crops such as oats and mustards as rotation partners or green manures.

**Ascochyta Blight** (chickpea, faba bean and lentil)

This foliar disease is caused by several *Didymella* species that are host-specific. Ascochyta blight is present and considered a major disease across pulse production growing regions on chickpea (*Didymella rabiei*), lentil (*Didymella lentis*) and faba bean (*Didymella fabae*). The pathogen is particularly problematic when crops are autumn-sown. It is more damaging in cool, wet years. All pulse crops are susceptible, with chickpea incurring the most damage. Pardina lentil varieties are also relatively susceptible.

Research needs:

• Develop disease modeling; expand on existing Pacific Northwest efforts in chickpea to

include other regions.

• Rigorously evaluate the capability of long-distance atmospheric movement of ascospores

produced on overwintered chickpea residues.

• Discern susceptibility among varieties.

• Conduct fungicide efficacy trials.

• Determine economic thresholds.

• Discern pathogen species diversity and aggressiveness.

• Investigate intercropping (such as flax w/ chickpea) for disease management.

• Develop and validate rapid detection methods.

• Study fungicide resistance and develop management strategies.

• Develop seed and foliar treatments compatible with organic systems.

**Bacterial Blight** (chickpea, faba bean and lentil)

This foliar disease is caused by *Xanthomonas campestris* pv. *cassiae*. It is very widespread and occurs frequently in chickpea, faba bean and lentil and is increasing in importance. It typically only occurs following hail or other mechanical damage. Plants often recover but recovery varies depending on variety and on the timing and severity of the infection.

Research needed:

• Explore cultivar/accession susceptibility and resistance.

• Identify products that manage foliar infections.

• Develop thresholds for acceptable levels of seed-borne inoculum.

• Assess the efficacy of seed treatment with streptomycin sulfate for management of seed-to-

seedling transmission

• Research relationship between bacterial blight and late-season fungal diseases and

physical damage.

• Determine whether other bacterial pathogens are associated with bacterial blight-like

symptoms.

**Brown spot** (lupine)

Brown spot (*Pleiochaeta setosa*) is the most widespread foliar disease of lupines in Western Australia and could be a potential major issue for lupine if they were widely grown in the US. The disease can infect lupines at all growth stages but seedling infection has the greatest impact on yield. Spores produced on dead tissue become incorporated into the surface layers of the soil where they can persist for several years, although under non-host crops the concentration reduces over time. Infection occurs when spores are splashed by rain from the soil onto new lupine plants. Factors which reduce the growth rate of plants such as colder environments, late sowing, poor nutrition, herbicide damage or unfavorable soil type, prolong exposure to rain-splash at the most susceptible seedling stage. All lupine species are affected although yellow lupines show resistance. This could be a major issue on autumn-sown plants in US due to favorable climate conditions.

Research needed:

• Determine if pathogen is present in US and would be a major issue for production.

• Determine resistance in white lupine lines

**Chocolate spot** (faba bean)

A disease of potential concern for faba bean growers in the US is chocolate spot, particularly for autumn-sown crops. Chocolate spot is caused by *Botrytis cinerea* and *Botrytis fabae,* of which the second is more virulent. The prevalence of the two and the epidemiology has not been fully studied in the US. Chocolate spot is a concern in most cool-temperate faba bean growing regions around the world. In Australia, where faba beans are well established as a winter crop, chocolate spot is one of the major disease problems and is most aggressive under moderately warm temperatures (10 to 20°C) and humid conditions, particularly at flowering time.

Research needed:

• Development of resistant varieties

• Research on connections between lygus bug and pea leaf weevil insect damage on predisposition to chocolate spot infection

**Cyst Nematode** (chickpea and lentil)

Cyst nematodes of concern in food legume production include *Heterodera ciceri* and *H. rosii* in

chickpea and *H. ciceri* in lentil. At low population densities, field symptoms are not visible. At high population densities, field symptoms occur as patches of stunted and yellow plants. Lemon-shaped cysts are the diagnostic signs. Cysts (adult female bodies) can be found embedded in the roots; they are white when young but turn brown when old. A cyst usually contains 100-300 eggs, which hatch to juveniles that then infect plant roots. Under optimal conditions for nematode development, yield losses have been assessed at 20-50%.

Research needs:

• Survey cyst nematodes.

• Evaluate improved means of detection and identification of cyst nematode species.

• Identify and develop resistant cultivars.

**Fusarium Root Rot** (chickpea, faba bean, lentil and lupine)

Fusarium root rot is a major and ubiquitous problem across all growing regions and food legumes. It is caused by a number of different *Fusarium* species including *Fusarium acuminatum, F. avenaceum*, *F. culmorum*, *F. solani* and *F. redolens*, this is a major root rot complex in food legume crops.

Favored by cool, wet springs followed by drought, fluctuating water conditions, and high soil

nitrogen levels, the symptoms include reddish-brown to brown or black roots and lack of

secondary roots.

Research needed:

• Discern resistance lines in food legumes crops to major *Fusarium* pathogens.

• Research species diversity and aggressiveness.

• Efficacy data are lacking for both chemical seed treatments and biological controls.

• Investigate crop rotation role in disease management. Host diversity makes this pathogen

difficult to address with rotation.

• Research agronomic practices including seeding density to reduce crop stress.

**Fusarium Wilt** (chickpea and lentil)

Fusarium wilt is a vascular disease caused by *F. oxysporum,* with subspecies being specific to

each crop: F*. oxysporum* f. sp. *lentis* on lentil and *F. oxysporum* f. sp. *ciceris* on chickpea. Relatively warm soil temperatures (74 to 82°F) are optimal for expression of Fusarium wilt symptoms. This fungus is seedborne. Resistance to the disease is conferred by at least two recessive genes. Host plant resistance offers the least costly, most effective and most environmentally acceptable means of control. This disease is prevalent on chickpea in California and was recently detected in the Palouse region. Its prevalence in the Northern Plains and High Plains and in Pacific Northwest on lentils and chickpeas has yet to be determined.

Research needed:

• Identify races and characterize the distribution of these races across major

production areas.

• Seed and foliar treatments should be investigated for management purposes.

• Chickpea and lentil varieties with resistance should be developed.

**Gray Mold** (chickpea and lentil)

This foliar disease is caused by the fungal pathogen *Botrytis cinerea* or *Botrytis fabae.* The disease impacts chickpea and lentil, and while it is considered of minor importance on U.S. pulses, it can have serious impacts when flower and pod infection occur. The pathogen can also cause a seedling soft-rot of chickpea. It is more prevalent in the Northern Plains than in the Pacific Northwest. Symptoms begin as water-soaked lesions on stems, branches, leaves, flowers, and pods, which progress to gray/brown lesions that may be fuzzy. Gray mold is favored by temperatures of 68 to 75°F and relative humidity >95%.

**Research:**

• Identify resistant varieties.

• Conduct fungicide efficacy trials for chemical and biological controls.

**Powdery Mildew** (chickpea and lentil)

This foliar infection is caused by a variety of pathogens including *E. trifolii* (lentil)*,* and *Leveillula taurica* (chickpea)*.* These pathogens can reside on infected trash, leguminous weeds, or volunteer plants from previous crops. Infected plants are covered with a white powdery mass of spores that can be rubbed off the leaf. Disease develops at moderate to warm temperatures (70 to 85°F) and is favored by overnight dew, not rain. Powdery mildew can cause the crop to mature unevenly and can create problems at harvest. Desiccants cannot penetrate the fungus and are thus not used.

Research needed:

• Study population genetics for identification and management.

• Assess comparative efficacy of registered fungicides.

• Develop varieties with resistance to *Leveillula taurica* in chickpea and *E. trifolii* in lentil.

• Develop disease forecast models.

**Pythium Seed and Root Rot** (chickpea, faba bean, lentil and lupine)

Caused by the oomycete *Pythium* spp., this is one of the major root rots across all food legumes. It is difficult to diagnose but is generally characterized by poor root system development in which the roots turn brown. It can be a major problem in cool, wet springs and can occur throughout the pulse-growing regions of the United States. Metalaxyl-resistant strains of *Pythium* are known to occur in the Pacific Northwest associated with poor chickpea stand development.

Research needed:

• Management for metalaxyl-resistant strains; understand mechanism of resistance.

• Monitor for metalaxyl resistance in the Pacific Northwest and other regions.

• Identify accessions with rapid emergence and/or resistance to Pythium.

**Reniform Nematode** (chickpea)

Reniform nematode (*Rotylenchulus reniformis*) is one of the major nematode pests of chickpea worldwide. Its presence has not been detected in pulses in the Northern Plains, High Plains, and the Pacific Northwest.

Research needs:

• Survey and detection of the possible presence of the nematode in the major chickpea producing regions.

**Rhizoctonia Root Rot** (chickpea, faba bean, lentil, lupine)

Caused primarily by the fungal pathogen *Rhizoctonia solani,* this is one of the major root

rots of pulse crops. The first sign of Rhizoctonia root rot is poor or declining stands. Root

development suffers and roots tend to be brown to black in color. This root rot is very common

where volunteer grain and weeds were sprayed with herbicide, particularly glyphosate, within

days of planting. The fungus grows quickly in the dying plants and reaches a high population,

which then attacks new seedlings. This is called the “green bridge.”

This root rot is present in all pulses and all growing regions. It is not currently a major problem in the Northern Plains.

Research needs:

• Research green bridge phenomena.

• Develop resistant varieties.

• Species diversity (population genetics) and pathogenicity analysis.

• Determine crop rotation impacts.

**Root-knot Nematode** (chickpea, faba bean, lentil, lupine)

The root-knot nematodes of potential concern in pulse production include *Meloidogyne arenaria*,

*M. artiellia*, *M. incognita*, and *M. javanica*. These nematodes have six life stages including eggs,

first and second juveniles within the egg, free second-stage juveniles in soil, three stages of

juveniles (J2, J3, and J4) in plant tissue, and sedentary adult females in plant tissue or adult

males moving freely in soil or stuck in egg sacs. Root-knot nematodes are the most economically important plant-parasitic nematode and some species have a wide host range including food legume crops. Infected plants lack vigor. The primary symptoms include galls or knots, stunted plants, and reduced roots. Infected plants cannot properly absorb water and nutrients. Yield losses of up to 80% have been reported. Lighter soil (sandy and sandy loam) tends to enhance the crop damage from root-knot nematodes.

Research needs:

• Detection, identification, and quantification of root-knot nematode species in food legumes.

• Identification of resistant or tolerant cultivars.

**Root Lesion Nematode** (chickpea, faba bean and lentil)

Several species of root lesion nematodes have been reported to infect roots of chickpea and

lentil including *Pratylenchus penetrans*, *P. neglectus*, and *P. thornei*. Both *P. neglectus* and *P.*

*thornei* are widespread in dryland wheat fields in the Pacific Northwest, where they damage

crops in rotation with wheat. The root lesion nematode is one of the most common plant-parasitic

nematodes and has a wide host range that includes faba bean. Root lesion nematodes are migratory endoparasites. The vermiform stages of root lesion nematodes completely enter root tissue and move inside the root to extract cellular contents, which results in dark lesions on invaded roots. These nematodes remain mobile and may move into and out of roots and may deposit eggs in soil as well as within root tissue. Yield losses of 20-75% have been reported depending upon the nematode species and population density. The field symptoms caused by root lesion nematodes are not diagnostic, as they are similar to other biotic and abiotic issues. Fields impacted by root lesion nematodes appear uneven and may exhibit areas of yellowing and wilting. Symptoms expressed in the foliage are easily confused with common problems such as poor soil depth, soil texture, soil pH, mineral nutrition, or water availability. The symptoms also have many of the same characteristics as diseases such as Fusarium crown rot, Pythium root rot, and Rhizoctonia root rot.

Research needed:

• Surveys of root lesion nematodes.

• Detection and identification of root lesion nematode species.

• Evaluation of the reproduction ability and the effect of root lesion nematodes on plant

growth parameters and yield.

• Identification and development of resistant cultivars.

**Rust** (chickpea, faba bean, lentil and lupine)

The rust pathogen on chickpea (*Uromyces ciceris-arietini*), lentil and faba bean (*Uromyces viciae-fabae*) and lupine (*Uromyces lupinicolus*) causes orange to brown pustules with golden haloes on the leaves. It is favored by warm and dry summer periods. Rust (Uromyces viciae-fabae) is a serious disease of lentil in South America, India, Pakistan, Morocco and Ethiopia, but does not occur in the US. Utmost care must be exercised in the movement of seeds into the US from rust-infested areas. Currently available commercial cultivars are susceptible to the disease. This is not a major pathogen on chickpea or lentil in the Pacific Northwest.

Research needs:

• Identification of resistant or tolerant cultivars.

**Stem and Bulb Nematode** (chickpea, faba bean and lentil)

The stem and bulb nematode, *Ditylenchus dipsaci*, is distributed mainly in temperate climates of

the world and has been associated with chickpea, faba bean and lentil crops. *D. dipsaci,* is aserious parasitic nematode of many plant species and a quarantine nematode in many countries.

Typical symptoms of *D. dipsaci* damage include swelling and distortion of stems, leaves, and

flowers, shortened internodes, proliferation of axillary buds, and stunting and necrosis of stems.

This nematode can reduce seed vigor and cause blackening on infected seed pods.

Research needed:

• Monitor the occurrence, abundance, and distribution of the nematode when its activity is

suspected.

• Identify species of stem and bulb nematodes.

**Stemphylium Blight** (chickpea and lentil)

This foliar disease of chickpea and lentil is caused by the fungal pathogen *Stemphylium*

*botryosum* on chickpea and lentil, and *Stemphylium sarciniforme* on chickpea*.* It is present in

Canada and in the Northern Plains and is a disease of emerging importance.

The pathogen prefers warm (~77°F), moist (85% relative humidity and eight hours of leaf

wetness) conditions for disease development. Infected seed has a much lower germination rate.

Research needed:

• Learn to better identify this disease.

• Monitor for presence and damage.

• Quantify the impact of the disease on seed yield and quality.

• Develop lentil varieties with improved resistance, especially red lentils.

• Assess fungicide efficacy.

**Verticillium Wilt** (chickpea and lentil)

This vascular disease is caused by *Verticillium dahliae* and *V. albo-atrum.* It is considered of

economic importance on chickpea, but *V. dahliae* can also infect lentil. Verticillium wilt

is favored by moist conditions and can progress very rapidly, defoliating plants and decreasing

yields. Warm, dry weather can halt the progression of the disease. The Verticillium wilt

pathogens are present in pulse-growing regions, but the disease is not causing economic

symptoms at this time and treatments are not being used. There are no critical needs with respect

to Verticillium wilt at this writing, but growers and researchers are monitoring for its presence

and impact.

