Gesellschaft zur
Förderung der Lupine e.V.

LUPINS

CULTIVATION AND USES

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LUPINS

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Contents

Foreword

In Central Europe, three lupin species are grown for agricultural use as grain: yellow lupin *(Lupinus luteus)*, white lupin *(L. albus)*, and narrow-leaved lupin *(L. angustifolius)*, known as blue lupin.

In the years 1927-1931, the breeder Reinhold von Sengbusch laid the foundations for the development of a useful cultivated plant by finding individual lupins low in bitter substances. Bitter lupins with their very high content of toxic alkaloids had previously been used mainly as green manure to improve the soil. A great diversity of varieties, especially yellow and white lupin, made it possible to expand the areas under cultivation. The narrow-leaved lupin played only a minor role in cultivation and, due to its smaller seeds, was mainly used as green manure.

The end of the 1990s saw an enormous spread of the plant disease anthracnose, which brought both white and yellow lupin cultivation to a standstill. Since the narrow-leaved lupin has a much higher tolerance to this disease, it was possible to establish its cultivation in Germany, where, today, lupins of almost exclusively this species are being cultivated. However, the approval of new varieties of white lupin with increased tolerance to anthracnose may lead to an increase of the acreage of white lupins.

The narrow-leaved lupin is often referred to as blue lupin. This synonym originates from the time when there were only blue-flowering forms. Later, breeding made white, light blue, pink, and multicoloured varieties available.

As a native protein plant, lupins have been improved in recent years. A variety of programmes have been designed to make cultivation more attractive and create incentives for farmers to produce lupins with high economic efficiency. The loosening of crop rotation combined with a variety of positive effects for the soil are valuable side effects of lupin cultivation. An extensive network of lupin growers, consumers and scientists has been created, which investigates important practice-relevant aspects.

Other programmes have promoted the development of the extraction of high-quality protein isolates for use in food production. In addition, funding of a large number of projects has allowed to improve breeding, cultivation and utilisation.

The conditions for the cultivation of indigenous legumes and especially for the narrow-leaved lupin are better than they have been for a long time. With this revised brochure, the Society for the Promotion of Lupins wants to make its contribution to this positive development.

Special thanks go to all authors who have presented the research on breeding, cultivation, and utilisation, as well as the economic efficiency under the current conditions.

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1 Location requirements and cultivation of lupins

Peter Wehling & Anke Böhme

1.1 Species of lupin

Lupins belong to the broom-like legumes. When we refer to 'lupins' in the agricultural context, we should be conscious of the fact that this is a collective term for botanically different plant species with different demands for growth conditions. In Central Europe, there are three lupin species that can be used for agricultural grain cultivation: **yellow lupin** *(Lupinus luteus)*, **narrow-leaved lupin** *(L. angustifolius)*, also known as blue lupin, and **white lupin** *(L. albus)*. Lupins are legumes and are characterised by high protein contents in the grain and the green mass. As a result, they can be used for grain utilisation as well as the production of protein-rich green fodder.

It should be emphasised that these three annual lupin species used in agriculture should not be confused with the multi-leaved or perennial lupin *(L. polyphyllus)*, which is an ornamental plant found in gardens. Its seeds are not suitable for food purposes because of their toxicity.

The three agriculturally used species differ in their ingredients and utilisation possibilities but also in their demands for soil and climate:

Yellow lupin:
Ability to produce grain yield even at low location quality; preferred grain legume for light to very light soils with low soil pH values; suitable for producing both grain and green fodder.

White lupin:
Because of its higher demands on soil quality, a grain legume for the better locations and for areas with longer ripening time; use as forage is economically less reasonable because of the large seeds that make seed costs high.

Narrow-leaved lupin:
Medium requirements in terms of area quality; cultivation areas of diverse quality; suitable for producing grain and green fodder.

Table 1.1 summarises some key data on the suitability of the three lupin species for cultivation. Figure 1 gives an overview of the regions of Germany suitable for the cultivation of narrow-leaved lupins.

Table 1.1: **Soil and climatic conditions for an optimal yield in lupin species**

	Yellow lupin ***(L. luteus)***	**Narrow-leaved lupin** ***(L. angustifolius)***	**White lupin** ***(L. albus)***
Soil	Light soils: sands, low loamy sands	Light to medium soils: sands, sandy loams, loess loams	Medium-heavy soils: sandy loams, loess loams, black earths
pH-value of the soil	4.6–6.0	5.0–6.8	5.5–7.3
Climate	No excessive temperatures during juvenile development; dry weather during ripening; vegetation period 135–150 days (depending on variety)	Suitable for all climates in Germany, also for areas with short vegetation period; foothills, coastal areas; vegetation period 120–150 days (depending on variety)	Warm, humid spring; high yields require cool temperatures until the beginning of extended growth and good water supply for flowering; vegetation period 140–175 days (depending on variety)
Grain yield	10 to 25 dt/ha	20 to 45 dt/ha	20 to 60 dt/ha

