THE UNIVERSITY OF MANITOBA

AN EVALUATION OF SEED YIELD, PROTEIN CONTENT, AND OTHER AGRONOMIC CHARACTERISTICS OF THE GENUS *LUPINUS*

by

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ABSTRACT

A preliminary investigation in 1971 indicated that lupins (*Lupinus* species) had some potential as a high protein seed crop in Manitoba. This prompted the present study in 1972 and during the two year period following numerous species and varieties were observed, but only *L. albus*, *L. angustifolius*, *L. luteus*, *L. mutabilis* and *L. cosentini* were considered to have any potential. The first three of the above species were tested in replicated trials at seven locations in Manitoba for seed yield, protein content and other agronomic characteristics. These species were found to be adapted, but were extremely variable in their yielding ability. Generally, *L. albus* performed substantially better than *L. angustifolius* and *L. luteus*. The average highest yield of *L. albus* (maximum cultivar yield at each location) was 30.8 qu/ha. The average yield on the same basis for *L. angustifolius* and *L. luteus* was 18.7 qu/ha and 13.6 qu/ha respectively, as compared to the fababean check which yielded an average of 24.2 qu/ha. The maximum yield obtained was for *L. albus*, cv. Reuscher, at 51.3 qu/ha (Winnipeg, 1973).

In addition to the replicated yield trials, eight single entry nursery yield trials consisting of the five lupin species were conducted in Manitoba, and were evaluated for seed yield, protein content and other agronomic characteristics. A trend similar to that in the replicated trials was found to exist, namely, *L. albus* is higher yielding than *L. angustifolius* and *L. luteus* and in that order. Average seed yields (all cultivars, all locations) obtained as a percent of the fababean check were 69%, 55% and 39% for *L. albus*, *L. angustifolius* and *L. luteus* respectively. *L. mutabilis* and *L. cosentini* did not seem to be adapted and

yielded less than 1% of the fababean check. Differences between yields of fababeans and lupins at different locations were attributed to limited soil moisture, where the latter proved to be more drought tolerant.

The protein content was found to be extremely variable between, and to a lesser extent within species. *L. luteus* was found to have the highest average protein content (all cultivars, all locations) of 44.4%, followed by *L. albus* and *L. angustifolius* at 35.9% and 35.5% protein respectively, as compared to the fababean check which had an average of 28.2%. Therefore on a protein yield basis the above species yielded 68%, 120%, & 80% of the fababean check respectively (average yields of all cultivars at all locations in replicated trials multiplied by the average protein values).

Lupin species were found to be consistent in their amino acid composition, having twice the lysine content of wheat but somewhat less than fababeans. Methionine content was found to be similar to fababeans, both having approximately half that found in wheat.

Lupins were found to be extremely sensitive to lime-induced chlorosis as follows, in diminishing order of susceptibility; *L. luteus, L. angustifolius, L. mutabilis* and *L. albus*.

Yield losses due to pod shattering were found to be variable between and within species. *L. albus* did not shatter on maturity, whereas the other species displayed varying degrees of this characteristic. Other agronomic characteristics were found to be satisfactory, but extremely variable, although maturity could be a problem. However, variability for this characteristic seems to exist also.

Lupins were commonly and severely infested with Caragana and Nuttall Blister Beetles in 1973. Wilt and root rot caused by *Fusarium* species was particularly severe in 1972, but less so in 1973.

PART I

INTRODUCTION

LITERATURE REVIEW

AND

MATERIALS AND METHODS

INTRODUCTION

Increasing emphasis can be expected throughout the world on the production of legumes for their seeds. This greater emphasis is due partly to increasing demand for protein feedstuffs and also to various catastrophies in many countries that have created a paucity of both animal and vegetable protein, such as failure in the Peruvian fish catch and delays and damage to the U.S. soybean crop amounting to an estimated 100 million bushels in 1972. These factors have recently culminated with unprecedented price increases in the protein market.