**Viral Diseases** (chickpea, faba bean, lentil and lupine)

A number of viruses can infect food legume crops. The symptoms of infection can be subtle and easily confused with other disorders, including nutritional deficiency. A common vector for many of these diseases is the pea aphid *(Acyrthosiphon pisum);* occurrence and severity of viral diseases tend to be greater when aphid populations are high. Among viruses vectored by the pea aphid are *Alfalfa mosaic virus, Pea enation mosaic virus* (PEMV), *Bean leafroll virus* (BLRV), *Bean yellow mosaic virus* (BYMV) and *Pea seedborne mosaic virus* (PSbMV). *Pea enation mosaic virus* is one of the most important and destructive viruses of lentil worldwide. Symptoms may be confused with growth regulator herbicide damage. The cowpea

aphid *(Aphis craccivora)*, green peach aphid *(Myzus persicae)*, potato aphid *(Macrosiphum*

*euphorbiae)*, and foxglove aphid *(Aulacorthum solani)* also vector PEMV. It is not known whether the virus is seed transmissible. *Bean leafroll virus* (also known as *Pea leafroll virus*) is a luteovirus, which means the aphid must feed for an extended time to acquire and transmit the virus to new plants, so insecticides to control aphids should be effective against this disease. The pea aphid is the principal vector. Other aphids can also transmit the virus. This virus is not seedborne. *Bean yellow mosaic virus* is a potyvirus that is transmitted non-persistently by more than 50 aphid species, including the pea aphid. The virus has a wide host range (>200 species) that includes chickpea, field peas, lentils, vetch, lucerne hay, and faba beans. BYMV may cause

mottling, bright mosaic, or vein clearing of leaves of infected plants, although the leaves may

remain asymptomatic. The virus is seedborne. Planting clean seed can help prevent the spread of

BYMV. *Pea seedborne mosaic virus* has the potential to be an important pathogen of food legumes. The virus is seedborne and seed transmissible and can also be transmitted by alate aphids that visit, but may not colonize the legume crop. PSbMV can also be transmitted mechanically, by plants rubbing against each other, and cause stunted clusters of plants in the field. The primary mechanism for eliminating PSbMV is planting clean seed.

*Bean mosaic virus* is an aphid transmitted virus that is a problem on Lupine.

Research needed for viruses:

• Explore and develop resistant varieties, especially to PEMV, BLRV and PSbMV.

• Study and compare vector competency among aphid species and biotypes.

• Study vector lifecycle and population genetics.

• Determine role of alternate hosts including weeds and cultivated legumes like clovers and

vetch.

• Study impacts of cropping systems and rotations and their effects on vectors.

• Identify seed-borne and seed-transmitted viruses.

• Deep sequencing to identify new potential viruses.

• Develop and validate quick, in-field virus identification methods for growers.

• Conduct commercial insecticide efficacy trials including optimal timing.

• Investigate role of trap crops.

• Refine existing prediction models for infection and spread of viruses.

• Determine seed thresholds for *Pea seedborne mosaic virus*.

**White Mold** (chickpea, faba bean, lentil and lupine)

This foliar disease is caused by the fungal pathogens *Sclerotinia sclerotiorum, S. trifoliorum,* and

*S. minor*, which have very broad host ranges, including the food legumes. The fungus can colonize pulse flowers or other parts of the plant such as dying leaves in the lower canopy after canopy closure and plant parts such as stems in contact with the soil. White mold can kill tissue and fill the stem with white hyphae and sclerotia, which then survive in the soil for many years. White mold is more common in fall-planted pulses than in spring pulses. It also occurs in chickpea but is less common. Favored by cold, wet conditions after canopy closure, this disease is common in the Northern and High Plains and is also seen in low-lying areas in the Pacific Northwest.

Research needed:

• Identify genes associated with resistance and develop and promote resistant varieties.

• Understand mechanism and effects of seed-borne infestation.

• Investigate biological control agents.

• Study plant architecture and spacing as means of disease avoidance.

• Develop forecasting and modeling methods.

• Develop fungicide-usage recommendations: fungicide application timing; fungicide

efficacy when products are applied shortly before canopy closure; fungicide efficacy

when products are applied after canopy closure; and fungicide application methods

needed to optimize fungicide performance, including nozzle spray pattern, droplet size,

application pressure, and water volume in lentil and chickpea.

**Critical research needs for diseases on food legume crops:**

• Develop Ascochyta blight*-*resistant chickpea varieties.

• Identify genes/QTLs associated with Aphanomyces resistance in lentil and develop genetic markers.

• Identify new chemistries for fungicide resistance management in chickpeas with a

particular focus on metalaxyl-resistant *Pythium* spp.

• Develop resistance to Aphamomyces root rots in lentil and identify genes associated with resistance.

• Determine resistant lentil varieties to major viruses such as PEMV, BLRV and PSbMV.

• Research management of *Fusarium* species complex (identification, variety

resistance, fungicide efficacy, cultural practices including crop rotation) in lentils and chickpeas.

• Quantify soil pathogen loads to assess risks for root rot in lentils with an emphasis on Aphanomyces root rot*.*

• Develop disease forecasting models such as one for white mold in lentils.

• Develop fungicide usage recommendations for white mold in lentils.

• Identify and determine white mold resistance genes in food legumes and develop and promote white mold-resistant varieties.

• Identify fungicides with alternate modes of action with efficacy against Ascochyta

blight of chickpea.

• Monitor nematodes across growing regions when nematode activity is suspected.

• Conduct nematode surveys in other regions as warranted.

• Research root-knot and root lesion nematodes in food legumes as a proactive measure.

**Specific Insect Problems in food legume growing regions**

**Aphids** (lentil, faba bean)

Aphids create serious problems in food legumes. The pea aphid *(Acyrthosiphon pisum)* is a small, light green insect that attacks most food legumes, causing direct damage by feeding on the plants. They feed by sucking plant juices, which can deplete plant vigor and result in plant death.

Pea aphid causes indirect damage by vectoring several important viruses that result in stunted, less productive (or non-productive) plants. Other aphids known to vector viral diseases include the cowpea aphid *(Aphis* *craccivora)*, green peach aphid *(Myzus persicae)*, potato aphid *(Macrosiphum euphorbiae)*, and foxglove aphid *(Aulacorthum solani).* The cowpea aphid, though present in fields, is not considered a serious direct pest because it arrives in the field after the seeds are formed. The black bean aphid (*Aphis fabae*) is considered the major insect pest on faba bean, although the cow pea aphid and pea aphid are prevalent as well. Pea aphids have historically been most problematic in the Pacific Northwest where they move to lentil fields in May to June. Aphids are increasingly moving into the Northern and High Plains and are becoming problematic there as well.

Research needed:

• Investigate Coccinellidae (lady beetles) and green lacewings (Chrysopidae) conservation

and augmentive biocontrol on a commercial scale against pea aphid.

• Study intercropping impacts.

• Identify aphid biotypes and determine their vector competency for key viruses.

• Identify other aphid species that serve as virus vectors.

• Investigate development and maintenance of beneficial arthropod habitats.

• Determine optimal pollinator-safe insecticides and application practices.

• Screen insecticides for efficacy.

• Validate thresholds established in Canada for use in the Northern Plains.

• Determine genetic resistance to the Pea aphid in food legumes.

**Armyworms** (chickpea and lentil)

Armyworms are caterpillars, or the larvae of moths. A species that may be present in food legumes is the western yellow-striped armyworm *(Spodoptera praefica)*. They are a relatively minor problem in terms of crop damage in lentil. Short-PHI products may be used before harvest. Armyworms are more likely to result in economic damage in chickpea, and more controls are registered for this pulse. Armyworms are a common pest in the Pacific Northwest and are also problematic in Montana but are not typically controlled in the rest of the Northern Plains or High Plains.

Research needed:

• Develop scouting and monitoring protocols.

• Expand emerging knowledge regarding pheromone-based monitoring to predict

population levels.

**Cotton bullworm** (chickpea)

Not in the US, but in other regions of the world, *Helicoverpa armigera* is by far the most damaging pest of chickpea and is associated with a pod borer.

**Cutworms** (chickpea and lentil)

Cutworms are caterpillars, or the larvae of moths. Species that may be present in pulses include

the variegated cutworm *(Pedroma saucia)*, dingy cutworm *(Feltia jaculifera),* red-backed

cutworm *(Euxoa ochrogaster),* pale western cutworm *(Agrotis orthogonia)*, and army cutworm

*(E. auxiliaris).* Cutworms occasionally cause damage to pulse crops. They overwinter as eggs or

young larvae. In spring, the larvae feed on newly emerged shoots, often cutting them off below

the soil surface. Pulse crops can recover from cutworm damage if cool, moist growing conditions

occur. Recovered plants are generally set back 4 to 7 days by the damage.

Cutworms are a major problem in the Northern Plains, but the damage is cyclical. They are a

pest of emerging importance in the Pacific Northwest.

Research needed:

• Efficacy studies needed on chemical options.

• Efficacy studies needed on entomopathogenic (predatory) nematodes.

• Habitat management including soil health and other preferences for predatory nematodes.

• Investigate availability, use, and efficacy of parasitoids for cutworms.

**Grasshoppers** (chickpea, faba bean, lentil and lupine)

Grasshoppers *(Caelifera* spp.) are a sporadic pest in pulse production. They have many hosts and

do not strongly prefer pulse crops, but when present can be problematic. As few as two

grasshoppers per square yard can cause serious yield losses in lentils. Grasshoppers chew

through young seedlings even if they do not eat the plant. Because they tend to gravitate toward

other hosts, grasshopper damage is often seen on pulse seedlings bordering ditches and roads.

Dry, drought-type conditions exacerbate grasshopper populations. Grasshoppers are present in all

pulse-growing regions.

Research needed:Biological controls.

**Lygus Bugs** (lentil)

Lygus bug (*Lygus* spp.) is a major insect pest on lentils in all growing regions. Hosts for these pests include weeds such as mustards and lambsquarters and crops such as alfalfa and clover. Lygus bugs pierce tender leaves, stems, buds, petioles, and developing seeds. The most important insect pest of lentil in the US is Lygus bug. They produce depressed, pale lesions on the seed known as “chalky spot syndrome.” Lygus bugs may also serve as vector of a bacterial disease of lupine.

Research needed:

• Further study impacts of weed control on Lygus populations.

• Understand Lygus movement between different crops.

• Research trap crops as a Lygus management tactic.

• Conduct insecticide efficacy studies.

• Develop threshold information.

• Identify which Lygus species are present and causing crop damage; understand life cycles

and regional differences.

• Areawide IPM development.

**Pea Leaf Weevil** (chickpea and faba bean)

The pea leaf weevil *(Sitona lineatus*)*,* not to be confused with pea weevil *Bruchus pisorum,*

is a very serious pest in dry peas, causing economic loss in all production areas every year. Most of the damage occurs in the spring on peas in the seedling stage. Early adults feed on seedlings, scalloping leaf edges and damaging terminal buds. Severe foraging may cause heavy leaf damage, destruction of the terminal buds, and ultimate destruction of the plant. The larvae, however, cause the most serious damage to the plants. Once the larvae hatch, they begin feeding on the *Rhizobium* or nitrogen-fixing nodules of the pea roots resulting in partial or complete inhibition of nitrogen fixation by the plant. This damage results in poor plant growth and low seed yields and may make the peas more susceptible to drought stress. Pea leaf weevil (PLW) infests wild and cultivated legumes, also causing economic damage to field pea and faba beans. Chickpeas are not preferred but may become infested when near a host crop. Faba bean are, but lentils are not considered a host for pea leaf weevil. Weather and soil conditions during the growing season have a strong influence on the damage caused by PLW. Cool, wet spring weather slows dry pea development and extends the time that peas remain in the seedling stage, which makes them more susceptible to PLW. Damage by the PLW can be localized or cover large areas. Severely infested dry pea fields may suffer up to 100% crop loss.

Research needed:

• Research new pesticides (foliar for adults and seed treatment for larvae) as alternatives to

OPs and carbamates.

• Study crop rotations in pea weevil management.

• Research role of beneficial insects and predatory organisms, including understanding

tactics and habitat management to conserve them.

• Understand intercropping as part of IPM.

• Develop degree-day modeling.

• Develop pheromone-based monitoring method.

• Research potential of biological control.

**Seed Corn Maggot** (chickpea, faba bean, lentil and lupine)

The seed corn maggot *(Delia platura)* feeds on germinating seeds and seedling of chickpea, faba bean, lentil and lupine plants and can thin or destroy stands. It is a minor pest in the Pacific

Northwest and is a sporadic, minor pest in the other regions.

Research needed:

• Assess presence and population levels.

• Understand role of green manures, cover crops, etc. in management.

• Develop attractants or baits as part of an attract-and-kill strategy.

**Wireworms** (chickpea and lentil)

Wireworms, the soil-dwelling larvae of click beetles (Elateridae), are a major pest

of wheat and also cause damage to pulse crops, especially lentils. Larvae are yellowish, slender, shiny, and have hard bodies with three pairs of legs and biting-chewing mouthparts. Larvae may pass through 8 to 14 instars depending on genera and soil conditions. Several species of wireworm may be present in pulses. *Limonius californicus, L. infuscatus, L.Canus, Hypnoidus bicolor*, *Aeolus mellillus*, *Selatosomus aeripennis*, *S. pruininus* and othersare known in the Northern to High Plains. Wireworm larvae feed on germinating seeds and lentil seedlings and can thin or destroy stands. The wireworm larvae typically take several years to develop. They cause little damage the first year but feed heavily thereafter, cutting off and damaging roots. As wireworm growth, development, and movement in soil are highly dependent upon soil moisture and temperature, their density and injury to lentils are directly related to soil moisture. Wireworm populations are generally low in years of average or below-average precipitation, and high and damaging in years of above average precipitation. The two peak periods of activity are from April to May and September to October.

Research needed:

• Further investigate validity of leaving weeds in the field as a management strategy.

• Continue research on predatory nematodes.

• Continue research on beneficial fungi.

• Need replacements for neonicotinyl seed treatments; need treatments that kill,

not just repel (repellants leave the population in the soil).

• Assess impact of soil health on wireworm populations.

• Research resistance management.

• Investigate whether the toxins in neonicotinoid seed treatments are systemically

translocated to the pollen and nectar, thereby impacting pollinator safety.

**Critical insect research for food legume crops**

• Expand insecticide options.

• Continue evaluating currently registered insecticide products.

• Review economic thresholds for insects and develop thresholds for insect pests that

do not have established thresholds.

• Increase host resistance and biological control research.

• Develop forecasting models.

• Develop pheromone-based monitoring methods.

**Specific weed problems in food legume growing regions**

The most problematic weed pests in each region are listed below.