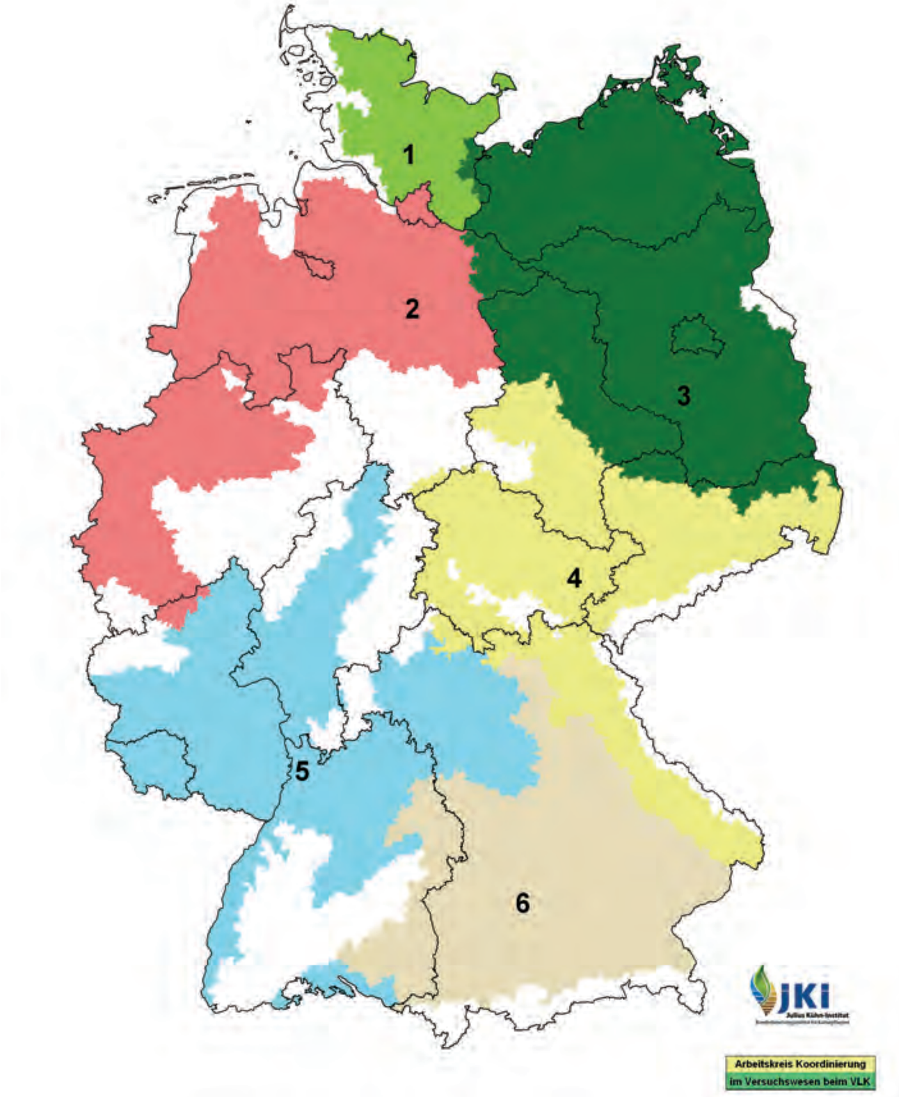

Fig. 1.1: **Cultivation areas suitable for conventional farming of narrow-leaved lupin in Germany:**

1 geest, hilly country in the north
2 sandy soils in the northwest
3 diluvial sites in the east
4 loess and weathering sites in central/eastern Germany
5 central and thermal sites in the southwest
6 hilly country in the southeast.

Image source: GeoPortal.JKI

1.2 Lupin breeding

The original, non-domesticated wild species of the three lupin species cultivated in Germany for grain use originate from the Mediterranean region and exhibit a number of characteristics unfavourable for their cultivation or use as cultivated plants, such as late maturity, high growth, and high bitter (alkaloid) content. For this reason, before the development of low-bitterness ("sweet") varieties, lupins were cultivated and used in Germany in the 19th century primarily as green manure to improve light soils. Fundamental breeding improvements were required before seeds or the plant could be used for animal or human consumption.

Between 1927 and 1931, the German plant breeder Reinhold von Sengbusch laid the basis for the development of lupins into fully usable cultivated plants by discovering plants of the yellow, white, and narrow-leaved lupin with low levels of bitter substances. These plants have an alkaloid content of less than 0.05% in the grain. From a nutritional-physiological point of view, a content of less than 0.02% is required. Today, there are low-bitterness varieties of all three species of lupin, which are adapted to German climatic conditions. The lupin breeders are also striving to reduce the low alkaloid content even further and guarantee it in the harvested crop. This requires a great deal of breeding effort and constant quality control.

As the alkaloid content of lupins is inherited dominantly, and lupins are partly cross-pollinated, crossings, mutations, or recombinations can occasionally lead to the development of bitter substance-rich plants. Therefore, the use of controlled seeds is a prerequisite for the safe use of the harvested material in the nutrition of humans and animals. We therefore urgently warn against re-growing of own seeds. Since the low alkaloid content is also inherited from various independently acting genes, the crossing of two plants whose alkaloid deficiency is determined by different genes can result in offspring with high alkaloid content. Thus, even the crossing of two low-bitter varieties can lead to seeds rich in bitter substances.

Another major advance has been achieved with the breeding of early-maturing varieties. The first cultivation trials in Germany in 1779, initiated by Frederick the Great, initially failed due to the late maturity of the forms imported from

Italy. Today, there are varieties whose characteristics can hardly be compared with these original forms. In the case of white lupin, a compact, early-maturing variety has been created by shortening the side shoots and developing terminated lines. In the case of yellow lupins, the elimination of the persistence in the rosette stage has resulted in a new type of plant (no need for vernalisation), which offers decisive advantages in terms of early ripening and arable handling. For narrow-leaved lupins in particular, the breeding of determined or terminal, i.e. unbranched, growth types, which only form the main shoot and no side shoots, has led to an improvement in stability and earlier ripening on better and higher-lying sites. In dry years, however, determined types can also have yielding disadvantages. In the recent past, the focus of variety breeding has been more on the branched growth type. Branched varieties are also suitable on light soils with limited water supply (see also Chapter 2.1).

Other important breeding objectives are stability, which is sufficient to good for most varieties, and the resistance of the pods to bursting, which can still be improved, especially in the case of narrow-leaved lupins. In white and yellow lupins, on the other hand, the pods are very burst-resistant.

A current challenge is breeding for resistance to anthracnose, a seed-borne disease caused by the fungus *Colletotrichum lupini*, which can lead to severe or even total loss of yield or seed propagation, and even lead to an official withdrawal of the propagation stock (see also Chapter 3). While yellow and white lupin varieties are highly susceptible, narrow-leaved lupin is comparatively less susceptible to infestation but is also infested when infection pressure is high. Over the last 15 years, breeding research in the genetic resources of the narrow-leaved lupin has identified a very effective resistance to anthracnose, clarified its heredity, and made it available for breeding purposes, so that the basis for breeding anthracnose-resistant varieties of this lupin species has been laid. The same applies to the yellow lupin, for which, however, there are currently no variety breeding programmes in Germany. Efforts are also being made to breed white lupins resistant to anthracnose.

In Germany, current collaborative projects funded by the Federal Ministry of Agriculture and Food are dedicated to improving the ability to grow yellow lupin (InnoLuteus project) and white lupin (LupiSmart), including the improvement of their cooling tolerance.

1.3 Lupin varieties and yields

Table 1.2 provides an overview of the lupin varieties registered in the “Descriptive List of Varieties” of the German Bundessortenamt in 2019. Their main characteristics and their areas of propagation are listed.