Western Canadian agriculture does not produce sufficient quantities of vegetable protein to meet domestic demand. This deficit may be attributed to various factors, but the most important is the lack of a well adapted, high-yielding crop plant that contains a high percentage of good quality protein. Until the recent introduction of fababeans (*Vicia faba* L.), production of grain legumes was seriously restricted in the West. Our short growing season prevents the cultivation of soybean, and field peas are rather low yielding and have many management and handling problems. Rapeseed, a cruciferous crop, is high in protein, but has many toxicity problems.

The necessity of a protein crop for local use as well as foreign markets has offered the impetus for the search for "new" crops that may be suited to production in Western Canada. Lupins (*Lupinus* spp.) are an example of such a new crop that may have potential in this area.

Lupins are erect growing plants that belong to the *Leguminosae* family.

They are relatively high yielding and their seeds contain large amounts of good quality protein. All production procedures may be handled with conventional cereal equipment. They are later in maturity than wheat, but are very frost tolerant. They also possess the very desirable characteristic of being able to grow well on soils that are extremely low in fertility. Hence the generic name *Lupinus*, "lupus, Latin for wolf, from some fancied ability to prey on the soil," (Bailey, 1963). Since lupins, like many other legumes, fix atmospheric nitrogen via a bacterial symbiosis, little or no nitrogen fertilization is required. In fact, such large amounts of nitrogen are fixed and left behind in crop residues that cropping with lupins increases soil fertility and therefore has a beneficial effect on subsequent crops.

Lupins are possibly best known in this country by the wild types that are represented by well over 100 different species distributed across Canada and Alaska. Small-seeded ornamental types may also be familiar, represented by such species as *Lupinus polyphylus* (Russel Lupin) and *L. hartwegii* (Hartweg Lupin). Little or no cultivation of the large-seeded agricultural types has been attempted in Western Canada. In many European countries, as well as Australia, New Zealand, Africa and southeastern United States, lupins are grown for forage, green manuring and for their seed which is fed to various classes of livestock. They also served in a lesser role as human food.

Preliminary investigations with Lupins in 1971 indicated that they may have some potential as a high protein grain crop in Manitoba. This led to the present study that evaluates lupins under Manitoba field conditions in terms of their adaptibility, seed yield, protein content and quality, and other agronomic characteristics.

Varieties belonging to the many varied species of lupins were observed and evaluated in 1972. Subsequent testing focused upon the more important, established agricultural species, namely, *Lupinus albus, L. angustifolius, L. luteus, L. mutabilis* and *L. cosentini*.

A very complete review on the subject of lupins as crop plants has been recently published by Gladstones (1970b). Others, such as Wells, and Forbes have carried out much research on lupins in the U.S.A. Reference to these authors will be extensive.

1.0 LITERATURE REVIEW

1.1 BOTANICAL DESCRIPTION

Lupins belong to the *Leguminosae* family. The genus *Lupinus* is comprised of many species with extensive genetic and morphological variation. Linnaeus (1753) listed only six species of lupins, namely, *L. albus*, *L. angustifolius*, *L. luteus*, *L. varius*, *L. perennis* and *L. hirsustus*. Upwards of 300 species have now been described, with more than 200 species occurring wild in North America (Bailey, 1963; Turner, 1959).

There are basically two groups of lupins - the large-seeded agricultural types which are mainly annuals, and the perennial small-seeded ornamentals. The later group is represented by species such as *L. polyphyllus* (Russel Lupin) and *L. hartwegii* (Hartweg Lupin).

The large-seeded crop varieties are of the following species: *L. albus*, *L. angustifolius*, *L. luteus*, *L. mutabilis* and *L. cosentini*. The present study focuses on the evaluation of these large-seeded types that are presently cultivated in various areas of the world.

In general, both large and small-seeded types have digitate leaves of 5 to 15 leaflets. The flowers are showy, in terminal racemes or sometimes whorled and can be white, yellow, blue, purplish or papilionaceous. The fruit (pods) are flattened and are mostly constricted or grooved between the seeds (Bailey, 1963). The overall taxonomy of the genus is somewhat confusing, even for the important agricultural types as indicated in Table 1 (Gladstones, 1970b).