***Pacific Northwest***

Perennials: Canada thistle, field bindweed, quackgrass

Annual Grasses: wild oat, Italian ryegrass, downy brome, jointed goatgrass, volunteer cereals

Annual Broadleaves: brassicas (esp. mustard, pennycress), prickly lettuce, dog fennel (mayweed

chamomile), nightshades, kochia, common lambsquarters, pigweeds, wild buckwheat, Russian

thistle

***Northern Plains***

Perennials: Canada thistle, field bindweed, quackgrass, perennial sowthistle, dandelion, foxtail

barley (perennial grass)

Annual Grasses: wild oat, downy brome, Japanese brome, jointed goatgrass, Persian darnel,

volunteer cereals, foxtail (green, yellow and giant)

Annual Broadleaves: brassicas (esp. wild mustard, pennycress, shepherdspurse), prickly lettuce,

nightshades, kochia, common lambsquarters, redroot pigweed, *Galium* spp., Russian thistle,

horseweed/marestail, volunteer canola, narrowleaf hawksbeard, vetch, common mallow, wild

buckwheat, wild sunflower, common ragweed, marshelder, waterhemp, biennial wormwood,

false chamomile

***High Plains***

Perennials: Canada thistle, field bindweed, quackgrass, perennial sowthistle, dandelion, foxtail

barley (perennial grass)

Annual Grasses: wild oat, downy brome, volunteer cereals, foxtail (green, yellow, and giant),

Persian darnel

Annual Broadleaves: brassicas (esp. mustard, pennycress), prickly lettuce, nightshades, kochia,

common lambsquarters, pigweeds, *Galium* spp., buckwheat, horseweed/marestail, volunteer

soybean, wild buckwheat

The parasitic weed *Orobanche crenata* is particularly problematic on faba bean. Faba bean is susceptible to several species of broomrape (*Orobanche* spp*.*) which are major pests in the Mediterranean Basin and North Africa. This parasitic weed causes severe yield loses on a variety of hosts and five species are listed as Federal Noxious Weeds in the United States. Currently, branched broomrape (*Orobanche ramose)* is listed as present in limited areas under quarantine in California, Texas, and several other states (USDA, NRCS 2019).

**Critical weed research in food legume crops**

• Expand herbicide options for broadleaf and grass weed management through

continued evaluation of currently available products and by breeding for tolerance to

herbicides.

• Expand management options for priority weed species.

• Prioritize and optimize cultural management inputs including seeding rate, row

spacing, planting date, and crop rotation for improved crop competitiveness with

weeds.

• Focus on systems-based weed management strategies grounded in sound

agroecological practices.

• Develop forecasting models.

**Specific vertebrate issues in food legume growing regions**

While pulse crops might appear to be less susceptible than other crops to damage by vertebrates,

a variety of birds and mammals can have negative impacts on pulse-crop production. At planting,

birds such as geese and pheasants and rodents including ground squirrels and voles may eat

surface and sub-surface seeds. After crop emergence, rabbits and other foliage-eating vertebrates

can pose problems in pulse crops, especially chickpeas. Elk, pronghorn antelope, and deer

present a problem in some areas; elk have been known to wipe out entire research trial plots.

Growers who swath or windrow crops may experience damage by ducks and geese feeding on

crops. Growers within two miles of lakes and similar staging areas are likely to suffer more

damage from waterfowl than other growers. Significant and specific information regarding widespread damage by vertebrates is lacking in pulse crops. It is unclear whether this lack of information is due to vertebrate avoidance, lack of producer awareness, under-reporting, or a combination of issues including the possibility of reasons not considered. Thus, pulse growers’ needs with respect to vertebrate pests focus on identification and assessment of damage.

**Critical Needs for Management of Vertebrates in food legume crops:**

**Research**

• Discern whether food legumes are less vulnerable to damage by vertebrate pests than other

crops, as opposed to the damage simply being less noticeable.

• Identify the environmental and habitat characteristics of areas that are more susceptible to

vertebrate damage, such as water proximity that influences waterfowl prevalence.

• Develop a simple decision model to signal the need for control of vertebrate pests.

• Refine damage assessment to ensure accurate identification of the pest.

• Investigate diversionary tactics. For instance, would leaving some narrow rows of

standing grain in a swathed field reduce damage by waterfowl to the pulse crop?

• Survey growers to understand issues such as hunting. Do producers believe current

hunting activity for ungulates is sufficient to meet control needs?

**2.2.2 Abiotic stresses (environmental extremes, climate change)**

*Chickpea*

Drought, cold and soil pH tolerance are the primary abiotic stresses impacting chickpea yields.

*Lentil*

Drought, cold and soil pH tolerance are the primary abiotic stresses impacting lentil yields.

*Faba bean* Cold tolerance to enhance winterhardiness of autumn-sown faba beans is critical. Drought and salt tolerant varieties are also desirable for faba bean production zones.

*Lupine*

Cold tolerance of the autumn-sown crops is needed. The susceptibility of white lupine to high pH (above 7.5) due to free lime expressed by iron deficiency is needed. Lime tolerance is desired in lupine lines that could help advance the total acreage where white lupine could be grown. Drought stress, especially at flowering and during pod growth, is a major abiotic stressor where advances need to be made. Another abiotic stress that may occur during the winter is water-logging. This may damage the tap root and favor later root infections by *Fusarium* and *Botrytis cinerea*. Early sowings will improve tolerance to water-logging.

**2.2.3 Production/demand (inability to meet market and population growth demands**

*Chickpea*

U.S. large (Kabuli) and small (Desi) chickpea area planted declined 38 and 62 percent, respectively, from 2019 estimates. Chickpea estimates for harvested acreage, production, and value followed similar downward trends from the previous year. The decrease in chickpea planted, harvested, and production is a result of grower reactions to low prices. Low chickpea prices fell below the loan rate in 2019 but no chickpea prices fell below the loan rate in the 2020 season thus far. Chickpea acres and prices have been trending down for the past 2 years following a large supply and soaring prices in 2017 and 2018 in addition to ongoing trade duties from India (Lucier and Davis 2020).

*Lentil*

U.S. lentil production is up by 21 percent for 2020 from 2019. Harvested acreage, production, value, and yield for dry peas and lentil estimates followed similar divergent trends from the previous year. U.S. lentil export volume is down by 52 percent with lentil exports to Canada declining 64 percent from the 2018-2019 season. Low lentil prices fell below the loan rate in 2019 and 2020 (Lucier and Davis 2020).

*Faba bean*

Faba bean production in the US is so insignificant that there are no records for it among the reports conducted by the USDA National Agricultural Statistics Service. Even though the global average grain yield has almost doubled during the past 50 years to the year 2009, the total area sown to faba beans declined by 56% over the same period and faba bean acreage has continued to decline. This is due to growers relying on fossil fuel nitrogen instead of using cover crops to produce the nitrogen for cereal-based cropping systems. A change in sustainable practices or increasing prices associated with commercial N fertilizers will increase the demand of faba beans to once again be used in crop rotations. A major issue with faba bean is it is characterized as having high yield variability from year to year.

*Lupine*

Lupine production in the US is so insignificant that there are no records for it among the reports conducted by the USDA National Agricultural Statistics Service.

**2.2.4 Dietary (inability to meet key nutritional requirements)**

Table 1. Nutritional values per 100 grams of chickpea, lentil, faba bean and lupine mature seeds that were boiled or cooked with no salt added. Numbers in parentheses are the percentage of the daily recommended allowance (%DV) for an adult based on a 2,000 calorie per day diet based on the new nutrition facts label released March of 2020 by the USDA Food and Drug Agency. %DV is characterized as low (5% or less, indicated in Blue), moderate (5.1 to 19.9%, indicated in orange) and high (20% or greater, indicated in red). The crop values listed in red are considered excellent sources of that product for consumers. If there is no color, the product does not have a recommended daily allowance.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Category** | **Chickpea** | **Lentil** | **Faba bean (Broadbeans)** | **Lupine** |
| Water (g) | 60.21  | 69.64  | 71.54 | 71.08  |
| Energy (kcal) | 164 (8.2%)  | 116 (5.8%)  | 110 (5.5%) | 119 (5.95%)  |
| Protein (g) | 8.86 (17.7%) | 9.02 (18.0%) | 7.60 (15.2%) | 15.57 (31.1%) |
| Total lipid (fat) (g) | 2.59 (3.3%) | 0.38 (0.5%) | 0.40 (2%) | 2.92 (3.7%) |
| Ash (g) | 0.92  | 0.83  | 0.81 | 0.55  |
| Carbohydrate, by difference (g) | 27.42 (10%) | 20.13 (7.3%) | 19.65 (7.1%) | 9.88 (3.6%) |
| Fiber, total dietary (g) | 7.6 (27.1%) | 7.9 (28.2%) | 5.4 (19.3%) | 2.8 (10%) |
| Sugar, total including NLEA (g) | 4.8  | 1.8  | 1.82 | Not provided |
| Calcium (mg) | 49 (3.8%) | 19 (1.5%)  | 36 (2.8%) | 51 (3.9%) |
| Iron (mg) | 2.89 (16.1%) | 3.33 (18.5%)  | 1.50 (8.3%) | 1.2 (6.7%) |
| Magnesium (mg) | 48 (11.4%) | 36 (8.6%) | 43.0 (10.2%) | 54 (12.9%) |
| Phosphorus (mg) | 168 (13.4%) | 180 (14.4%) | 125 (10%) | 128 (10.2%) |
| Potassium (mg) | 291 (6.2%) | 369 (7.9%) | 268 (5.7%) | 245 (5.2%) |
| Sodium (mg) | 7 (0.3%)  | 2 (0.1%)  | 5 (0.2%) | 4 (0.2%) |
| Zinc (mg) | 1.53 (13.9%) | 1.27 (11.5%) | 1.01 (9.2%) | 1.38 (12.5%) |
| Copper (mg) | 0.352 (39.1%) | 0.251 (27.9%) | 0.259 (28.8%) | 0.231 (25.7%) |
| Manganese (mg) | 1.03 (44.8%) | 0.494 (21.5%) | 0.421 (18.3%) | 0.676 (29.4%) |
| Selenium (µg) | 3.7 (6.7%) | 2.8 (5.1%)  | 2.6 (4.7%) | 2.6 (4.7%) |
| Vitamin C, total ascorbic acid (mg) | 1.3 (1.4%) | 1.5 (1.7%) | 0.3 (0.3%) | 1.1 (1.2%) |
| Thiamin (mg) | 0.116 (9.7%) | 0.169 (14.1%) | 0.097 (8.1%) | 0.134 (11.2%) |
| Riboflavin (mg) | 0.063 (4.8%) | 0.073 (5.6%)  | 0.089 (6.8%)  | 0.053 (4.1%) |
| Niacin (mg) | 0.526 (3.3%) | 1.06 (6.6%)  | 0.711 (4.4%) | 0.495 (3.1%) |
| Pantothenic acid (mg) | 0.286 (5.72%) | 0.638 (12.8%)  | 0.157 (3.1%) | 0.188 (3.8%) |
| Vitamin B-6 (mg) | 0.139 (8.2%) | 0.178 (10.5%) | 0.072 (4.2%) | 0.009 (0.5%) |
| Folate, total (µg) | 172 (43%) | 181 (45.3%)  | 104 (26.0%) | 59 (14.8%) |
| Choline, total (mg) | 42.8 (7.8%) | 32.7 (5.9%)  | 30.6 (5.6%) | Not provided |
| Vitamin B-12 (µg) | 0 (0%) | 0 (0%)  | 0 (0%) | 0 (0%) |
| Vitamin A, RAE (µg) | 1 (0.1%) | 0 (0%)  | 1 (0.1%) | 0 (0%) |
| Retinol (µg) | 0  | 0  | 0  | 0  |
| Carotene, beta (µg) | 16  | 5  | 9  | Not provided |
| Carotene, alpha (µg) | 0  | 0  | 0  | Not provided |
| Cryptoxanthin, beta (µg)  | 0  | 0  | 0  | Not provided |
| Vitamin A, (IU) | 27  | 8  | 15  | 7  |
| Lycopene (µg)  | 0  | 0  | 0  | Not provided |
| Lutein + zeaxanthin (µg) | 0  | 0  | 0  | Not provided |
| Vitamin E (alpha tocopherol) (mg) | 0.35 (2.3%) | 0.11 (0.7%)  | 0.02 (0.1%) | Not provided |
| Vitamin D (D2 +D3) (µg) | 0 (0%)  | 0 (0%) | 0 (0%) | 0 (0%) |
| Vitamin K (phylloquinonea) (µg)  | 4 (3.3%) | 1.7 (1.4%) | 2.9 (2.4%) | Not provided |
| Fatty acids, total saturated (g) | 0.269 (1.3%) | 0.053 (0.3%) | 0.066 (0.3%) | 0.346 (1.7%) |
| Fatty acids, total monosaturated (g) | 0.583  | 0.064  | 0.079 | 1.18  |
| Fatty acids, total polysaturated (g) | 1.156  | 0.175  | 0.164 | 0.73  |
| Fatty acids, total trans (g) | 0  | 0  | 0 | 0  |
| Cholesterol (g) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) |
| Tryptophan (g) | 0.085 (30%) | 0.081 (29%)  | 0.072 (26%) | 0.125 (45%)  |
| Threonine (g) | 0.329 (31%) | 0.323 (31%)  | 0.270 (26%) | 0.573 (55%)  |
| Isoleucine (g) | 0.38 (27%) | 0.39 (28%)  | 0.306 (22%)  | 0.695 (50%)  |
| Leucine (g) | 0.631 (23%) | 0.654 (24%) | 0.572 (21%) | 1.181 (43%)  |
| Lysine (g) | 0.593 (28%) | 0.63 (30%) | 0.486 (23%) | 0.832 (40%)  |
| Methionine (g) | 0.116  | 0.077  | 0.062 | 0.11  |
| Cystine (g) | 0.119  | 0.118  | 0.097 | 0.192  |
| Phenylalanine (g) | 0.475 | 0.445  | 0.321 | 0.618  |
| Tyrosine (g) | 0.22  | 0.241  | 0.241 | 0.585  |
| Valine (g) | 0.372 (20%)  | 0.448 (25%) | 0.338 (19%) | 0.65 (36%)  |
| Arginine (g) | 0.835  | 0.697  | 0.702 | 1.669  |
| Histidine (g) | 0.244 (35%) | 0.254 (36%)  | 0.193 (28%) | 0.443 (63%)  |
| Alanine (g) | 0.38  | 0.377  | 0.311 | 0.558  |
| Aspartic acid (g) | 1.042  | 0.998  | 0.849 | 1.669  |
| Glutamic acid (g) | 1.550 | 1.399  | 1.291 | 3.739  |
| Glycine (g) | 0.369 | 0.367  | 0.319 | 0.663  |
| Proline (g) | 0.366  | 0.377  | 0.320 | 0.635  |
| Serine (g) | 0.447  | 0.416  | 0.348 | 0.805  |
| Phenylalanine + Tyrosine (g) | 0.695 (40%) | 0.686 (39%) | 0.562 (32%) | 1.203 (69%) |
| Methionine + Cysteine | 0.116 (11%) | 0.077 (7%) | 0.062 (6%) | 0.110 (10%) |
| Alcohol, ethyl (g) | 0  | 0  | 0 | Not provided |
| Caffeine (g) | 0  | 0  | 0 | Not provided |
| Theobromine (g) | 0  | 0  | 0 | Not provided |

Nutritional data taken from the USDA FoodData Central website (https://fdc.nal.usda.gov). The percent USA recommended daily allowances per 2.2 pounds (1 kg) of body weight for the nine essential amino acids was taken from Nutrition Value (Nutritionvalue.org).