In 2019, ten varieties of narrow-leaved sweet lupin were registered in Germany, including four younger varieties – ‘Mirabor’, ‘Lila Baer’, ‘Bolero’, and ‘Carabor’ – from the registration years 2013, 2015, and the latter two, 2018, respectively. Two older varieties (‘Boruta’ and ‘Haags Blaue’) belong to the determinate growth type. The newer approvals show significant improvements in terms of several characteristics, in particular the grain yield, but also the protein content, the bursting strength, and the alkaloid content. The current cultivation extent of the approved varieties can be derived from the proportion of the total propagation area of lupins (Table 1.2).

In 2019, there were also two new registrations for white lupin; in total, three varieties are now approved, although only one of them has a significant area of propagation. In the case of yellow lupin, recently, there was no variety approval due to the lack of breeding programmes. As Table 5 shows, the lupin propagation area in Germany is dominated by narrow-leaved sweet lupin. The reason for this is the high susceptibility of yellow and white lupin to anthracnose, which first appeared in Germany in 1995, initially affecting white lupin stands in southern Germany and then spreading northwards, where it destroyed yellow lupin propagation stocks on a large scale between 1997 and 1999. The yellow lupin, however, has the highest crude protein content of all tested species. Its cultivation can produce economic grain yields even on the poorest sandy soils, which, although at a low level (10–25 dt/ha), are absolutely competitive with those of other crops on such sites. Breeding research activities are currently underway to improve the resistance of yellow lupin to anthracnose, the early and even maturation of yellow lupins, and to investigate its yield potential even on less extreme areas.

Table 1.2: **Varieties of narrow-leaved, white or yellow sweet lupin, which have been approved in Germany or recognised under § 55 of the Seed Act, subject to the condition that they are of value for cultivation in Germany;** characteristic ratings from 1 (low expression) to 9 (high expression) and multiplication areas (Bundessortenamt, 2019)

	Year of registration	Multiplication area 2019 (ha) *)	Bitter substance content	Determined growth	Flowering colour	Grain ornamentation	Start of flowering	Mature	Plant length	Tendency to lay down	Grain yield	Raw protein yield	Raw protein content	Thousand grain mass
Narrow-leaved sweet lupins, branched type														
Arabella	2002	--	1	1	1	3	--	--	--	--	--	--	--	--
Bolero	2018	63	1	1	3	4	3	4	3	6	7	7	5	5
Boregine	2003	1375	1	1	1	1	3	5	4	4	8	7	4	6
Borlu	2002	--	1	1	3	2	-	-	-	-	-	-	-	-
Carabor	2018	15	1	1	3	4	3	5	3	4	7	7	4	5
Lila Baer	2015	--	1	1	3	5	3	5	4	4	4	4	6	5
Mirabor	2013	30	1	1	4	2	3	5	4	6	7	7	5	6
Probor	2005	206	1	1	3	3	3	5	3	5	6	7	7	3
Narrow-leaved sweet lupins, determinated type														
Boruta	2001	166	1	9	4	3	4	4	3	4	6	6	5	3
Haags Blaue	2007	30	1	9	3	4	3	3	2	3	4	4	5	4
Narrow-leaved sweet lupins – varities, § 55 SaatG														
Salsa **)	1998	14												
total		**1900**												
White sweet lupins														
Feodora	2004	--	1	1	2	1	3	4	5	--	6	7	3	6
Frieda	2019	101	1	1	2	1	3	4	5	3	6	7	3	7
Victor Baer	2019	2	1	1	2	1	4	5	6	4	6	7	4	7
White sweet lupins – Varities, § 55 SaatG														
Boros		7												
Sonstige		29												
total		**140**												
Yellow sweet lupins – varities § 55 SaatG														
Other		22												
total		**22**												

*) To field inspection of propagation areas for basic and certified seed (Bundessortenamt, statistics on seed production 2019)

(**) Multiplication area: Certified seed

Despite the low level of breeding activity compared to other crops, narrow-leaved sweet lupin has a growing yield potential. Figure 1.2 shows that the grain yields determined in national variety trials show an increasing trend over the years of registration. At the weathering and loess sites of the national variety trials in Central Germany, average annual yield increases of 0.4 and 0.5 decitonnes per hectare and year was achieved between the approval years 1997 ('Bordako' variety) and 2018 ('Bolero', 'Carabor' varieties). In addition to other factors, such as crop improvements, breeding progress is likely to play a significant role in this development, especially since the value of the crop, which is determined by improvements in yield potential and other relevant characteristics, is a prerequisite for the approval of new varieties. When assessing the annual yield increase, it should be considered that the test years 2017 and 2018 led to significant yield decrease due to very wet weather and extreme drought, respectively. Also, in the test year 2019 there was a pronounced water shortage in middle to deeper soil layers. Thus, the yield progress achieved by varieties from more recent approval years cannot be conclusively assessed yet.

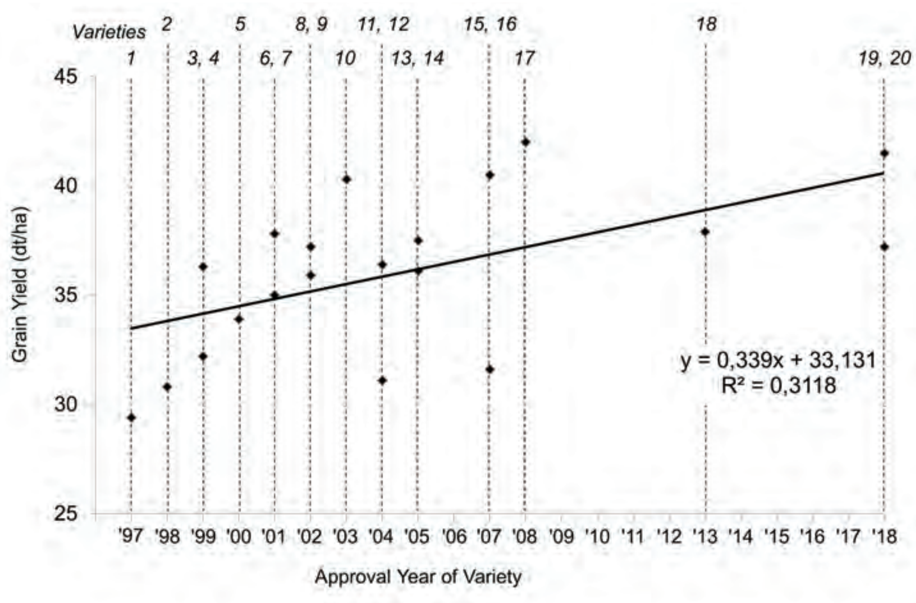

Fig. 1.2: **Yield development of narrow-leaved lupin in Germany:** average grain yields (86% dry matter (DM) according to variety approval years. Twenty varieties in total:

1	Bordako	11, 12	Baron, Vitabor
2	Sonet	13, 14	Idefix, Probor
3, 4	Bolivio, Boltensia	15, 16	Haags Blaue, Sonate
5	Bora	17	Haagena
6, 7	Borlana, Boruta	18	Mirabor
8, 9	Arabella, Borlu	19, 20	Bolero, Carabor
10	Boregine		

Loess or weathering sites in Thuringia, Saxony, Saxony-Anhalt; mean values over 4-77 test environments (test sites x years).