The genus has chromosome numbers ranging from 2n = 32 to 2n = 96 (Gustafsson and Gadd, 1965). The large-seeded species have a widely differing chromosome number, and interspecific crossing is impossible or very rare (Kazimierski, 1960, 1961, 1964a). This genetic diversity forces independent breeding of the different species. Along with the genetic diversity there exists a fairly wide morphological separation in the genus, which will be displayed in a following section. Interspecific crossing does occur in many of the wild, small-seeded species (Kazimierski, 1964b).

Table 1. Common names, synonyms and chromosome number of the agricultural species of lupins

Species	Common names	Synonyms	2n
L. albus	White lupin	*L. termis* *L. graecus* *L. jugoslavicus*	50
L. angustifolius	Blue lupin narrow-leafed	*L. varius* *L. linifolius* *L. riticulatus*	40
L. luteus	Yellow lupin		52
L. mutabilis			48
L. cosentini	Sandplain lupin W. Australian Blue lupin	*L. varius* ssp. *varius*	32

WHITE LUPINS (*L. albus*) are erect growing annuals that branch considerably and attain a height of 0.4 to 1.4 meters. The oblong leaflets are 3.5 to 5 cm long. The flowers, white with tinges of blue that vary in intensity, are borne in terminal racemes. The pods are 6 to 10 cm long and 1 to 2 cm broad, each containing 4 to 6 seeds. The seeds are pinkish or whitish, compressed and obicular, approximately 0.8 cm wide (Bailey, 1963).

BLUE LUPINS (*L. angustifolius*) are erect growing annuals which have fine, profuse, lateral branching and grow from 0.4 to 1.5 meters tall. The terminal flowers may be blue, pink, purple or white. The pods range from 5 to 6 cm long and 1.5 to 1.6 cm wide and usually contain 5 to 6 seeds, which may be slate-grey with brown marbling and whitish spots, or rarely white, black, brown, or intermediate colors. They are smooth and spheroidal, 6 to 8 mm long and 5 to 6 mm wide (Bailey, 1963).

YELLOW LUPINS (*L. luteus*) are less erect, spreading annuals that branch strongly from the base and grow to heights ranging from 0.2 to 1.0 meter. The leaflets are intermediate between those of the above two species and may be 2.5 to 3 cm long. The flowers are always yellow and set rather hairy pods that are 5 to 6 cm long and 1.5 to 1.6 cm wide, and contain 4 to 7 seeds. The seeds are smooth and compressed and 6 to 8 mm long and 5 to 7 mm wide. They may be whitish with brown to black mottling or white in the improved cultivars (Gladstones, 1958).

Only a few cultivars of *L. mutabilis* and *L. cosentini* were observed and none were tested in replicated yield trials, therefore a full description is omitted.

1.2 ORIGIN AND DISTRIBUTION

The three main agricultural species of lupins, *L. albus*, *L. angustfolius* and *L. luteus*, are all of Mediterranean origin. *L. albus* was grown in antiquity, whereas the other two species have been taken into cultivation only recently. In spite of being cultivated by man, the above species still have many characteristics of related wild species. The main difference between the wild and the cultivated is that gigantism of both seed size and plant size has developed (Schwanitz, 1967). Various non-agricultural types have had their origins in North and South America (Gladstones, 1958).

Assuming a monophyletic origin of all lupin species, it follows that American and Mediterranean populations were once united. Separation took place in the late Cretaceous or early Tertiary era resulting in the independent speciation that gave rise to the two different populations of related species (Dunn and Gillett, 1966).

THE WHITE LUPIN (*L. albus*) was cultivated by the ancient Greeks and Romans as a green manure, for cattle feed and for human food. Its antiquity in Spain is shown by the existence of four different common names according to the province (DeCandolle, 1959). This species is widely distributed in a wild form in countries bordering the Mediterranean and in Ethiopia. It is cultivated in these areas as well as in Argentina, Central Europe and parts of the southern U.S.S.R. as a grain legume (Gladstones, 1958).