*Chickpea*

Chickpeas are high sources of fiber, copper, manganese, folate and seven of the nine amino acids with the sulfur amino acids methionine and cysteine only being moderate sources. Chickpea is an excellent source of plant-based protein, although only ranked as a moderate source of amino acids compared to animal protein. Chickpeas are moderate sources of calories, carbohydrates, iron, magnesium, phosphorus, potassium, zinc, selenium, thiamin, pantothenic acid, vitamin B-6, and choline. Chickpeas are low sources of fat, calcium, sodium, vitamin C, riboflavin (vitamin B2), niacin (vitamin B3), vitamin A, vitamin E, vitamin K, total saturated fatty acids. Chickpeas do not contain detectable levels of vitamin B12, vitamin D and cholesterol. The small amount of lipid in chickpea is mostly of the beneficial kind (mono-unsaturated and polyunsaturated) rather than saturated fats that have been linked to heart and circulatory diseases. Palmitic acid, a saturated fatty acid, is hypercholesterolemic and adverse to health and is found in small amounts. Although contributing only 4-6% of the adult RDA for calcium and potassium, the contribution of chickpea seeds to the daily intake of these minerals is none the less important. Chickpea has the potential to supply approximately 40% of the adult RDA for manganese and copper in a single serving, or 15% for iron and zinc. Chickpea can provide about 7% of selenium in a single serving. Chickpea contains several water-soluble vitamins such as the B-complex vitamins including folate, vitamin C, vitamin A, vitamin E and vitamin K. Vitamin B2 (Riboflavin) is present in chickpea in small amounts. Chickpea is a rich source of vitamin B3 (niacin) and B6 in the form of pyridoxine. Chickpea is a good source of folate at 150-557 ug/g folate. Chickpea contains 4 mg/100 g vitamin C. Chickpea contains 49 ug/100 g B-carotene which is known to be a precursor to vitamin A. Chickpea contains carotenoids that can act as anti-oxidants. Chickpea also contains the carotenoids lutein and zeaxanthin believed to prevent atherosclerosis and age-related macular degeneration. Chickpea is a reasonable source of vitamin E containing approximately 3-9% lipids and up to 13.7 mg/100 g vitamin E. Chickpea contains a low concentration of vitamin K compared to leafy vegetables, but higher than fruits and most animal products. Chickpea is a very good source of carbohydrates and proteins. Seed crude protein content ranges between 12.6 and 30.5%. Starch content of whole seed samples of several chickpea cultivars evaluated ranged from 41 to 50.8% with a mean of 47.3%. Starch values for Desi versus Kabuli cultivars were lower. Total seed carbohydrates vary from 52.4 to 70.9%. The concentration of unavailable carbohydrates in chickpea is the highest (25.6%) among the commonly consumed pulses. Chickpea also has the lowest carbohydrate digestibility as determined by using *in vivo* and *in vitro* procedures. Chickpea contributes a considerable amount of fat to the human diet. Its fat content ranges between 3.8% and 10.2%. Chickpea is a very good source of minerals and trace elements with the exception of calcium. Calcium and iron are important nutrients but are usually deficient in diets of low-income people particularly infants, preschool children, and pregnant and lactating women in many developing countries. The seed coat contains approximately 70% of the calcium that is in the chickpea seed, so whole consumption of whole seed is nutritionally desirable. In general, chickpea meets all the adult human requirements for the essential amino acids except for methionine and cystine. Tryptophan levels in chickpeas are normally satisfactory but there is considerable variation in chickpea lines for this amino acid. Threonine and valine appear important as in the majority of cases the chemical levels for these amino acids are also below satisfactory levels. However, based on amino acid composition, chickpea seeds were found to have a higher nutritive value than that of other grain legumes.

*Lentil*

Lentils are high sources of fiber, copper, manganese, folate and seven of the nine amino acids with the sulfur amino acids methionine and cysteine only being moderate sources. Lentil is an excellent source of plant-based protein although only ranked as a moderate source of amino acids compared to animal protein. Lentils are a moderate source of calories, carbohydrates, iron, magnesium, phosphorus, potassium, zinc, selenium, thiamin, pantothenic acid, vitamin B6, riboflavin (vitamin B2), niacin (vitamin B3) and choline. Lentils are low sources of fat, calcium, sodium, vitamin C, vitamin E, vitamin K and total saturated fatty acids. Lentils do not contain detectable levels of vitamin B12, vitamin A, vitamin D and cholesterol.

*Faba bean*

Faba beans are high sources of copper, folate and six of the nine amino acids with the amino acids methionine, cysteine and valine being moderate sources. Faba beans are an excellent source of plant-based protein although only ranked as a moderate source of amino acids compared to animal protein. Faba beans are a moderate source of calories, carbohydrates, fiber, iron, magnesium, phosphorus, potassium, zinc, manganese, thiamin, riboflavin (vitamin B2) and choline. Faba beans are a low source of fat, calcium, sodium, selenium, vitamin C, niacin (vitamin B3), pantothenic acid, vitamin B6, vitamin A, vitamin E, vitamin K and total saturated fatty acids. Faba beans do not contain detectable levels of vitamin B12, vitamin D and cholesterol. Faba beans can contain varying levels of anti-nutritional compounds such as tannins, vicine (V), and convicine (C). Vicine and convicine are inactive precursors of divicine and isouramil, redox compounds potentially toxic to human carriers of a widespread genetic deficiency of the erythrocyte (red blood cell, RBC) enzyme glucose-6-phosphate dehydrogenase (G6PD). Ingestion of faba beans by these deficient individuals may cause a severe, potentially lethal hemolytic anemia called favism (Mavelli et al., 1984: Preston and Isely, 2012). The positive impact of using tannin-free varieties in monogastric animal diets and the development of faba bean cultivars with very low levels of V and C would represent a real advantage in terms of nutritional performance in poultry diets and of food safety to humans (Crepon et al. 2010). Faba beans also contain high concentrations of the amino acid L-DOPA, the amino acid is used in the treatment of Parkinson’s Disease and dopamine responsive dystonia (Crepon et al., 2010).

*Lupine*

Lupines are high sources of protein, copper, manganese, and seven of the nine amino acids with the sulphur amino acids methionine and cysteine only being moderate sources. Lupine contains the highest levels of plant-based protein among the food legumes compared in this statement. Tannin concentrations in lupine vary between cultivars, and those with lower tannin levels often have higher levels of protein (Crepon et al., 2010; Hickman and Canevari, 2018). Lupines are moderate source of calories, fiber, iron, magnesium, phosphorus, potassium, zinc, thiamin and folate. Lupines are low sources of fat, carbohydrates, calcium, sodium, selenium, vitamin C, riboflavin, niacin, pantothenic acid, vitamin B6 and total saturated fatty acids. Lupines do not contain detectable levels of vitamin B12, vitamin A, vitamin D and cholesterol. Low alkaloid levels (less than 0.02%) are necessary for human consumption (Jansen 2006).

**2.2.5 Accessibility (inability to gain access to needed plant genetic resources because of phytosanitary/quarantine issues, inadequate budgets, management capacities or legal bureaucratic restrictions.**

*Chickpea*

*Lentil*:

*Faba bean*

*Lupine*

**3.** **Status of plant genetic resources in the NPGS available for reducing genetic vulnerabilities**

* + 1. **Germplasm collections and in situ reserves**

*Chickpea*

There are no natural *in situ* conservation sites for chickpea in the US, but accessions from the collection are maintained within a traditional farming situation. See Table 2 of this document for chickpea (*Cicer* sp.) holdings present in the USDA-ARS Western Regional Plant Introduction Station. Core collections of germplasm were developed for the chickpea collection in 1988. The chickpea core consists of 505 accessions. The core was selected by a modified logarithmic method, which placed primary emphasis on the geographic country of origin. After grouping by country, secondary selection was performed based on seed and flower characteristics. Known unique phenotypes were selected for inclusion as well. A Cicer Single Plant Core Collection was developed by selecting seed from a single plant. This collection consists of 538 accessions. An Cicer ICRISAT Mini Core Subset is also present in the collection consisting of 210 accessions.

*Lentil*

There are no natural *in situ* conservation sites for lentil in the US, but accessions from the collection are maintained within a traditional farming situation. See Table 2 of this document for lentil (*Lens* sp.) holdings present in the USDA-ARS Western Regional Plant Introduction Station. A core collection of germplasm was developed for the lentil collection in 1989. There are 280 lentil accessions in the core. The core was selected by a modified logarithmic method, which placed primary emphasis on the geographic country of origin. After grouping by country, secondary selection was performed based on seed and flower characteristics. Known unique phenotypes were selected for inclusion as well. A Lens Single Plant Core Collection was developed by selecting seed from a single plant. This collection consists of 386 accessions.

*Faba bean*

There are no natural *in situ* conservation sites for faba bean in the US, but accessions from the collection are maintained within a traditional farming situation. See Table 2 of this document for faba bean (*Faba* sp.) holdings present in the USDA-ARS Western Regional Plant Introduction Station.

*Lupine*

There are no natural *in situ* conservation sites for white lupine in the US, but accessions from the collection are maintained within a traditional farming situation. There is a native lupine, *Lupinus arizonicus*, that is part of the tertiary gene pool of the andean lupine found in the US, but there is no *in situ* conservation sites for this species. See Table 2 of this document for Lupine (*Lupinus* sp.) holdings present in the USDA-ARS Western Regional Plant Introduction Station.

*Lathyrus and Trigonella*

There are no natural *in situ* conservation sites for white lupine in the US since it is not native, but material from the collection is maintained within a traditional farming situation. See Table 2 of this document for grasspea (*Lathyrus* spp.) and fenugreek (*Trigonella* spp.) holdings present in the USDA-ARS Western Regional Plant Introduction Station.

* 1. **Holdings**

**3.2.1 Genetic coverage and gaps**

Table 2.Current (February, 2021) holdings of chickpea (*Cicer arietinum*), faba bean (*Vicia* *faba*), grasspea (*Lathyrus sativus*), lentil (*Lens* *culinaris* subsp. *culinaris*), lupine (*Lupinus* *albus*) and fenugreek (*Trigonella* *foenum-graecum*) species available at the USDA-ARS Western Regional Plant Introduction Station in Pullman, WA and their crop wild relatives and the gene pool associated with the relatives.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Species | Total accessions | Total active | Total available | Gene pool |
| ***Cicer arietinum*** | 7,002 | 6,593 | 6,370 | NA |
| *Cicer anatolicum* | 7 | 6 | 4 | Quaternary |
| *Cicer atlanticum* | 0 | 0 | 0 | Tertiary |
| *Cicer bijugum* | 19 | 19 | 14 | Tertiary |
| *Cicer canariense* | 1 | 1 | 1 | Tertiary |
| *Cicer choroassanicum* | 2 | 2 | 2 | Quaternary |
| *Cicer cuneatum* | 10 | 9 | 9 | Tertiary |
| *Cicer echinospermum* | 79 | 78 | 23 | Secondary |
| *Cicer incisum* | 1 | 1 | 0 | Tertiary |
| *Cicer judaicum* | 37 | 36 | 34 | Tertiary |
| *Cicer microphyllum* | 16 | 16 | 10 | Quaternary |
| *Cicer montbretii* | 8 | 7 | 0 | Quaternary |
| *Cicer pinnatifidum* | 25 | 24 | 22 | Tertiary |
| *Cicer reticulatum* | 253 | 248 | 98 | Primary |
| *Cicer songaricum* | 4 | 2 | 2 | tertiary |
| *Cicer yamashitae* | 3 | 3 | 3 | ? |
| ***Lathyrus sativus*** | 404 | 295 | 283 | NA |
| *Lathyrus amphicarpos* | 0 | 0 | 0 | Secondary |
| *Lathyrus angulatus* | 0 | 0 | 0 | Tertiary |
| *Lathyrus annuus* | 24 | 7 | 2 | Tertiary |
| *Lathyrus aphaca* | 61 | 40 | 31 | Tertiary |
| *Lathyrus basalticus* | 0 | 0 | 0 | Tertiary |
| *Lathyrus belinensis* | 0 | 0 | 0 | Tertiary |
| *Lathyrus blepharicarpus* | 0 | 0 | 0 | Secondary |
| *Lathyrus cassius* | 1 | 1 | 1 | Tertiary |
| *Lathyrus chloranthus* | 2 | 2 | 2 | Tertiary |
| *Lathyrus chrysanthus* | 0 | 0 | 0 | Tertiary |
| *Lathyrus cicera* | 61 | 41 | 34 | Secondary |
| *Lathyrus gorgoni* | 16 | 1 | 1 | Tertiary |
| *Lathyrus hierosolymitanus* | 14 | 4 | 3 | Tertiary |
| *Lathyrus hirticarpus* | 0 | 0 | 0 | Tertiary |
| *Lathyrus hirsutus* | 27 | 21 | 15 | Tertiary |
| *Lathyrus marmoratus* | 0 | 0 | 0 | Tertiary |
| *Lathyrus ochrus* | 48 | 25 | 19 | Tertiary |
| *Lathyrus pseudocicera* | 2 | 1 | 0 | Tertiary |
| *Lathyrus pulcher* | 0 | 0 | 0 | Secondary |
| *Lathyrus roseus* | 5 | 1 | 0 | Tertiary |
| *Lathyrus setifolius* | 0 | 0 | 0 | Secondary |
| *Lathyrus tingitanus* | 32 | 4 | 3 | Tertiary |
| ***Lens culinaris* subsp. *culinaris*** | 3,320 | 3,046 | 2,939 | NA |
| *Lens culinaris* | 74 | 10 | 0 | Same |
| *Lens culinaris subsp. orientalis* | 133 | 67 | 17 | Primary |
| *Lens culinaris subsp. tomentosus* | 0 | 0 | 0 | Primary |
| *Lens ervoides* | 64 | 34 | 28 | Tertiary |
| *Lens nigricans* | 41 | 24 | 4 | Tertiary |
| *Lens odemensis* | 8 | 6 | 4 | Secondary |
| *Lens lamottei* | 0 | 0 | 0 | Secondary |
| ***Lupinus albus*** | 460 | 354 | 191 | NA |
| *Lupinus albus* var. *albus* | 45 | 35 | 30 | NA |
| *Lupinus albus* var. *graecus* | 4 | 3 | 0 | Primary |
| *Lupinus angustifolius* | 313 | 198 | 159 | Not related |
| *Lupinus angustifolius* var. *angustifolius* | 28 | 28 | 22 | Not related |
| *Lupinus luteus* | 347 | 155 | 104 | Not related |
| *Trigonella* *foenum-graecum* | 267 | 200 | 192 | NA |
| ***Vicia faba*** | 1,223 | 772 | 543 | NA |
| *Vicia faba* var. *faba* | 10 | 10 | 6 | Same |
| *Vicia faba* var*. minuta* | 7 | 7 | 7 | Same |
| *Vicia faba* var. *equina* | 5 | 1 | 1 | Same |
| *Vicia bithynica* | 0 | 0 | 0 | Tertiary |
| *Vicia lathyroides* | 1 | 1 | 1 | Tertiary |
| *Vicia melanops* | 0 | 0 | 0 | Tertiary |
| *Vicia narbonensis* | 3 | 3 | 3 | Tertiary |
| *Vicia oroboides* | 0 | 0 | 0 | Tertiary |
| *Vicia cappadocica* | 0 | 0 | 0 | Secondary |
| *Vicia cuspidate* | 0 | 0 | 0 | Tertiary |
| *Vicia johannis* | 0 | 0 | 0 | Sec./Tert. |

Wild species, especially those in the primary gene pools of the cool season food legumes, are needed to expand the available genetic variation for growth, yield, tolerance to stresses, and disease resistance. Currently, the wild species are not being used to any great extent in breeding these crops. Introgression of genetic material from the primary gene pool into the genomes of these crops can be accomplished by hybridization followed by selection and backcrossing to adapted cultivars to recover adapted and/or disease resistant types. A continuing effort is required to continually introgress desired traits from the wild species of food legumes into the cultivated species. Gaps in food legume collections by additional exploration and collection in areas poorly represented in our existing collection such as Afghanistan, central Asia, Ethiopia, Iran, Iraq and eastern Turkey should be realized.