Data source: Test reports 2000-2019 of the Thuringian State Office for Agriculture and Rural Areas (TLLLR, Jentsch U, Günther K).

With regard to grain yields achieved in practice, narrow-leaved lupins lie between the yellow and white lupins. Their cultivation is possible on almost all soils. In normal years, their yields range between 15 and about 45 dt/ha depending on the quality of the location. In national variety trials in Central Germany, grain yields of up to 40 dt/ha and occasionally yields of over 50 dt/ha are achieved on a long-term average, whereby the yield level on loess sites, loess transition sites, and weathered sites is, at approx. 38 dt/ha on a 10-year average, noticeably higher than on D sites (approx. 24 dt/ha; Table 1.3). These figures, which in some cases differ significantly from the yields usually realised in agricultural practice, demonstrate the considerable genetic yield potential of narrow-leaved lupin and its potential when cultivated on better sites. However, the ranges in Table 1.3 also show that the yield fluctuations are high.

Table 1.3: **Grain yields (dt/ha; 86% DM) for narrow-leaved sweet lupin in national variety trials.** Yields for site categories L, V, and D averaged over test sites and reference varieties per test year.

Data sources: Test reports 2010-2019 of the Thuringian State Office for Agriculture and Rural Areas (TLLLR) and the State Research Centre for Agriculture and Fisheries Mecklenburg-Western Pomerania (LFA-MV).

	Test year									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Loess and weathering sites Thuringia, Saxony, Saxony-Anhalt (TLLLR)										
Medium L-locations	35.5	48.3	43.6	34.8	39.5	42.6	37.4	42.0	36.1	34.8
Medium V-locations	33.1	43.5	29.9	29.0	29.7	--	45.6	42.9	33.3	29.1
Medium L, V locations	34.9	46.4	40.2	32.5	37.0	42.6	39.5	42.3	35.4	33.7
Range location-mean	33.1–37.9	41.4–52.7	29.9–52.3	24.6–47.4	21.3–50.6	33.0–52.3	36.8–45.6	39.3–44.7	31.8–40.4	24.4–42.6
Diluvial sites north-east (LFA-MV)										
Mean D-sites N-O	23.0	27.8	35.4	37.1	30.7	20.0	20.3	22.1	6.0	23.0
Range	15.0–31.6	21.4–34.5	31.6–44.3	26.7–45.9	29.2–31.7	11.7–26.4	8.2–26.7	17.2–25.6	5.7–6.3	15.5–30.3

The fact that stable and attractive yields with narrow-leaved lupin are possible on medium location qualities of the D cultivation area is demonstrated by a cultivation trial lasting several years (2016–2019) under practical conditions at the JKI location Groß Lüsewitz, a site in the D cultivation area. The trial years were characterised by a very different water supply of the stands. While the cultivation year 2017 was very wet, the other years were dominated by dry stress conditions due to low rainfall, up to extreme drought in 2018. Despite these strongly varying weather conditions, yield fluctuations were moderate (Fig. 1.3). The average grain yield for the 'Boregine' and 'Probor' varieties at the location Groß Lüsewitz under practical conditions over the years 2016–2019 was 31.6 dt/ha, which is about 50% above the average grain yield determined for Mecklenburg-Western Pomerania (21 dt/ha; source: Destatis) in the same period. The results underline that narrow-leaved sweet lupin has an attractive yield potential on medium soil qualities, which can be exploited with sufficient stability under varying growth conditions through good professional practice.

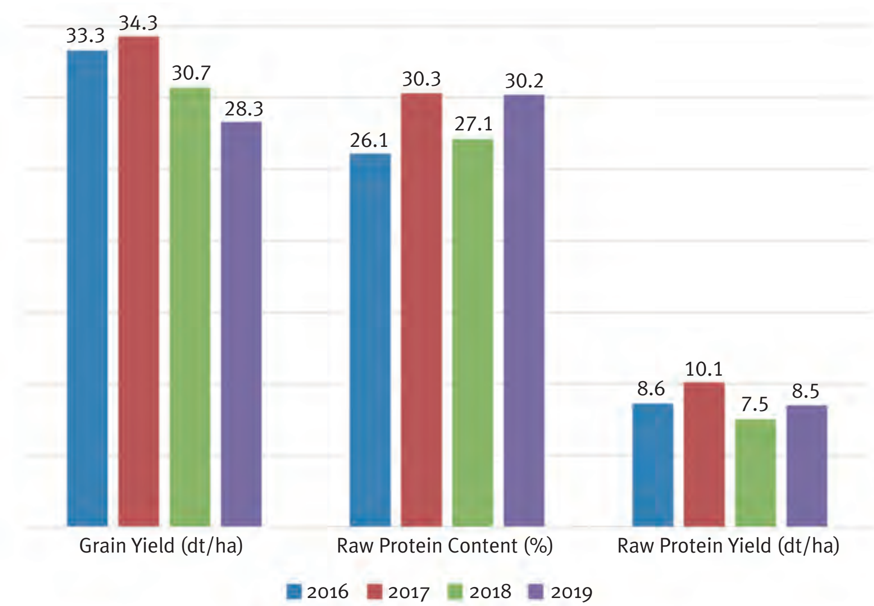

Fig. 1.3: **Cultivation of narrow-leaved lupin under practice-oriented cultivation in Groß Lüsewitz, Germany:** Average grain yields (86% DM), crude protein content (86% DM), and crude protein yields for the 'Boregine' and 'Probor' varieties in the 2016–2019 cultivation years.