THE BLUE LUPIN (*L. angustifolius*) has been taken into cultivation only recently when compared to *L. albus*. It was sparingly used in the Mediterranean region, where it is native, without having become domesticated. It has been widely used as a coffee substitute and as human food in times of great need. It is widely cultivated in Holland, Sweden, Germany, Poland and the U.S.S.R., and finds uses in South Africa and New

Zealand, mainly for soil improvement. It is used as a forage and a grain crop for cattle or sheep feed in Florida and Western Australia (Gladstones, 1958).

THE YELLOW LUPIN (*L. luteus*) has had minimal use as a crop plant in comparison to the other two species. Cultivation has been established for a long period of time in the Western parts of the Iberian Peninsula, North Africa and Maderia (Gladstones, 1970b). It occurs naturally on the sandy soils in the Western Mediterranean including Tunisia, Algeria, Spain, Portugal, Corsica, Sardinia, Sicily and Italy. The cultivation has spread and increased throughout Northern Europe, Holland, Sweden, Germany, Poland and the U.S.S.R. It is also cultivated in South Africa, New Zealand and Florida for soil improvement and seed for animal feed, and for forage (Gladstones, 1958). The acreage in these areas has decreased steadily however, but some sporadic cultivation still occurs.

Many other species of lupins have had limited use as ornamentals, or crop plants (*L. mutabilis, L. pilosus, L. cosentini*) and are therefore omitted from this section. However, we should make some mention of the early use of *L. pilosus* in Canada. Cornut (1635) writing of Canadian plants, states that this species was used for making flour at that time.

1.3 CLIMATIC REQUIREMENTS

1.31 General Requirements

All the important agricultural species, have a long day photoperiod requirement and a variable response to vernalization. The distribution of lupins clearly displays their ability to grow over a wide range of latitudes. The main factor in their distribution seems to be temperature. They are grown as summer annuals in cool temperate climates and as winter annuals in subtropical climates (Gladstones, 1970a).

The "ecological optimum" concept as developed by Klages (1930, 1934) would be met for lupins if the following conditions prevailed; at least five months of adequate moisture, during which the mean temperature is between 15 and 25 degrees Centigrade (Gladstones, 1958). In areas where they are grown as winter annuals a lower temperature is tolerated for short periods, providing the temperatures before and after this period compensate for these lower temperatures.

1.32 Specific Requirements

Although climatic requirements are similar for all the agricultural species, minor, distinct differences exist.

The primitive Balkan progenitor of *L. albus* can withstand periodic cold temperatures in a winter cropping regime. Winter cropping in the Northern U.S.A. also suggests that this species is quite frost tolerant (Henson and Stephens, 1958). Offutt (1961) found that in Arkansas *L. albus* is more frost hardy than *L. angustifolius*. However, Hackbarth and Troll (1960) found that *L. albus* occupied a range farther south than other species under a summer cropping regime, and growth was somewhat better under warmer and dryer conditions. This varied distribution of cultivated types of *L. albus* suggests that Turesson's (1922) "ecotype concept" is operative for this species, that is, in a taxonomic Linnean species, a number of races exist which exhibit inherent differences in both morphology and physiology, however, these differences are not great enough to warrant taxonomic distinction. Gladstones (1969a) summarized its climatic requirements as follows; cool to moderately warm growing season temperatures, being fairly resistant to frost.

Hackbarth and Troll (1960) suggested that *L. angustifolius* is adapted to relatively cool growing seasons. Forbes and Wells (1966) reported that this species can tolerate frosts down to -6 degrees Centigrade and that some of the wild types can withstand frosts in the magnitude of -16 degrees Centigrade or lower. Excessively high temperatures at flowering time results in a large percentage of flower abortion in *L. angustifolius* and to a lesser degree in *L. albus* and *L. luteus* (Hackbarth, 1955). Gladstones' summary of climatic requirements is very similar to that for *L. albus*.