*Chickpea*

Wild species from southeastern Turkey and parts of Iraq are particularly lacking in the collections but represent potentially useful germplasm for cultivar improvement. Even though the collections of chickpea held by the USDA RPIS in Pullman, WA are large, a number of identifiable gaps exist. These gaps include Afghanistan, Ethiopia, Iran, Iraq, Russia, eastern Turkey, Turkmenistan, Ukraine and Uzbekistan. In particular, collections are needed in Iraq and southeastern Turkey where this crop is widely grown and where the wild relatives of this crop are also found.

*Lentil*

Even though the collections of lentil held by the USDA RPIS in Pullman, WA are large, a number of identifiable gaps exist. These gaps include Afghanistan, Algeria, Eastern Europe, Ethiopia, Iran, Iraq, Morocco, Russia, eastern Turkey, Turkmenistan, Ukraine and Uzbekistan. In particular, collections are needed in southeastern Turkey and Iraq where this crop is widely grown and where the wild relatives of this crop are also found.

*Faba bean*

Germplasm of faba bean from Afghanistan, China, India, Iran and the Andes of South America is under-represented in these collections. Faba beans have been isolated in the Andes for over 300 years and many land races are present, with one or more in each valley.

*Lupine*

Additional collection of lupine has not been a high priority item in the past in view of the numerous collection of lupines held in other countries. What is important, however, is to develop formal agreements which will allow the timely exchange of material.

**3.2.2 Acquisitions**

*Chickpea*

*Lentil*:

*Faba bean*

*Lupine*

**3.2.3 Maintenance**

The seed collections of chickpea, faba bean, fenugreek, grasspea, lentil and lupine at the RPIS in Pullman are stored at 4-5 C and a relative humidity of 30-35%. Also, a backup of these collections is maintained at the National Seed Storage Laboratory (NSSL) at Ft. Collins, Colorado at -18 C and/or under cryopreservation conditions (liquid N). New material from exploration and collection expeditions and other sources is systematically increased and added to the collection.

**3.2.4 Regeneration**

*Chickpea*

For detailed information on regeneration guidelines for chickpea please see:

<https://cgkb.cgiar.croptrust.org/index.php/crops-mainmenu-367/chickpea-mainmenu-360/regeneration-mainmenu-374>

*Lentil*

For detailed information on regeneration guidelines for lentil please see:

<https://cgkb.cgiar.croptrust.org/index.php/crops-mainmenu-367/other-crops-regeneration-guidelines-mainmenu-290/lentil-mainmenu-405>

*Faba bean*

For detailed information on regeneration guidelines for faba bean please see:

<https://cgkb.cgiar.croptrust.org/index.php/regeneration-guidelines-of-crops/faba-bean-mainmenu-402>

*Lupine*

For information on regeneration guidelines for Lupine please see Aslam et al. 2020 in the reference section.

**3.2.5 Distribution and outreach**

*U.S. National Plant Germplasm System Distribution Policy*

Plant germplasm is distributed to scientists, educators, producers and other bona fide research and education entities from U.S. National Plant Germplasm System (NPGS) active collection sites. The NPGS Curator and/or Research Leader will, in accordance with current NPGS policies and procedures, determine the legitimacy of a request when necessary. Distributions to fulfill requests for repatriation of subsamples of germplasm collections to a country or community of origin, especially following natural or man-made catastrophes, are considered a high priority.

Although distributions for research, education, and repatriation are of the highest priority, the NPGS also encourages various seed-saver organizations and public gardens to conduct germplasm conservation activities that engage many individuals and groups throughout the country. Elements of the NPGS cooperate with seed-saver organizations and public gardens and may store germplasm for and distribute germplasm to such organizations. Distribution of germplasm from NPGS collections to fulfill requests from individuals seeking free germplasm strictly for home use is generally considered an inappropriate use of limited resources and conflicts with U.S. Government policy of not competing with commercial enterprises. Requestors can be asked, in an appropriate manner, to justify the use of specific NPGS germplasm instead of suitable commercially available germplasm. Accessions listed in the Germplasm Resources Information Network (GRIN) database as “not available” due to insufficient or low viability seed and/or scheduled for regeneration will generally not be available for distribution. Other accessions are listed in GRIN as “not available” because they are not a part of the NPGS collection per se but are conserved in NPGS genebanks to meet specific needs as described later in the section entitled “Categories of Germplasm Distributed and Availability.” In this category are certain accessions of improved germplasm that are only available from the owner/developer. Other accessions require that specific conditions be met by the requestor before distribution is possible. NPGS sites will not distribute germplasm internationally when they cannot comply with the importation or quarantine requirements of the recipient country unless the requestor can provide a valid waiver of such requirements.

**3.2.6 Genebank and/or crop-specific web site(s)**

*Chickpea:*

**AARI:** Aegean Agricultural Research Institute, Izmir, Turkey https://arastirma.tarimorman.gov.tr

**GRDC:** Grains Research and Development Corporation, Australia, houses the Australian Temperate Field Crops Collection, Horsham, Victoria, https://grdc.com.au/

**AV:** Agriculture Victoria, https://agriculture.vic.gov.au/biosecurity/plant-diseases/grain-pulses-and-cereal-diseases

**CT:** Crop Trust. <https://www.Croptrust.org>

**CGKB:** Crop Genebank Knowledge Base, https://www.cgkb.cgiar.croptrust.org

**GCDT**: The Global Crop Diversity Trust, Genesys-PGR Database. https://www.genesys-pgr.org

**GRIN:** USDA-ARS, National Genetic Resources Program, Pullman, WA, USA https://ars-grin.gov

**ICARDA:** International Centre for Agricultural Research in the Dry Areas, Aleppo, Syria. <https://icarda.org>.

**ICRISAT:** International Crops Research Institute for Semi-Arid Tropics, Patancheru, India. https://icrisat.org

**ICUC:** International Centre for Underutilized Crops, Southampton, UK https://southampton.ac.uk

**ILRI:** International Livestock Research Institute, Addis Ababa, Ethiopia. https://www.ilri.org

**IPK:** Institute for Plant Genetics and Crop Plant Research, Gatersleben, Germany <https://ipk-gatersleben.de>

**NBPGR:** National Bureau of Plant Genetic Resources, India, http://www.nbpgr.ernet.in/

**NPGA:** Northern Pulse Growers Association. <https://northernpulse.com>

**PARC:** Pakistan Agricultural Research Council. http://www.parc.gov.pk/index.php/en/pgrp-home

**PC:** Pulse Canada <https://pulsecanada.com>

**PUSA**: Pulse USA <https://pulseusa.com>

**SPG:** Saskatchewan Pulse Growers <https://saskpulse.com>

**SPII:** Seed and Plant Improvement Institute, Iran. http://www.spii.ir/en-US/DouranPortal/1/page/Home

**USADPLC:** USA Dry Pea and Lentil Council, Moscow, ID. <https://usapulses.org>

**VIR:** N. I. Vavilov Research Institute of Plant Industry, St. Petersburg, Russia. <http://vir.nw.ru>

**WRPIS:** Western Regional Plant Introduction Station, Pullman, WA https://www.ars.usda.gov/pacific-west-area/pullman-wa/plant-germplasm-introduction-and-testing-research/docs/facilities/

*Lentil*:

**AV:** Agriculture Victoria, <https://agriculture.vic.gov.au/biosecurity/plant-diseases/grain-pulses-and-cereal-diseases>

**GRDC:** Grains Research and Development Corporation, Australia, houses the Australian Temperate Field Crops Collection, Horsham, Victoria, https://grdc.com.au/

**ICARDA:** International Centre for Agricultural Research in the Dry Areas, Aleppo, Syria. <https://icarda.org>.

**VIR:** N. I. Vavilov Research Institute of Plant Industry, St. Petersburg, Russia. <http://vir.nw.ru>

**CGKB:** Crop Genebank Knowledge Base, <https://www.cgkb.cgiar.croptrust.org>

**CT:** Crop Trust. <https://www.Croptrust.org>

**GCDT**: The Global Crop Diversity Trust, Genesys-PGR Database. <https://www.genesys-pgr.org>

**GRIN:** USDA-ARS, National Genetic Resources Program, Pullman, WA, USA <https://ars-grin.gov>

**USADPLC:** USA Dry Pea and Lentil Council, Moscow, ID. <https://usapulses.org>

**WRPIS:** Western Regional Plant Introduction Station, Pullman, WA https://www.ars.usda.gov/pacific-west-area/pullman-wa/plant-germplasm-introduction-and-testing-research/docs/facilities/

*Faba bean*

**AV:** Agriculture Victoria, https://agriculture.vic.gov.au/biosecurity/plant-diseases/grain-pulses-and-cereal-diseases

**CGKB:** Crop Genebank Knowledge Base, <https://www.cgkb.cgiar.croptrust.org>

**CT:** Crop Trust. <https://www.Croptrust.org>

**GCDT**: The Global Crop Diversity Trust, Genesys-PGR Database. <https://www.genesys-pgr.org>

**GRIN:** USDA-ARS, National Genetic Resources Program, Pullman, WA, USA <https://ars-grin.gov>

**IGV:** Istituto Di Genetica Vegetale, Italy, https://www.urp.cnr.it/dedicato/ded\_ambiente/iistituto.php?istituto=IGV

**IPK:** Institute for Plant Genetics and Crop Plant Research, Gatersleben, Germany <https://ipk-gatersleben.de>

**VIR:** N. I. Vavilov Research Institute of Plant Industry, St. Petersburg, Russia. <http://vir.nw.ru>

**WRPIS:** Western Regional Plant Introduction Station, Pullman, WA https://www.ars.usda.gov/pacific-west-area/pullman-wa/plant-germplasm-introduction-and-testing-research/docs/facilities/

*Lupine*

**AV:** Agriculture Victoria, <https://agriculture.vic.gov.au/biosecurity/plant-diseases/grain-pulses-and-cereal-diseases>

**GRIN:** USDA-ARS, National Genetic Resources Program, Pullman, WA, USA <https://ars-grin.gov>

**GRDC:** Grains Research and Development Corporation, Australia, houses the Australian Temperate Field Crops Collection, Horsham, Victoria, https://grdc.com.au/

**PA:** Pulse Australia,http://www.pulseaus.com.au/growing-pulses/bmp/lupin

**WRPIS:** Western Regional Plant Introduction Station, Pullman, WA https://www.ars.usda.gov/pacific-west-area/pullman-wa/plant-germplasm-introduction-and-testing-research/docs/facilities/

**3.2.7 Passport information**

*Chickpea*

Passport information for all *Cicer* species can be found on the U.S. National Plant Germplasm System (<https://npgsweb.ars-grin.gov/gringlobal/search>)

*Lentil*:

Passport information for all *Lens* species can be found on the U.S. National Plant Germplasm System (https://npgsweb.ars-grin.gov/gringlobal/search)

*Faba bean*

Passport information for all *Faba* species can be found on the U.S. National Plant Germplasm System (https://npgsweb.ars-grin.gov/gringlobal/search)

*Lupine*

Passport information for all *Lupinus* species can be found on the U.S. National Plant Germplasm System (https://npgsweb.ars-grin.gov/gringlobal/search)

**3.2.8 Genotypic characterization data**

*Chickpea*

According to Kumar et al. 2014, target region amplification polymorphism (TRAP) markers were used to evaluate the genetic diversity and relationship among a sample of 263 chickpea landrace germplasm accessions maintained at the Western Regional Plant Introduction Station, Pullman, WA. Two-hundred sixty-two TRAP markers were amplified by eight primer combinations. Altogether, 110 (42%) markers were polymorphic, while 152 (58%) presented as monomorphic. The high level of polymorphism was revealed among the accessions with an estimated pair-wise genetic similarity of 25.82%, ranging from 2.8 to 50.0%. Genetic distance analysis divided the accessions into two major groups with 113 and 150 accessions each and substantial association between molecular diversity and origin was evident. Bayesian analysis of population structure revealed two groups (K = 2) with evidence for six sub-groups. Additionally, the population structure of a subset of 110 lines was determined (K = 3) for testing marker-trait associations (MTAs). Phenotypic traits included seed concentrations for protein and nine mineral elements. Two MTAs were significant (p <0.01) for seed concentrations of the macro-minerals Ca and K and three MTAs were significant for the microminerals Cu and Ni seed concentrations using three statistical models. The results indicate that this will be a useful population for genome-wide association studies.

*Lentil*:

According to Khazaei et al. 2016, a cultivated lentil (*Lens culinaris* Medik.) collection from the Western Regional Plant Introduction Station, Pullman, WA consisting of 352 accessions originating from 54 diverse countries was used 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.

*Faba bean*

According to Kwon et al. 2010, target region amplification polymorphism markers were used to assess the genetic diversity and relationship among 151 worldwide collected faba bean (*Vicia faba* L.) entries (137 accessions maintained at the USDA–ARS, Pullman, WA, 2 commercial varieties and 12 elite cultivars and advanced breeding lines obtained from Link of Georg-August University, Germany). Twelve primer combinations (six sets of polymerase chain reaction) amplified a total of 221 markers, of which 122 (55.2%) were polymorphic and could discriminate all the 151 entries. A high level of polymorphism was revealed among the accessions with an estimated average pairwise similarity of 63.2%, ranging from 36.9 to 90.2%. Cluster analysis divided the 151 accessions into five major groups with 2–101 entries each and revealed a substantial association between the molecular diversity and the geographic origin.

All 101 accessions in Group V are originated from China and 13 of the 15 accessions

in Group II were from Afghanistan. Thirty-two individual plants were sampled from two

entries to assess the intra-accession variation. It was found that the advanced inbred line

(Hiverna/5-EP1) had very little variation (5.0%), while the original collection (PI 577746)

possessed a very high amount of variation (47.1%). This is consistent with the previous reports

that faba bean landraces have a high level of outcrossing in production fields and thus contain

larger amounts of variation within each landrace. One implication of this observation for

germplasm management is that a relatively larger population is needed in regeneration to mitigate the possible loss of genetic variation due to genetic drift.