Lead soil type: Sandy loam para brown soil; soil points: 40–47; usable field capacity: 60–85 mm; water holding capacity: low; soil pH: 5.8; preceding crop: ryegrass in each case; sowing: 100 K/m²; row spacing: 12.5 cm; Nmin: 26–32 kg/ha; fertilisation: none; herbicide: Stomp Aqua 2.6 l/ha; area under cultivation: 0.6–0.8 ha (without headlands) per variety and year. Image source: Roux, S., JKI.

The crude protein content and yield of narrow-leaved lupin can compete with that of other grain legumes. The crude protein content of narrow-leaved lupins in the loess and weathering sites of the state variety trials in Thuringia, Saxony and Saxony-Anhalt was on average 29.5% (86% DM) between 2010 and 2019 and thus significantly higher than that of forage peas (19.5%) and field beans (25.6%). ‘Probor’ proved to be the variety with the highest protein content, averaging 30.9%.
White lupins have the highest requirements in terms of soil quality and the heat balance. On good soils, for example, loess or loam locations, it can produce up to 60 dt/ha of grain yield and very high protein yields. On sandy soils, it usually does not achieve grain yields of more than 20 dt/ha. The yield fluctuations are very high. An advantage is the absolute resistance of the pods to bursting. However, the opportunities for significant cultivation of white lupin in terms of area are likely to arise with the breeding of anthracnose-resistant varieties.

1.4 Lupin acreage

Until the mid-1990s, lupin cultivation in Germany was dominated by white and yellow sweet lupin. As already mentioned, the areas under cultivation of these two lupin species decreased considerably with the appearance of anthracnose, and they have hardly any cultivation significance today. With the introduction of anthracnose-tolerant narrow-leaved lupins in 1997, there was a further increase in the area under cultivation at the end of the 1990s. However, due to a lack of profitability compared to market crops such as cereals and oilseed rape, the cultivation of lupin and other large-grain legumes or pulses declined again in the 2000s. This trend could not be stopped by the EU grain legume premium (55.57 euros per hectare until 2008) or by various support programmes of the federal states. With the implementation of “greening” in 2015, the cultivation rose slightly again, but the discontinuation of pesticides in greening relativised the positive trend (Fig. 1.4).

In contrast to the other grain legumes, lupin cultivation is regionally concentrated in the federal states of Brandenburg, Mecklenburg-Western Pomerania, and Saxony-Anhalt. These regions have a high proportion of sandy soils and low pH values, which is particularly conducive to the growth of lupins (Table 1.4).

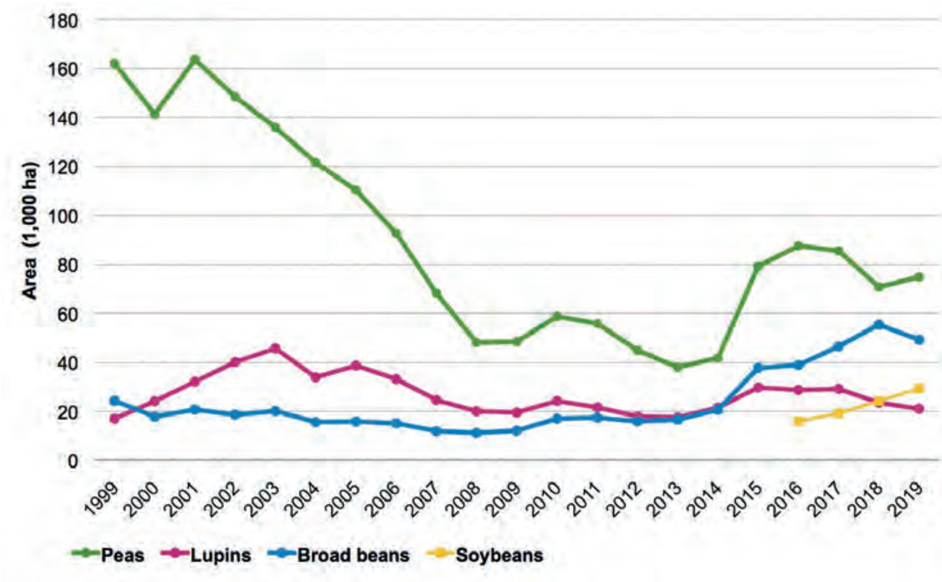

Fig. 1.4: Cultivation of grain legumes (or pulses) in Germany 1999–2019.
Data source: Destatis.

Table 1.4: **Area under grain legume cultivation in Brandenburg, Mecklenburg-Western Pomerania, and Saxony-Anhalt 2014–2019** (area under cultivation in 1000 ha).
Data source: Destatis.

Federal State	2014	2015	2016	2017	2018	2019
Brandenburg	10.6	14.3	12.9	12.3	10.0	8.5
Mecklenburg-Western Pomerania	2.8	5.2	6.2	6.7	5.2	5.3
Saxony-Anhalt	5.6	6.3	5.3	5.4	5.0	3.4
Germany	21.4	29.6	28.6	29.0	23.4	20.9

2 Cultivation technique

Bernd Schachler & Jens Bojahr

2.1 Location

The choice of location is crucial for successful lupin cultivation. The pH value of the soil should be the main factor in the choice of location (Table 1.1). Soils with stagnant moisture and also shallow soils are less suitable for cultivation.

Since yellow and white lupin have a fairly long growing season (Table 2.1), locations that allow a reliable harvest in September to October should be chosen. If early harvesting is a decisive criterion for cultivation, only narrow-leaved lupin can be grown. Due to the different growth forms, varieties that cover a very broad spectrum of ripening are available. Terminal forms usually ripen more evenly and more reliably. They should be in particular cultivated on good soils, in areas with high rainfall, and in low mountainous areas. In the case of the branched forms, constant new sprouting occurs when grown in the above-mentioned regions and thus varying degrees of ripening can be observed. They are therefore more suitable for drier locations.

Table 2.1: **Growing period of cultivated lupin species**

Species	Days from sowing to harvest
Narrow-leaved Lupin	110–130
Yellow Lupin	150–170
White Lupin	170–190

The cultivation method is very similar for the three species. Since yellow and white lupins only play a minor role in practical cultivation, the following points primarily concern narrow-leaved lupin. However, fundamental differences are pointed out.

2.2 Crop rotation

Fig. 2.1: Root system of a narrow-leaved lupin.

Lupins are nitrogen collectors and contribute to the structural improvement of the soil through their strong, widely branched root system. All three species have a long taproot (Fig. 2.1), which enables them to absorb nutrients and water even from deeper layers of soil. Furthermore, they are able to recover phosphorus, which is difficult to access, and thus make it available.