Henson and Stephens (1958) suggested that *L. luteus* requires a milder growing season and is less tolerant to frosts than *L. albus* and *L. angustifolius*. Kubok (1965) and Laczynska (1954) considered both temperature (vernalization) and photoperiod important in floral iniation, but the relative importance of each is not known. Gladstones (1969a) summarized its requirements as follows; mild growing season temperatures and only light frosts are tolerated.

Barbacki (1960), on the basis of greenhouse water rationing trials suggested that a difference in drought tolerance exists among the three species of lupins, with *L. luteus* more tolerant than *L. albus* or *L. angustifolious*. Gladstones (1969a) suggested that an opposite relationship exists between *L. luteus* and *L. angustifolious* under Western Australian conditions. Regardless, differences in drought resistance exist and are attributed to the branching tap root's ability to penetrate to a greater depth more quickly on light soils rather than other forms of physiological resistance (Ozanne _et_ _al_. 1965).

Excessive moisture also effects the three species differently. Gladstones (1969a) reported that *L. luteus* is the most tolerant to water logging, and Vuuren (1964) suggested that *L. albus* is the most sensitive.

1.4 SOIL AND FERTILITY REQUIREMENTS

The various species of lupins are well known for their ability to grow on sub-marginal soils that are low in fertility, such as sands and gravels. Heavy soils should be avoided since they delay the maturity of this already late maturing crop.

"Lupins characteristically grow on coarse-textured, well drained soils of acid to neutral reaction," (Gladstones, 1970b). However, they are very susceptible to alkalinity and do not grow well in soils that contain even small amounts of lime. High levels of lime in the soil will eventually result in lime induced chlorosis at some stage in the development of the plant. This type of chlorosis is usually associated with an iron deficiency, but may also reflect a manganese deficiency in some instances (Scholz, 1933, 1934).

Lupins, like other legumes, fix atmospheric nitrogen via the root nodules, therefore little or no nitrogen fertilizer is required. Gladstones et al. (1964) suggested that all lupins require much phosphate fertilization on new land, but are more efficient than many plants in utilizing phosphorous that is less readily available. Little is known about the sulphur nutrition of lupins, but many other legumes are sensitive to sulphur deficiencies.

Just as the different agricultural species have distinct differences in climatic requirements, they also have different requirements for soil and fertility.

L. albus is best adapted to mildly acid to slightly basic sandy loams of intermediate fertility and suffers less readily from lime induced chlorosis (Suranyi, 1935, Sengbush, 1937; Henson and Stephens, 1958; Hackbarth, 1953; Gladstones, 1959). It has the highest fertility requirement of the agricultural species. Lastora (1964) found that low phosphorous levels resulted in decreased yields. Little else is known about the nutrition of this species.

L. angustifolius is best adapted to moderately acid to neutral sandy loams. Its fertility requirement is lower than *L. albus* and may be grown on poor soils if properly fertilized. It is less tolerant of soil lime than *L. albus* but suffers less readily from nutritional deficiencies. It has a lower requirement for P and K than *L. albus*, but greater than for *L. luteus* (Hackbarth, 1960; Gladstones et al. 1964). Gladstones (1962, 1970b) reported that this species is susceptible to Cu deficiency, but to a lesser degree than *L. luteus*. He also suggested that it is highly susceptible to Co deficiency but not to Mo deficiency.

L. luteus is noted for its ability to grow well on very acid soils which are extremely low in fertility (Suranyi, 1935; Oldershaw, 1951; Gladstones, 1959; Hackbarth and Troll, 1960). It is extremely susceptible to lime induced chlorosis which results even if only trace amounts of lime are present in the soil. Studies by numerous authors suggest that this species rarely suffers from mineral deficiencies other than Fe or Mn on high lime soils (Gladstones, 1962; Gladstones and Drover, 1962; Gladstones et al. 1964; Gladstones and Loneragan, 1967).