*Lupine*

According to Ji et al. 2020, narrow-leafed lupin *(Lupinus angustifolius* L.) was assessed for genetic diversity among a set of 109 newly introduced accessions from the Western Regional Plant Introduction Station, Pullman, WA, using 76 genomic SSR markers. Data analysis suggested that the average gene diversity index and average polymorphism information content (PIC) were 0.4758 and 0.4328, respectively. The mean allele number per loci (Na) was 6.3816. The population structure analysis identified two subgroups based on delta K (ΔK) values. This result is in accordance with that of a PCA. The AMOVA analysis showed that most of molecular variance were within population. These results will be useful to guide the genetic improvement of the narrow-leafed lupin crop.

**3.2.9 Phenotypic evaluation data**

*Chickpea*

The chickpea collection in the National Plant Germplasm System (NPGS) has been characterized for the following traits:

1. Concentration of calcium, copper, iron, magnesium, manganese, nickel, phosphorus, potassium, zinc and protein in the seed.
2. Disease resistance to Ascochyta blight, *Pea enation mosaic virus* and *Pea streak carlavirus*.
3. Growth such as plant growth habit, plant height, plant width, and relative plant size.
4. Morphology such as primary branching, flower color, flowers per peduncle, hypocotyl color, leaf color, leaf color using Munsell chart, leaf size, leaf type, leaflet number, pigmentation, pod concentration, pod length, pod shatter, pod width, pods per peduncle, pods per plant, seed black dots, cotyledon color, seed shape, seed size, seed texture, seed type, seed weight, seed coat color and seeds per pod.
5. Phenology traits such as day of first bloom, pod maturity day of the year, days to flower, emergent day of the year and pod maturity.
6. Production traits such as biomass kg/ha dry vegetation and natural life span.
7. Drought stress

*Lentil*

The lentil collection in the NPGS has been characterized for the following traits:

1. Concentration of calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sulfur, zinc and protein in the seed.
2. Disease resistance to anthracnose Race Ct1, *Pea enation mosaic virus* and *Pea seedborne mosaic virus*.
3. Growth such as plant habit, plant height, plant size and plant width.
4. Morphology such as seed cotyledon color, flower ground color, flowers per peduncle, hypocotyl color, lodging, pod drop, pod length, height to lowest pod, pod pigmentation, pod shatter, pod width, pods per peduncle, seed ground color, seed pattern, seed pattern color, seed size, seed weight, and seeds per pod.
5. Phenology such as days to flower and days to pod maturity.
6. Production traits such as seed production and yield kg/ha on seed produced.

*Faba bean*

The faba bean collection in the NPGS has been characterized for the following traits:

1. Disease resistance to rust.
2. Growth traits such as plant height and seedling vigor.
3. Morphological traits such as basal node branching, stem branching, flower banner color, higher node branching, hilum color, leaflet shape, leaflet size, lodging, pod-bearing odes, pod angle, pod color, pod distribution, pod length, pod shape, pod shatter, pod surface, pod wall characteristics, pod width, pods per node, pods per plant, seed coat color, seed weight, seeds per plant, seeds per pod, stem color as seedling, stem pigmentation and plant width.
4. Phenology traits such as day of first bloom, days for bud to flower, days to flower and days to pod maturity.
5. Production traits such as vegetative biomass per plant and seed yield per plant.

*Lupine*

The lupine collection in the NPGS has been characterized for the following traits:

1. Chemical traits such as alkaloid concentration.
2. Growth traits such as height.
3. Morphology traits such as primary branch height, flower color, leaf diameter, leaf color using Munsell chart, leaf color intensity, leaf pubescence lower surface, leaf pubescence upper surface, leaf shape, lodging, petiole color, petiole color intensity, petiole length, height of first pod, pod length, pod pubescence maturity, pod pubescence green, pod shattering, pod shedding, pod width, pods per plant, seed primary color, seed secondary color, seed shape, seed weight, seeds per pod, stem branching, stem color, stem color intensity, stem formation, stem primary branching count, stem pubescence, stem thickness, stem waxiness, stipule length and plant width.
4. Phenology traits such as days to first flowing, days to total ripening and days to first ripe pod.
	1. **Plant genetic resources research associated with the NPGS**

**3.3.1 Goals and emphases**

*Chickpea*

Primary focuses for chickpea are:

1. Determine genetic resources and genes/QTLs associated with resistance to Ascochyta blight, Pythium seed and seedling blight, and Fusarium root rot and wilt species.
2. Identifying accessions with high yields and high seed protein content and associated genes/QTL.
3. Insect resistance to army worm and cotton bullworm.
4. Determine winterhardiness and early maturity.
5. Determine genetic resources and genes/QTL associated with resistance to drought, cold and low soil pH tolerance.
6. Evaluate accessions for herbicide tolerance/resistance to herbicides used to manage critical weeds limiting chickpea production.Identify lines with advanced levels of key nutrients important for human consumption such as iron and zinc.
7. Collections of genetic resources need to be made from the primary (*Cicer reticulum*) and secondary (*Cicer echinospermum*) gene pools of the crop wild relatives. Currently there are 253 accessions of *C. reticulum* and 79 of *C. echinospermum*.
8. Based on Table 2 of this document, accessions need to be identified that increase concentrations of critical human nutrients classified as low or moderate sources, to being moderate or high sources, respectively, while keeping the level of other nutrients the same or higher.

*Lentil*

Primary focuses for lentil are:

1. Determine resistance to Aphanomyces root rot, anthracnose, PEMV, BLRV, PSbMV, Fusarium root rots, Stemphylium blight, white mold and root lesion nematodes and associated genes/QTL.
2. Evaluate genetic resources for resistance to aphids, lygus bugs and wireworms and associated genes/QTL.
3. Determine resistant accessions to lygus causing chalky spot.
4. Determination of genetic resources and genes/QTL associated with resistance to drought, cold and low soil pH tolerance.
5. Identify accessions with high yields and high seed protein content and associated genes/QTL.
6. Evaluate accessions for herbicide tolerance/resistance to herbicides used to manage critical weeds limiting lentil production.
7. Identify lines with advance levels of key nutrients important for human consumption such as iron and zinc.
8. Increase the height and harvestability
9. Collections of genetic resources need to be made from the primary (*Lens culinaris* subsp. *tomentosus*) and secondary (*Lens odemensis* and *Lens lamottei*) gene pools of the crop wild relatives. Currently there are zero collections of *L. culinaris* subsp. *tomentosus* and *L. lamottei* and only 8 accessions of *Lens odemensis*.
10. Improve lentil height and harvestability
11. Determine accessions with high protein content and yield and associated genes/QTL.
12. Based on Table 2 of this document, accessions need to be identified that increase concentrations of critical human nutrients classified as low or moderate sources, to being moderate or high sources, respectively, while keeping the level of other nutrients the same or higher.

*Faba bean*

Primary focuses for faba bean are:

1. Determine sources of genetic resistance and genes/QTLs associated with Chocolate spot caused by *Botrytis cinerea* and *Botrytis fabae.*
2. Evaluate genetic resources for resistance to pea leaf weevil and associated genes/QTL.
3. Determine genetic resources and genes/QTL associated with cold tolerance to enhance winterhardiness of autumn-sown faba beans and drought and salt tolerance.
4. Identify accessions with high yields and high seed protein content and associated genes/QTL.
5. Evaluate seeds for levels of anti-nutritional factors such as tannins, vicine, and convicine.
6. Collections of genetic resources need to be made from the *Vicia faba* vars. *faba*, *minuta*, and *equina* and from the secondary [*Vicia cappadocica* and *Vicia johannis* (sometimes considered tertiary)] gene pools of the crop wild relatives. Currently there are 10, 7 and 5 accessions of the *V. faba* varieties *faba*, *minuta* and *equina*, respectively, and zero accessions of *V. cappadocica*.
7. Determine accessions with high protein content and yield and associated genes/QTL.
8. Based on Table 2 of this document, accessions need to be identified that increase concentrations of critical human nutrients classified as low or moderate sources, to being moderate or high sources, respectively, while keeping the level of other nutrients the same or higher.

*Lupine*

Primary focuses for Lupines are:

1. Evaluate accessions for alkaloid content and associated genes/QTL.
2. Identify lines with high yields and high seed protein content and associated genes/QTL.
3. Identify sources of genetic resistance to brown spot, Fusarium root rot and Colletotrichum and associated genes/QTL.
4. Collections of genetic resources need to be made from the primary (*Lupinus albus* var. *graecus*) gene pool of the crop wild relatives. Currently there are 4 accessions of *L. albus* var *graecus* in the collection.
5. Determine cold, high pH (above 7.5), and water-logging resistance/tolerance and associated genes/QTL.
6. Based on Table 2 of this document, accessions need to be identified that increase concentrations of critical human nutrients classified as low or moderate sources, to being moderate or high sources, respectively, while keeping the level of other nutrients the same or higher.

**3.3.2 Significant accomplishments**

*Chickpea*

*Lentil*:

*Faba bean*

*Lupine*

**3.4 Curatorial, managerial and research capacities and tools**

**3.4.1 Staffing**

*Chickpea*

*Lentil*:

*Faba bean*

*Lupine*

**3.4.2 Facilities and equipment**

*Chickpea*

*Lentil*:

*Faba bean*

*Lupine*

**3.4.3 Fiscal and operational resources**

*Chickpea*

*Lentil*:

*Faba bean*

*Lupine*

**4. Other genetic resource capacities (germplasm collections, ex situ reserves, specialized genetic/genomic stocks, associated information, research and managerial capacities and tools, and industry/technical specialists/organizations) (2 pp. maximum)**

Table 3. Number of accessions as of February 2021 of food legumes present in the following national or international genetic resource collections. The accessions are in the Genesys-PGR database. China and India do not participate.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Crop** | **Azerbaijan** | **Australia** | **Bulgaria** | **Ethiopia** | **France** | **Hungry** | **ICARDA** | **ICRISAT** | **Russia** | **United****Kingdom** | **USA** | **Other** |
| Chickpea | 0 | 9,771 |  | 0 | 0 | 0 | 15,585 | 20,762 | 2,767 | 0 | 6732 | 8,244 |
| Faba bean | 0 | 2,736 | 731 | 0 | 0 | 0 | 9,938 | 0 | 1,269 |  | 769 | 1,158 |
| Grasspea | 28 | 0 |  | 126 | **4,0008** | 0 | 4,416 | 0 | 0 | 1,103 | 883 | 4 |
| Lentil | 0 | 5,601 |  | 0 | 0 | 1,075 | 14,959 | 0 | 2,598 | 0 | 3,178 | 4,057 |
| Lupine | 0 |  |  |  |  |  |  |  |  |  | 230 |  |

\*Item from France in bold is not part of the Genesys collection of grasspea accessions.

*Chickpea*

There are about 63,863 chickpea accessions listed in Genesys (www.genesys-pgr.org). The two largest collections are at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India, and the International Crop Research Institute for the Semi-Arid Tropics (ICARDA) in Lebanon, with additional important collections in Australia, USA and Russia. ICARDA’s collection include *kabuli*-type chickpeas, whereas ICRISAT’s specializes in *desi* types. More than half (58%) of the listed accessions are traditional cultivars and landraces, with just over 30% breeding material and improved varieties. Wild relatives currently make up 1.5% of the accessions. There are 62,384 accessions of *Cicer arietinum*, 424 *Cicer reticulatum*, 244 *Cicer judaicum*, 176 *Cicer pinnatifidum*, 167 *Cicer bijugum* and 468 other *Cicer* sp. The *Cicer arietinum* collection in Genesys consists of 31,283 traditional culitivar/Landraces, 8,365 breeding/research material, 6,549 other, 1,340 breeder lines, 1,125 advanced/improved cultivars, 82 genetic stock, 28 wild, 6 inbred lines, 3 natural, 2 hybrids, and 13,601 non-specified accessions. The *Cicer reticulatum* collection in Genesys consists of 353 wild, 3 breeders lines, 1 traditional cultivar/landrace, and 67 non-specified accessions. The *Cicer judaicum* collection in Genesys consists of 190 wild, 8 other, 1 traditional cultivar/landrace, and 35 non-specified. The *Cicer pinnatifidum* collection in Genesys consists of 133 wild, 5 natural, 4 others, 1 traditional cultivar/landrace and 33 non-specified. The *Cicer bijugum* collection in Genesys consists of 111 wild, 4 other, and 52 non-specified.

In a publication by Upadhyaya et al. in 2017 on chickpea genetic resources, a global collection of about 100,000 accessions were identified that are maintained in 120 national and international genebanks in 64 countries. Of these, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) genebank contains the largest share (20.8%), with 20,764 accessions from 59 countries followed by ICAR-National Bureau of Plant Genetic Resources (ICAR-NBPGR; 16%) and the International Center for Agricultural Research in the Dry Areas (ICARDA; 15%) representing more than 50% of the global collection of chickpea. The genetic resources conserved at the ICRISAT and ICARDA genebanks have been characterized for basic traits, with germplasm subsets developed for breeding purposes. These subsets, including core collection (1956 accessions), mini-core collection (211 accessions), global composite collection (3000 accessions), trait-based FIGS (Focused Identification of Germplasm Strategy) sets and reference set (300 accessions), are considered perfect resources for mining allelic diversity, dissecting population structure and association mapping in chickpea (Upadhyaya and Ortiz [2001](https://link.springer.com/article/10.1007/s00122-020-03584-2#ref-CR76); Upadhyaya et al. [2006](https://link.springer.com/article/10.1007/s00122-020-03584-2#ref-CR77), [2008](https://link.springer.com/article/10.1007/s00122-020-03584-2#ref-CR78)). This will help to detect QTLs that can be deployed in breeding programs to develop improved chickpea varieties.

Table 4. Number of annual wild *Cicer* (and *C. anatolicum*) accessions held in the world collection, based on data from the genebanks of the CGIAR system, as well as those registered with the International Plant Genetic Resources Institute (Berger et al. 2003).

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | ICARDA | ATC | USDA-ARS | ICRISAT | AARI | ICUC | ILRI | IPK | VIR | Total |
| *C. anatolicum* | 1 | 2 | 5 | 3 | 3 |  |  |  |  | 14 |
| *C. bijugum* | 41 | 35 | 18 | 8 | 2 |  |  |  |  | 104 |
| *C. chorassanicum* | 5 | 3 | 2 | 3 |  |  |  |  |  | 13 |
| *C. cuneatum* | 5 | 3 | 1 | 1 |  |  | 2 |  |  | 12 |
| *C. echinospermum* | 13 | 10 | 11 | 4 | 5 |  |  |  |  | 43 |
| *C. judaicum* | 73 | 4 | 35 | 23 |  | 5 |  |  |  | 135 |
| *C. pinnatifidum* | 52 | 3 | 21 | 11 | 7 |  |  | 3 | 1 | 98 |
| *C. reticulatum* | 60 | 50 | 17 | 6 | 6 |  |  |  |  | 139 |
| *C. yamashitae* | 5 | 3 | 3 | 3 |  |  |  |  |  | 14 |
| Total | 255 | 111 | 112 | 62 | 23 | 5 | 2 | 3 | 1 | 572 |

ICARDA: International Centre for Agricultural Research in the Dry Areas, Aleppo, Syria

ATC: Australian Temperate Field Crops Collection, Horsham, Victoria

GRIN: USDA-ARS, National Genetic Resources Program, Pullman, WA, USA

ICRISAT: International Crops Research Institute for Semi-Arid Tropics, Patancheru, India.