The inclusion of lupins in crop rotation has a very positive influence on the entire cultivation system. The most important factors are the high nitrogen fixation and the supply of nitrogen for the following crops. Humus enrichment and the resulting improved soil structure and soil fermentation are further positive preceding crop effects. Fewer working steps and easier workability due to improved soil structures lead to a reduction of work completion costs.

The economic performance of the lupin (see also Chapter 5) thus extends not only directly to the subsequent crop, but also to other crop rotation units and thus to the entire crop rotation. The more one-sided the crop rotation and/or the lower the soil fertility of the location, the higher the crop rotation effect can be rated. In organic farming, lupins are an indispensable source of nitrogen, and the preceding crop effect can be rated even higher here.

The most favourable subsequent crops are winter cereals and winter rape. The valuable nitrogen is utilised by the subsequent crop and is therefore not washed out. However, if during the summer season lupins are planned as the main crop, a fast-growing cover crop must be drilled in any case. Mustard, oil radish, and phacelia are particularly suitable in this case. These crops utilise and bind the nitrogen so that the risk of leaching is minimised.

The three lupin species should not be grown too frequently in the crop rotation. Breaks in the cultivation of more than four years must be respected. With closer crop rotations, there are severe yield losses due to a number of fungal pests but also due to increased weevil infestation (see also Chapter 3).

The lupins have little requirements on the preceding crop. Cultivation after potatoes is not recommended as increased levels of *Rhizoctonia* infection is to be expected. The same applies to maize with regard to fusariosis. In crop rotations with rape, an infestation with *Sclerotinia* can have negative effects on the yield.

2.3 Nutrition

Fertilisation with the basic nutrients is required from supply stage C in conventional cultivation and from stage B in organic cultivation.

As there is a risk of potassium leaching, depending on the soil type, fertilisation should be applied directly to the lupins, especially on light and permeable soils. Grain legumes have a high overall requirement for sulphur. It is therefore recommended to apply 20–30 kg S/ha. This can be done in combination with potassium fertilisers containing sulphur.

As nitrogen collectors (Table 2.2), lupins are not given nitrogen fertiliser in any form. With the addition of nitrogen, the free factor of biological N-fixation would be significantly reduced. Thus, a great advantage of lupin cultivation would be lost. In addition, nitrogen fertilisation would strongly promote weed growth, delay ripening, and thus significantly worsen harvesting conditions. These aspects apply equally to organic fertilisers, such as manure and slurry.

Table 2.2: **Benchmarks for nitrogen fixation in grain legumes**

Adapted after: Körnerleguminosen anbauen und verwerten. (2013) KTBL 100, Darmstadt, KTBL.

Species	Grain yield 86% DM (t/ha)	N-content in grain (kg N/t FM)	N-with-drawal (kg N/ha)	N-fixation (kg N/ha)	N-Saldo (kg N/ha)
Narrow-leaved lupin	2.5	48	120	150	30
Yellow lupin	1.5	61	92	114	22
White lupin	2.5	52	130	163	33
Grain peas	3.0	35	105	123	8

2.4 Inoculation with nodule bacteria

Lupins are supplied with the necessary amount of nitrogen through symbiosis with nodule bacteria. These bacteria are specific for different legumes, and for lupins it is *Bradyrhizobium lupini*. They must be present in the soil in sufficient numbers to allow a safe infection of the plants. On sites where lupins have never been grown or have not been grown for more than 8 to 10 years, vaccination with the bacteria is a prerequisite for a safe yield.

The bacteria are nutritionally dependent on the plant. The plant provides organic carbon compounds to cover the energy requirement for nitrogen fixation. These substances originate from the photosynthesis of the plant. By breaking down the compounds, the bacteria acquire energy for splitting and reducing the nitrogen molecule. This reaction is extremely energy-intensive. In return, the bacteria supply plant cells mainly with ammonia (NH3) as the first stable product of nitrogen fixation, which is converted to ammonium ions (NH_4^+) in an aqueous environment. However, ammonia is a strong cell poison. In order to prevent ammonia accumulation in plant cells, it is immediately used for the synthesis of glutamine and glutamic acid (ammonia assimilation).

Many experiments have made it clear that efficient cultivation is only possible through vaccination if no bacteria are present in the soil. Increased yields and significantly higher crude protein content have been proven to be the effects of the vaccination.

If vaccination is not carried out, the plants show signs of nitrogen deficiency, which indicates the lack of colonisation with bacteria (see Figures 2.2 a/b).

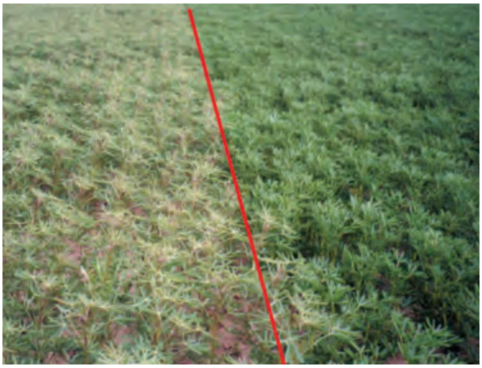

Fig. 2.2 a: Lupin cultivation without bacteria (left) and with bacteria (right).

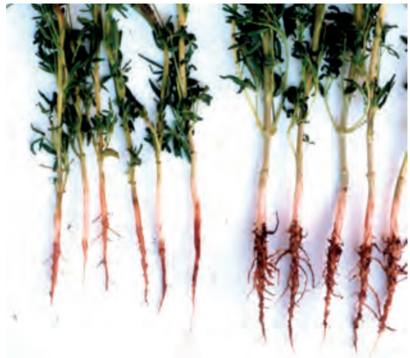

Fig. 2.2 b: Lupin plants without bacteria (left) and with bacteria (right).

The activity of the bacteria can be checked by cutting a root; a reddish colouring is a sign of their presence.

Two vaccines of practical relevance are currently being developed for cultivation. These are the preparations HiStick (BASF) and RADICIN Lupin (Jost GmbH). Up-to-date information can be found on the website www.lupinenverein.de.

2.4.1 HiStic

HiStick is a bacteria-containing peat substrate. It is usually packaged in a 400 g foil bag, which is sufficient for 100 kg of seed.

It can be filled directly into the seed drill as dry inoculation. Care should be taken to ensure that it is distributed as evenly as possible. For moist inoculation, the seed is wetted with approximately 200 ml water per 100 kg seed and mixed with the substrate. For suspension inoculation, one bag of HiStick is mixed with 800 ml water evenly and lump-free. The corresponding amount of seed is then evenly coated in a suitable mixer.