1.5 CULTURAL PRACTICES

1.51 Inoculation

Lupins, like other legumes, store large amounts of protein in their vegetative parts and seeds. Protein synthesis is dependent upon organic nitrogen, which is obtained from the symbiosis between the root system and the bacterium *Rhizobium lupini*. This particular bacterium is classified into the lupin inoculation group and will not function with other legume species (Erdman, 1953).

Norris (1956) and Graham (1964) found that the lupin nodule bacterium differs in many respects from the *Rhizobium* classification. They are relatively slow growing and can survive low soil fertility and pH, therefore Graham suggests that this inoculation group be transferred to the genus *Phytomyxa*.

Nel (1960) found that inoculation is not always necessary. Yield decreased when uninoculated seed was grown on land that had not carried lupins for seven years, however no yield decreases resulted when uninoculated seed was grown on land that was cropped with lupins two years previous. McKee and Ritchey (1947) suggested that inoculation should be carried out every year, even on land previously cropped with lupins.

Schmidt (1967) found that some indigenous strains of lupin inoculum are parasitic. However, if an active strain was placed on the seed prior to planting, it prevented infection by the inactive parasitic strain. Differences in strain efficiency exist. Kretovich et al. (1972) found a correlation between intensity of respiration, cytochrome P_{450} and effectiveness of the *Rhizobium* strain. Ineffective strains had only 25% of the respiration of effective strains and contained no cytochrome P_{450}.

Cheremisov et al. (1969) also found strain differences using Nitragen inoculum.

When inoculation is not successful or if fixation is not efficient nitrogen starvation results with its usual symptoms and seed yields will seriously decrease if soil N is also low. Previous to such symptoms, inefficient fixation may be determined by exposing the inside of a root nodule to air. A blood red coloration indicates effective fixation. If nodulation is not successful a top dressing of 9 to 18 kg/ha of N or inoculum mixed with a carrier may rectify the situation (Wells et al. 1956).

Zakharchenko and Pirozhenko (1970), with pot trials, found that the percentage of the total N in the plant that was derived from fixation of atmospheric N was 82.2% and N uptake from the soil was approximately 50% of the amount applied. Gukova et al. (1971) found that nitrogen applications reduced the amount of N fixed from the atmosphere and that yields of dry matter and seed increased with increased rates of N applied. When the nitrogen applied was increased from 28 kg/ha to 280 kg/ha seed yield increased from 1.4T/ha to 2.7 T/ha. Dorosinskii (1969) found that inoculation had no effect on yield at high N levels. These studies suggest that seed yield may be limited by atmospheric N fixation or that bacterial strains used were inefficient. Gukova (1968), using pot experiments, found that increasing K fertility increased nodule number and total nodule weight, and that K deficiencies suppressed N fixation. Elevated levels of N also depressed nodule formation and the ratio of N fixed to N absorbed decreased (Posypanov, 1972).

Poor nodulation accompanied by low soil N is a major factor in reducing lupin seed yields. Poor nodulation can be a result of many factors:

1) Inefficient Rhizobial strain or low concentrations of viable bacteria in commercial inoculum preparations
2) Seeds are carefully inoculated, but planted into dry soil, which results in dessication of inoculum
3) Dessication of inoculum during the seeding operations indicated by decreased nodulation in successive drill widths
4) Toxicity of fertilizers that come into contact with the inoculum
5) Use of chemical seed treatments which are harmful to the Rhizobia

To prevent nodulation failure commercial inoculum should be kept refrigerated and seeding should be done immediately after inoculum is applied to the seed. The use of a sticking agent will facilitate adherence of the inoculum to the seed coat and increase the survival rate of the bacteria. This can be a commercial preparation, or blackstrap molasses at ½ cup per 100 pounds of seed (Wells et al. 1956; Gladstones, 1969b).

Shipton and Parker (1966), and Parker and Oakley (1965) found that the practice of lime-pelleting commonly used for many legumes decreased nodulation of lupins when inoculum was obtained from agar cultures. However, peat cultures that were pelleted did not show decreased nodulation even after storage for 61 days at 75 degrees F. This technique may be