AARI: Aegean Agricultural Research Institute, Izmir, Turkey

ICUC: International Centre for Underutilised Crops, Southampton, UK

ILRI: International Livestock Research Institute, Addis Ababa, Ethiopia.

IPK: Institute for Plant Genetics and Crop Plant Research, Gatersleben, Germany

VIR: N. I. Vavilov Research Institute of Plant Industry, St. Petersburg, Russia.

Note the sum total of accessions held across the various genebanks considerably overestimates the actual number in the world collection because of duplication.

Table 5. In 2008, CropTrust.org put together a comprehensive list of world *Cicer* collections, but these have not been updated since then. An “x” indicates the data were not provided.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Country** | **Genebank/Institute** | **No. of accessions** | **% Wild relatives** | **% Landraces** | **% Breeding material** | **% Collected within country** |
| Global | ICRISAT | 18,963 | 1 | 93 | 7 | 36 |
| India | NBPGR | 15,986 | 1 | 65 | X | 89 |
| Global | ICARDA | 13,065 | 2 | 68 | 23 | X |
| Australia | Australian Temperate Field Crops Collection | 8410 | 3 | 26 | X | X |
| USA | USDA | 6197 | X | X | X | X |
| Iran | Seed and Plant Improvement Institute | 5600 | X | X | X | X |
| Russian Federation | VIR | 2643 | X | 73 | X | 24 |
| Pakistan | Plant Genetic Resources Institute, National Agricultural Research Center | 2110 | 4 | 95 | X | 70 |
| Turkey | Aegean Agricultural Research Institute | 2063 | 1 | 98 | 1 | 100 |
| Ukraine | Institute of Plant Production, Kharkiv | 1404 | 1 | 20 | 70 | 4 |
| Spain | Centro de Recursos Fitogeneticos, INIA | 1389 | 1 | 60 | X | 58 |
| Portugal | Estacao Nacional Melhoramento Plantas, Elvas | 1283 | X | 20 | X | 20 |
| Ethiopia | Biodiversity Conservation and Research Institute | 1156 | X | 75 | X | 71 |
| Hungary | Research Centre for Agrobotany | 1154 | 1 | 2 | X | 2 |
| Uzbekistan | Uzbek Research Institute of Plant Industry (UZRIPI) | 726 | X | X | X | X |
| Bangladesh | Bangladesh Agricultural Research Institute (BARI) | 666 | X | X | X | X |
| Canada | Plant Gene Resources of Canada (PGRC) | 641 | 20 | 80 | X | X |
| China | Institute of Crop Germplasm Resources, CAAS, Beijing, China | 567 | X | 3 | X | 3 |
| Nepal | Agricultural Botany Division | 424 | X | 100 | X | 97 |
| Italy | Institute of Plant Genetics (IGV)-Bari | 358 | X | X | X | X |
| Morocco | National Institute for Agronomic Research (INRA) | 332 | X | X | X | X |
| Germany | Leibniz Institute of Plant Genetics and Crop Plant Research (IPK)-Gatersleben | 310 | X | X | X | X |
| Mexico | Centro de Investigaciones Forestales y Agropecuarias, INIFAP | 299 | X | 33 | X | X |
| Portugal | Banco Portuges de Germoplasma, Braga | 253 | X | X | X | 100 |
| Ecuador | Departamento Nacional de Recursos Fitogeneticos y Biotechnologia | 150 | X | 100 | X | 100 |
| Portugal | Banco de germosplasma Genetica, EAN Oieras | 115 | X | 90 | X | 70 |
| Tadjikistan | Makhsumov Scientfic Research- production Center “Ziroatkor” & Scientific Research Institute of Farming & TJK-Genebank (MSRPC) | 74 | X | X | X | X |
| Turkmenistan | Turkmen Scientific Research Institute for Cereals | 48 | X | X | X | X |
| Azerbadjan | Agricultural Research Institute (ARI) | 42 | X | X | X | X |
| Azerbadjan | Azerbaijan National Academy of Sciences, Genetic Resource Institute | 40 | X | X | X | x |
| Armenia | Institute of Botany, Botanical Gardens (IBNAS) | 19 | X | X | X | X |
| Egypt | Field Crops Research Institute, Agricultural Research Centre | 12 | X | X | X | X |

*Faba bean*

There are about 16,601 faba bean accessions listed in Genesys (www.genesys-pgr.org). The two largest collections are at the International Crop Research Institute for the Semi-Arid Tropics (ICARDA) in Lebanon, with additional important collections in Australia, Russia, USA and Bulgaria. There are 16,599 accessions of *Vicia faba*, 1 accession of *Faba vulgaris* and 1 unknown species of *Vicia*. The *Vicia faba* collection in Genesys consists of 4,431 breeding/research material, 4,004 traditional cultivar/landrace, 973 advanced/improved cultivars, 429 other, 228 breeders lines, 10 wild, 7 genetic stock, 1 inbred line, and 6,517 non-specified. The *Faba vulgaris* accession in Genesys consists of 1 accession that is an advanced/improved cultivar. The unknown *Vicia* sp. accession in Genesys consists of the “other” category.

Table 6. In 2009, CropTrust.org put together a comprehensive list of world *Vicia faba* collections, but these have not been updated since then. An “x” indicates the data were not provided.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Country** | **Genebank****Institute** | **No. of accessions** | **No. of accessions, wild relatives** | **% Landraces** | **% Breeding material** | **% Improved varieties** | **%****Collected in country** |
| Global | International Centre for Agricultural Research in Dry Areas (ICARDA) | 12,015 | 6148 | 24 | 35 | X | NA |
| China | Institute of Crop Science | 5,229 | X | 64 | X | X | 65 |
| Australia | Australian Temperate Field Crops Collection, Victoria | 2,665 | 2 | 30 | 40 | X | 24 |
| Germany | Genebank, Leibniz Institute of Plant Genetics and Crop Plant Research (IPK), Gatersleben | 1,925 | 1106 | 69; also 787 accessions of other Vicia species | 13; also 176 accessions of other Vicia species | 18; also 353 accessions of other Vicia species | 5 |
| Italy | Istituto di Genetica Vegetale (IGV), CNR, Bari | 1,875 | 69 | 100 | 0 | 0 | 16 |
| Ecuador | Instituto de Ciencias Naturales Universidad Central del Ecuador (ICN) | 1,650 | X | X | X | X | X |
| Russian Federation | N. I. Vavilov All-Russian Scientific | 1441 | X | 67 | 5 | X | 25 |
| Ethiopia | Biodiversity Conservation and Research Institute (BCRI) | 1208 | X | 55 | X | X | 94 |
| Spain | Centro de Recursos Fitogeneticos (CRF), INIA, Madrid | 1179 | 1 | 87 | X | X | 54 |
| Spain | Centro de Investigacion y Desarrollo Agrario Alameda del Obispo. | 1098 | X | X | X | X | X |
| France | Staton d”Amelioraton des Plantes (INRA) | 1057 | 0 | 41 | 34 | 17 | 28 |
| Romania | Banca de Recurse Genetice Vegetale-Suceava (BRGV) | 801 | 0 | 69 | 20 | 11 | 63 |
| Bulgaria | Institute for Plant Genetic Resources “K. Malkov” (IPGR) | 729 | 60 | 2 | 29 | 0 | 10 |
| Netherlands | Centre for Genetic Resources, the Netherlands (CGN) | 728 | 0 | 54 | 1 | 32 | 9 |
| USA | Western Regional Plant Introduction Station, USDA-ARS, Pullman, WA | 589 | X | X | X | X | X |
| India | National Bureau of Plant Genetic Resources (NBPGR) | 554 | 1 | 10 | X | X | 40 |
| Turkey | Aegean Agricultural Research Inst. (AARI) | 351 | 33 | 67 | X | X | 100 |
| Portugal | Banco Portuges de Germoplasma Vegetal, Braga (BPGV) | 340 | 0 | 99 | 0 | 1 | 99 |
| Portugal | Estacao Nacional Melhormento Plantas, Elvas (ENMP) | 331 | X | 54 | 45 | X | 54 |
| Hungary | Research Centre for Agrobotany (RCA) | 328 | X | 9 | 4 | X | 33 |
| Canada | Plant Gene Resources of Canada (PGRC) | 274 | 16 | 84 | X | X | 0 |
| Greece | National Agricultural Research Foundation, Agricultural Research Centre of Northern Greeze, Greek Gene Bank | 267 | 99 | 98 | 1 | 0 | 100 |
| Ecuador | Departamento Nacional de Recursos Fitogenticos y Biotechnologia- Sta Caltalina; estacion experimental Santa Catalina DENAREF INIAP | 262 | 0 | 99 | 0 | 1 | 80 |
| Eritrea | National Agricultural Research Institute (NARI) | 200 | 0 | 100 | 0 | 0 | 100 |
| Poland | Research Institute of Vegetable Crops (RIVC), Plant Genetic Resources Laboratory | 188 | 0 | 50 | <1 | 8 | 40 |
| Pakistan | Plant Genetic Resources Institute National Agricultural Research Center (PGRI) | 181 | 40 | 60 | X | X | 64 |
| Syria | General Commission for Scientific Agricultural Research, Dept. of Genetic Resources (DUMA) | 159 | X | 100 | X | X | 100 |
| UK | John Innes Centre (JIC) Norwich | 156 | X | 5 | X | X | 70 |
| Egypt | Field Crops Research Institute, Agricultural Research Center (NGB) | 125 | 2 | X | 98 | X | 10 |
| Portugal | Banco de germoplasma Genetica, (EAN) Oieras | 66 | 38 | 58 | X | X | 70 |
| Portugal | Estacao Agronomica Nacional (EAN) (Forages Section) | 12 | 11 | 60 | 89 | X | 92 |
| Kenya | National Genebank of Kenya (NGBK) | 1 | 5 | 0; also 31 accessions of other *Vicia* species | 0 | 0 | 36 |

*Grasspea*

There are about 6,562 grasspea accessions listed in Genesys. The two largest collections are at the ICARDA (4,416 accessions) followed by the collection in Great Britain. Additional collections are at the Conservatoire Botanique National des Pyrenees et de Midi-Pyrenees, France (4,000 accessions) and the National Bureau of Plant Genetic Resources, India (2,600 accessions). The accessions listed in Genesys show that the grasspea accessions are divided into the following species: *Lathyrus sativus* (3,160 accessions), *Lathyrus aphaca* (575), *Lathyrus cicero* (339), *Lathyrus inconspicuous* (310), *Lathyrus hierosolymitanus* (220), and other *Lathyrus* species (1,956). The *Lathyrus sativus* collection in Genesys consists of 2,193 traditional cultivar/landrace, 425 breeding/research material, 245 other, 152 natural, 91 wild, 46 advanced/improved cultivar, 2 breeder lines, 1 weedy, and 5 non-specified. The *Lathyrus aphaca* collection in Genesys consists of 346 wild, 188 natural, 19 other, 13 weedy, 6 traditional cultivars/landraces and 3 semi-natural/sown. The *Lathyrus cicera* collection in Genesys consists of 157 wild, 77 natural, 61 traditional cultivar/landrace, 29 other, 10 weedy, 3 semi-natural/sown, and 2 advanced/improved cultivar. The *Lathyrus inconspicuus* collection in Genesys consists of 223 wild, 76 natural, 6 weedy, 4 other and 1 semi-natural/sown accessions. The *Lathyrus hierosolymitanus* collection in Genesys consists of 133 wild, 86 natural, and 1 other accession.

Table 7. In 2007, CropTrust.org put together a comprehensive list of world *Lathyrus* collections, but these have not been updated since then. An “x” indicates the data were not provided.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Country** | **Genebank****Institute** | **No. of accessions** | **% No. of accessions, wild relatives** | **% Landraces** | **% Breeding material** | **%****Collected in country** |
| Global | ICARDA | 3239 | 45 | 54 | 0.1 | 17 |
| France | Universite de Pau, IBEAS | 4477 | X | X | X | 34 |
| India | NBPGR | 2619 | 3 | 85 | X | 94 |
| Bangladesh\*\*\* | GRC Bangladesh Agric. Res. Inst. | 1841 | X | X | X | X |
| Chile | Centro Reg. de Inv. Carillanca | 1424 | X | X | X | X |
| Australia\*\*\* | Australian Temp. Field Crops Coll. | 986 | 28 | 39 | 19 | X |
| Russia\*\*\* | VIR | 848 | 43 | 30 | 18 | 40 |
| Canada | PGRC, Canada | 840 | 10 | 90 | X | X |
| USA | Western Regional Plant Introduction Station, USDA, Pullman, WA | 669 | X | X | X | 7 |
| Ethiopia\*\*\* | BCRI | 588 | 2 | 75 | 25 | 98 |
| Germany\*\*\* | IPK | 568 | 40 | X | X | 5 |
| Spain\*\*\* | Fernando Franco Jubete | 543 | X | X | X | X |
| Algeria | Institute national Agronomique | 437 | X | X | X | X |
| Hungary\*\*\* | Research Centre for Agrobotany | 394 | 1 | 22 | X | 20 |
| Spain\*\*\* | INIA | 377 | X | 100 | X | 89 |
| Bulgaria\*\*\* | Institute for PGR “K. Malkov” | 368 | X | X | X | X |
| Turkey | AARI | 363 | 94 | X | X | 100 |
| Nepal\*\*\* | Nepal Agricultural Research Council | 164 | 0 | 100 | 0 | 100 |
| Armenia\*\*\* | Institute of Botany, National Academy of Sciences of Armenia | 157 | X | X | X | X |
| Pakistan | Plant Genetic Resources Institute | 130 | X | X | X | X |
| Portugal\*\*\* | Genebank, Braga | 199 | 5 | 30 | X | 45 |
| China | CAAS | 80 | X | X | X | 100 |
| Azerbaijan\*\*\* | Genetic Resource Institute, National Academy of Science | 66 | X | X | X | X |
| Czech Republic\*\*\* | Research Institute of Crop Production | 52 | X | X | X | X |
| Greece\*\*\* | Greek Genebank, Agricultural Center of Mecedonia and Thrace | 47 | X | X | X | X |
| Slovakia\*\*\* | Research Institute of Plant Production | 47 | X | X | X | X |
| Cyprus\*\*\* | Agricultural Research Institute | 31 | X | X | X | X |
| Poland\*\*\* | PGR Laboratory Research Institute of Vegetable Crops | 10 | X | X | X | X |
|  | Total | 21227 |  |  |  |  |

\*\*\* - from accession-level data sent to ICARDA in April 2007

*Lentil*

There are about 31,468 lentil accessions listed in Genesys and an estimated 43,214 accessions worldwide. The largest collection is located at the ICARDA. The accessions listed in Genesys show that the lentil accessions are divided into the following species: *Lens culinaris* (30,810 accessions), *Lens ervoides* (320), *Lens nigricans* (151), *Lens esculenta* (55), *Lens orientalis* (51), and other *Lens* species (81). The *Lens culinaris* collection in Genesys consists of 8,072 traditional cultivar/landrace, 3,462 other, 2,741 breeding/research material, 735 advanced/improved cultivar, 447 wild, 431 inbred line, 243 breeders line, 64 natural, 18 genetic stock, 1 weedy, 1 other, 14,690 non-specified. The *Lens ervoides* collection in Genesys consists of 209 wild, 15 natural, 2 advanced/improved cultivar, 1 breeders line, 1 genetic stock, and 92 non-specified accessions. The *Lens nigricans* collection in Genesys consists of 94 wild, 12 natural, 1 breeders line and 44 non-specified. The *Lens esculenta* collection in Genesys consists of 12 traditional cultivar/landraces and 43 non-specified. The *Lens orientalis* collection in Genesys consists of 24 natural, 13 wild, 1 traditional cultivar/landrace and 13 non-specified.