HiStick can be stored in the sealed bag for approximately two years after the date of manufacture. Opened packages should be used within a few hours.

Treated seed should be stored dry, cool and above all dark, but can nevertheless only be stored for a short time.

2.4.2 RADICIN Lupin

RADICIN Lupin is a liquid suspension available in 75 ml and 400 ml packaging units. For one hectare of cultivated area, 75 ml suspension is required.
The application is made with 300 to 400 l water/ha directly before or after sowing. Due to the high UV sensitivity of the bacteria, they should be worked into the soil immediately after the application.

RADICIN Lupin can be stored for approximately six weeks and should only be opened immediately before application.

2.5 Tillage

Lupins can be regarded as fairly undemanding crops, but this does not mean that they can do without a good arable crop condition of the field. Lupins have little competition and can only thrive well where the condition of the soil allows it.

In both conventional and organic farming, all arable measures must be designed to keep weed pressure as low as possible. There are only very limited possibilities for weed control, and these must be supported by choice of field, tillage measures, sowing time, and sowing methods.

Soil preparation should, if possible, begin with the autumn furrow in the previous year. Especially on sandy soils, deep tillage in spring is always associated with high water losses, and a large part of the winter moisture is lost.

Deep tillage would promote a renewed weed seed potential into the upper soil layers. Therefore, seedbed preparation should be done shallow because in this way germinated or germinating weeds would be destroyed, and it would also mean that water loss would be low. The seedbed should be finely crumbled and well deposited to ensure even placement depth. In organic farming, a longer period of time may well be left between seedbed preparation and sowing in order to control re-growing weeds during sowing.

2.6 Sowing

Lupins germinate at low temperatures and are tolerant of frost down to –7° C depending on the species. Early sowing promotes generative growth, the plants are smaller, and the possible yield potential is higher. Late sowing leads to increased vegetative growth, and as a result the green mass increases and the grain yield is lower.

The date of sowing should not be chosen according to the calendar alone, but should be more closely related to the soil temperature. Early sowing in cold soil means longer emergence times, but weed seeds are also not yet in germination mood and cannot be controlled either mechanically or with herbicides. In order to have optimum sowing conditions, a later sowing date is definitely to be accepted. The upper limit for sowing could be around 10 April. Yellow lupins have a variety-specific need for vernalisation and are therefore dependent on early sowing.

Lupin germination is called epigeal, i.e. they push the cotyledons over the ground. Flat sowing of 2–3 cm is therefore necessary. The seeds must be evenly covered with soil, otherwise the seeds on the top will germinate poorly. Deeper sowing leads to uneven emergence and to yield depressions. The row spacing is the same as for cereals. Row spacing of more than 30 cm makes sense, but places particularly high demands on soil cultivation, weed management and sowing technique.

The sowing rate depends on the corresponding species and growth type. The following table 2.3 shows the sowing rates in grains/m² for the lupin species.

Table 2.3: **Recommended sowing rates in grains/m²**

Yellow lupin	White lupin	Narrow-leaved lupin branched shoot	Narrow-leaved lupin determined shoot
80–100	60–70	80–90	110–120

The seed requirement is calculated using the following formula:

$$\text{kg/ha} = \frac{\text{grains / m}^2 \cdot \text{TGW (g)}}{\text{germination ability (\%)}}$$

2.7 Weed control in organic farming

The basic requirements for good weed control are good crop rotation, targeted selection of areas with no root weeds, and weed control that starts as early as autumn.

With a false seedbed, weeds can be stimulated to germinate even before sowing in spring and thus reduce weed pressure as a preventive measure. For this purpose, a seedbed preparation is carried out two to four weeks before sowing. For optimum germination of the weeds, the crumb should be moist and finely crumbly, and the soil temperature should be above 8° C. The actual sowing achieves the best control success in the thread to the cotyledon stage of the weeds.

In the pre-emergence as well as in the 4–5 leaf stage, the use of a harrow is possible (Fig. 2.3). As the plants are very sensitive directly after the emergence, treatment is not recommended in this case. The use of hoes requires wide row spacing. Both mechanical measures should always be carried out in dry weather with slightly wilted plants, preferably at midday.

Fig. 2.3: Lupin plot before (left) and after (right) the harrow has been used.

2.8 Chemical weed control

In Germany, only a few substances are available for chemical weed control. For optimum effect, the pre-emergence agents require not only sufficient soil moisture but above all a clod-free, uniform seedbed. As the effect of the herbicides is limited in time, the time of application and the emergence of the weeds must match. This is the case when the seed is sown in a warm, slightly moist soil and the lupins as well as the weeds can emerge quickly. Therefore, as already mentioned, a slightly delayed sowing date should also be accepted for optimum effect.

Tillage, sowing, and sowing dates must be scheduled and carried out in such a way that the herbicides have the best conditions for their effect. Chemical post-emergence treatment against dicotyledonous weeds is not allowed in Germany. The pre-emergence treatment must be carried out shortly after sowing, and the lupins must not yet have lifted the soil. Afterwards, these agents sometimes cause severe damage. Only agents with a graminicidal effect are permitted in the post-emergence period.

2.9 Harvest

The lupin species differ significantly in their vegetation period. The narrow-leaved lupin needs the shortest time to ripen. Due to the cultivation on good soils, white lupin has a very long growing season. The vegetation period of the yellow lupin lies in between but is much longer than that of the narrow-leaved lupin.

Yellow and white lupin are both very burst-resistant, while narrow-leaved lupin has only moderate burst resistance and must under no circumstances be allowed to grow over. It should therefore be threshed as accurately as possible to the day, especially in warm and dry summers. In order to minimise losses due to breakdowns, the very hot midday hours should be avoided, and threshing should preferably be carried out in the morning and evening. It is essential to check the current approvals for the problem of siccation.

For heavily weedy stands, the use of a screen in the transverse screw conveyor (Fig. 2.4) has proven to be very effective. Under dry conditions, melliferous and knotweed seeds in particular are well screened, and the crop is much cleaner (Fig. 2.5).