Table 8. A 2019 assessment of the global Ex-situ lentil collections held by the global gene bank of ICARDA and other national gene banks (Malhotra et al. 2019). An “X” indicates the data is unknown.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Country** | **Gene Bank/Institute** | **Total Accessions** | **% Wild relatives** | **% Land races** | **% Collection Safety Duplicates** |
| Syria | International Centre for Agricultural Research in Dry Areas | 10,822 | 583 | 82 | X |
| Australia | Australian Temperate Field Crops Collection | 5,254 | 4 | 54 | 67% |
| Iran | Seed and Plant Improvement Institute | 3,000 | 9 | 12 | X |
| United States | United States Department of Agriculture  | 2875 | 1 | 14 | 94 |
| Russian Federation | N. I. Vavilov Russian Scientific Research Institute of Plant Industry | 2,556 | 11 | 80 | 100 |
| India | National Bureau of Plant Genetic Resources | 2285 | 5 | 42 | X |
| Chile | Inst de Inv. Agropecuarias, Centro Regional de Investigacion Carillanca | 1345 | 10 | 15 | X |
| Canada | Plant Genetic Resource Centre | 1139 | 17 | 56 | X |
| Turkey | Plant Genetic Resource Department Aegean Agricultural Research Institute | 1095 | 1 | 99 | X |
| Syria | General Commission for Scientific Agricultural Research | 1072 | 7 | 38 | X |
| Hungary | Research Centre for Agrobotany | 1061 | 4 | 3 | 100 |
| Egypt | National Gene Bank | 875 | 5 | 5 | X |
| China | Institute of Crop Germplasm Resources | 855 | 10 | 60 | 100 |
| Pakistan | Plant Genetic Resources Institute, National Agricultural Research Center | 805 | 8 | 91 | 29 |
| Bangladesh | Bangladesh Agricultural Research Institute | 798 | X | X | X |
| Spain | Centro de Recursos Fitogeneticos | 703 | 10 | 87 | X |
| Ethiopia | Biodiversity Conservation and Research Institute | 678 | 70 | X | X |
| Ukraine | Institute of Plant Production V.J. Yurjev of UAAS, Kharkiv | 666 | 1 | 52 | 61 |
| Chile | Instituto de Investigaciones Agropecuarias, C.R.I. La Platina | 600 | X | X | X |
| Israel | Agricultural Research Organization | 500 | X | X | X |
| Nepal | Nepal Agricultural Research council, Agricultural Botany Division | 489 | 1 | 97 | 100 |
| Chile | Centro Regional de Investigacion Quilamapu INIA | 450 | X | 64 | 100 |
| Portugal | Estacao Nacional Mehhoramento Plantas, Elvas | 423 | 1 | 2 | 60 |
| Morocco | Institute National de la Recherche Agronomique INRA | 365 | X | X | X |
| Bulgaria | Institute for Plant Genetic Resources “K. Makov” | 361 | X | 16 | X |
| Italy | Istituto di Genetica Vegetale (IGV)-Bari | 348 | 1 | X | X |
| Spain | Banco de Germoplasma, Centro de Investigacion, Agraria de Albaladejito | 321 | 1 | 21 | X |
| Ecuador | Instituto de Ciencias Naturales Universidad Central del Ecuador | 295 | 3 | 28 | X |
| Ecuador | Estacion Experimental Santa Catalina, DENAREF, INIAP | 252 | 1 | 70 | 13 |
| Slovakia | Research Institute of Plant Production Piestany | 239 | X | X | X |
| Poland | Plant Breeding Station | 216 | X | X | X |
| Mexico | Estacion de Iguala, Instituto Nacional de Investigaciones Agricolas | 200 | X | X | X |
| Tunisia | Minister of Agriculture | 65 | X | X | X |
| Yemen | Agricultural Research and Extension Authority | 60 | 1 | 14 | X |
| Armenia | Institute of Botany, Botanical Gardens | 34 | X | X | X |
| Tadjikistan | Makhsumov Scientific Research-Production Center “Ziroatkor” & Scientific Research Institute of Farming & TJK-Genebank (MSRPC) | 28 | X | X | X |
| Azerbaijan | Agricultural Research Institute (ARI) | 27 | X | X | X |
| Turkemenistan | Turkmen Scientific Research Institute for Cereals | 22 | X | X | X |
| Azerbaijan | Azerbaijan National Academy of Sciences, Genetic Resources Institute | 15 | X | X | X |
| Portugal | Banco de Germoplasma Genetica, EAN Oieras | 15 | 1 | 40 | 100 |
| Portugal | Banco Portuges de Germoplasma, Braga | 5 | X | X | X |

Table 9. In 2008, CropTrust.org put together a comprehensive list of world *Lens* collections, but these have not been updated since then. An “x” indicates the data were not provided.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Country** | **Genebank****Institute** | **No. of accessions** | **No. of accessions, wild relatives** | **% Landraces** | **% Breeding material** | **%****Collected in country** |
| Global | International Centre for Agricultural Research in Dry Areas (ICARDA) | 10822 | X | 82 | X | 17 |
| Australia | Australian Temperate Field Crops Collection, Victoria | 5254 | 4 | 54 | X | X |
| Iran | Seed and Plant Improvement Institute | 3000 | X | X | X | X |
| USA | Western Regional Plant Introduction Station, USDA-ARS, Pullman, WA | 2875 | 1 | X | X | X |
| Russian Federation | N. I. Vavilov All-Russian Scientific Research Institute of Plant Industry | 2556 | X | 80 | X | 0 |
| India | National Bureau of Plant Genetic Resources | 2285 | 1 | 42 | X | 78 |
| Chile | Inst. De Inv. Agropecuarias, Centro Regional de Investigacion Carillanca | 1345 | X | X | X | X |
| Canada | PGRC | 1139 | X | 56 | X | X |
| Turkey | Plant Genetic Resources Dept. Aegean Agricultural Research Inst. | 1095 | 1 | 99 | X | 100 |
| Syria | General Commission for Scientific Agricultural Research | 1072 | X | X | X | X |
| Hungry | Research Centre for Agrobotany | 1061 | X | 3 | X | 3 |
| Egypt | NGB | 875 | X | 5 | X | X |
| China | Institute of Crop Germplasm Resources (CAAS) | 855 | X | 60 | X | 60 |
| Pakistan | Plant Genetic Resources Institute, National Agricultural Research Center | 805 | 8 | 91 | X | 60 |
| Bangladesh | Bangladesh Agricultural Research Instititute | 798 | X | X | X | X |
| Spain | Centro de Recursos Fitogeneticos, INIA | 703 | 10 | 87 | X | 60 |
| Ethiopia | Biodiversity Conservation and Research 521Institute | 678 | 70 | x | X | 71 |
| Ukraine | Institute of Plxant Pro0duction n. a. V.x J. Yurje0v of UAASx, Kharkiv | 666 | 1 | 52 | X | 6 |
| Chile | Instituto de Investigaciones Agropecuarias, C. R. I. La Platina | 600 | X | X | X | X |
| Israel | Agricultural Research Organisation, The Volcani Center | 500 | X | X | X | X |
| Nepal | Central Plant Breeding and Biotec. Nepal Agricultural Research Council, Agricultural Botany Division | 489 | 0 | 97 | X | 97 |
| Chile | Centro Regional de Investigacion,; Quilamapu, INIA | 450 | X | 64 | X | 0 |
| Portugal | Estacao Nacional Melhoramento Plantas, Elvas | 423 | 0 | 0 | 100 | 0 |
| Morocco | Institut National de la Recherche Agronomique (INRA) | 365 | x | x | X | X |
| Bulgaria | Institute for Plant Genetic Resources “K. Malkov” | 361 | X | x | X | X |
| Italy | Istituto di Genetica Vegetale (IGV)- Bari | 348 | X | x | X | X |
| Spain | Banco de Germoplasma, Centro de Investigacion Agraria de Albaladejito | 321 | X | x | X | X |
| Ecuador | Instituto de Ciencias Naturales Universidad Central del Ecuador | 295 | X | x | X | X |
| Ecuador | Estacion Experimental Santa Catalina, DENAREF, INIAP | 252 | 0 | 100 | 0 | 8 |
| Slovakia | Research Institute of Plant Production Piestany | 239 | X | x | X | X |
| Poland | Plant Breeding Station | 216 | X | x | X | X |
| Mexico | Estacion de Iguala, Instituto Nacional de Investigaciones Agricolas | 200 | X | x | X | X |
| Tunisia | Minister of Agriculture | 65 | X | x | X | X |
| Yemen | Agricultural Research and Extension Authority (AREA-NGRC) | 60 | X | x | X | X |
| Armenia | Institute of Botany, Botanical Gardens (IBNAS) | 34 | x | x | x | x |
| Tadjikistan | Makhsumov Scientific Research- production Center “Ziroatkor” & Scientific Research Institute of Farming & TJK-Genebank (MSRPC) | 28 | x | x | x | X |
| Azerbaijan | Azerbaijan National Academy of Sciences, Genetic Resources Institute | 27 | X | X | X | X |
| Turkemenistan | Turkmen Scientific Research Institute for Cereals | 22 | X | X | X | X |
| Azerbaijan | Azerbaijan National Academy of Sciences, Genetic Resources Institute | 15 | X | X | X | X |
| Portugal | Banco de germoplasma Genetica, EAN Oieras | 15 | 0 | 100 | 0 | 10 |
| Portugal | Banco Portuges de Germoplasma, Braga | 5 | X | X | X | X |

Lupine

There are no accessions of lupine listed in Genesys. Twelve major International Centers maintain substantial number of lupine accessions. The largest collections are maintained in Australia, France, Germany, and the UK.

**5. Prospects and future developments**

Recent advances in genomics tools and technologies have facilitated the generation of large-scale sequencing and genotyping data sets in food legume crops. Combined analysis of high-resolution phenotypic and genetic data is paving the way for identifying genes and biological pathways associated with breeding-related traits. Genomics technologies have been used to develop diagnostic markers for use in marker-assisted backcrossing programs, which have already yielded several molecular breeding products in food legumes. We anticipate a sequence-based holistic breeding approach, including the integration of functional omics, parental selection, forward breeding and genome-wide selection, will bring a paradigm shift in development of superior food legume varieties. There is a need to integrate the knowledge generated by modern genomics technologies with molecular breeding efforts to bridge the genome-to-phenome gap. Modern genomics technologies have the potential to speed up the process for trait mapping, gene discovery, marker development and molecular breeding, in addition to enhancing the rate of productivity gains in food legumes.

*Chickpea*

Development of high yielding varieties that are easy to grow, adaptable to the target areas, climate-resilient, and desirable for consumers are needed. Larger seed sizes for Kabuli-type that can increase grower profits are desired. Improvement of the nutritional quality of chickpeas such as iron content and Vitamin A is needed. Growing chickpea varieties that enhance desired qualities for humus are needed. Grower risk of producing chickpeas by developing varieties that have early maturity and disease resistance to Ascochyta blight, Pythium seed and seedling rot, Fusarium wilt and root rot, botrytis gray mold and collar rot are sought after. The chickpea crop needs to be more herbicide tolerant and competitive for weed management. Upright varieties that are easy to harvest need to continue to be developed. Autumn-sown chickpeas need to be developed with improved cold-tolerance for spring plantings and drought and heat stress tolerant resistant cultivars need to be identified and developed.

*Lentil*

There is a need to improve the harvestability of lentils by improving plant height and other measures and develop autumn-sown lentils with excellent winter hardiness. Development of resistance to Aphanomyces root rot, Stemphylium blight, *Pea enation mosaic virus* and *Bean leafroll virus* are major issues that needs to be addressed.

*Faba bean*

Development of the following seed characteristics is desirable: small seed size, protein content, zero-tannins and zero-vicine-covicine. The following plant characteristics are desired: seed yield, yield stability, earliness of flowering, autofertility in winter types, closed flower, determinate-Ti, ½ determinate, stiff-strawed, short-strawed, branching, high number of pods/node, high number of seeds/pod. The following disease/pest resistance is desired to the following pathogens: *Botrytis*, *Ascochyta*, *Uromyces*, and *Orobanche*. The following abiotic stress resistances are desired: freezing and drought tolerance. Cold tolerance is a problem in some regions of the Continental United States and selection of cultivars to tolerate a wider temperature range is a goal of the USDA-ARS Faba Bean Research Program, along with selection of small-seeded cultivars that can be easily planted with corn and cover crop planters (Hu et al., 2009; Landry et al., 2015b).

*Lupine*

Creation of high yielding dwarf-determinate autumn-sown cultivars is desirable. The main potential market for white lupine grain is clearly in ruminant feed where its high oil and protein contents are of great value. Because of the absence of anti-nutritional factors (alkaloid or trypsine inhibitors), the grains may be used directly on dairy cattle, beef cattle, or sheep farms, making the farming systems more sustainable. Must be used extensively in industrial feed compounding for it to be impactful. The market for human consumption needs to be considered. The traditional market around the Mediterranean using the raw grains is not likely to expand. But, lupine flour because of its color, dietary fiber and protein contents offer very good prospects in bakery and pastry. Developing thinner lupine pod walls to improve the harvest index is desired. Pod walls account for approximately 35 to 40% or the pod weight and in other grain legumes this is only 20 to 27%. White lupine is not commonly available from nurseries, garden stores and other plant dealers and distributors in the US. Major germplasm sources are in France, United Kingdom, Australia, and Spain. White lupine breeders are selecting for accessions that grow rapidly, are alkaloid-free, disease resistant, high-yielding, alkaline-tolerant, frost tolerant, dwarf cultivars, and well adapted to specific local ecological conditions.

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