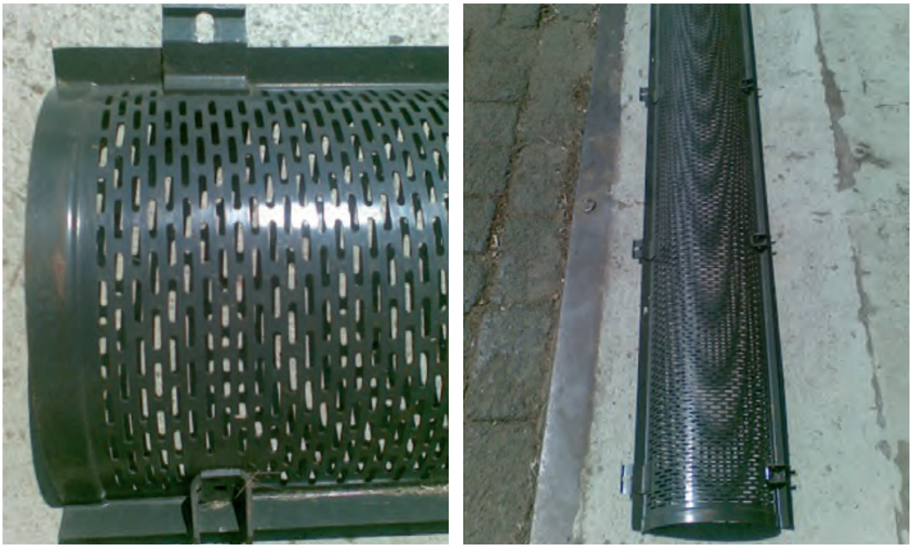

Fig. 2.4: Inserting of a special sieve into the transverse auger of the combine harvester (perforated Claas grain pan).

Fig. 2.5: Lupin harvest result without grain pan (left) and with grain pan (right).

Threshing should be carried out gently to avoid broken grain. This is particularly important in the field of seed production to ensure a high germination capacity. However, the production for the feed and food industry also requires high raw material qualities. Broken grains lead to increased fungal contamination or to oxidation of the oils contained and thus to significantly poorer quality.

In contrast to the instrument shown here (Fig. 2.6), the grain moisture meters available on the farms (Pfeuffer HE 50 etc.) are usually not designed for lupins. The measurement with other legume settings is inaccurate and can only give a clue. Grinding should be carried out three times in order to obtain good and uniform consistency of the lupin flour. Depending on the consistency and appearance of the ground material, a rough indication of the moisture content can be given (Fig. 2.6 a–c).

Fig. 2.6 a: **Measurement of the moisture content of a lupin sample with 20.5%**

- Humidity > 19%
- The ground material is stuck together
- Difficult to detach from the measuring cell

Fig. 2.6 b: **Measurement of the moisture content of a lupin sample with 16.5%**

- Humidity 15–18%
- Lupins are only partially ground
- Whole grains have imprints from the measuring cell

Fig. 2.6 c: **Measurement of the moisture content of a lupin sample with 14.3%**

- Humidity < 15%
- Lupins are completely ground
- Grains crack audibly during grinding

3 Fungal diseases and pests and their control

Christine Struck

3.1 Fungal diseases

Lupins can be attacked by numerous plant pathogenic fungi. Only the most important pathogens that cause diseases leading to high yield losses are described here. These include primarily soil-borne (or crop rotation) pathogens, such as *Fusarium* and *Sclerotinia* species, *Pythium* spp., *Rhizoctonia solani* and the pathogen of black root rot *Thielaviopsis basicola*. Furthermore, the grey mould *Botrytis cinerea* is described as well as anthracnose caused by *Colletotrichum lupini* which is already mentioned in Chapter 1. The foliage disease grey leaf spot, caused by *Stemphylium botryosum*, and the pathogenic fungus *Pleiochaeta setosa* causing root rot and brown leaf spot, rarely have a high incidence in Germany.

3.1.1 Root and stem rots

***Fusarium* wilt of lupin**

Among the *Fusarium* species that cause root and wilt diseases of lupin plants, some of which lead to considerable yield losses, *F. avenaceum* and *F. oxysporum* are the most important. Both are considered to be seed- and soil-borne and develop in the seed root if the seed is contaminated. If conditions are too moist and unfavourable for the plant, this can lead to the death of the seedlings. However, the pathogens mainly penetrate the plant, starting from spores or mycelium residues from the soil via injuries to the roots or stem base. From there, they then colonise the vascular tissue, resulting in reduced water and nutrient supply. The typical symptoms only become visible relatively late. The plant shows signs of wilting and red discolouration of the leaves (Fig. 3.1) and remains stunted; roots show browning (Fig. 3.4; root rot). *F. avenaceum* in particular also causes pod rot.

Fig 3.1: Narrow-leaved lupin plant showing lupin wilt.

Sclerotinia basal stalk rot

Sclerotinia sclerotiorum is a soil-borne pathogen with a broad host spectrum, which includes all legumes and sunflowers, and especially oilseed rape. Under high infection pressure and warm and humid conditions, infestation leads to seedling death. However, the main time of infection is later, when ascospores, which have developed in the apothecia on the ground, reach the plant through rain drops. In warm weather and at very high humidity, the fungus can develop on dying leaves/flower petals and colonise the stem from the attachment points of the leaves or side shoots. The stem becomes soft, and white fungal mycelium becomes visible. The plant parts above this point are no longer supplied with water and nutrients and begin to wilt and mature prematurely. Black, hard sclerotia are formed in the stem and sometimes also in the pods, which can survive in the soil. Cereals are not attacked by this pathogen and are therefore considered a suitable secondary crop.

Other root and stem rot pathogens

In addition to the pathogens mentioned above, other pathogens are important as causative agents of root and stem rot, such as *Pythium* spp., *Thielaviopsis basicola* (pathogen of black rot or root rot of many vegetable species), and *Rhizoctonia solani*, all of which cause quite similar symptoms. These are soil-borne pathogens which cause damage to the seedlings or even lead to their fall and to dark constrictions or browning at the base of the stem and/or root (recognisable as an "eye spot" in *Rhizoctonia*). In later stages of lupin development, brown or black discolouration or marbling at the stem base or root becomes visible (Fig. 3.4). The plants show signs of wilting, yellowing, and stunted growth. Direct control of these pathogens is hardly possible. The most important thing here is to maintain a wide crop rotation.

3.1.2 Anthracnose

The disease is caused by the pathogen *Colletotrichum lupini*. All three lupin species are affected, but while it can cause considerable losses up to total failure in yellow and white lupins, narrow-leaved lupins are less susceptible. Significant losses can occur in this species if the infected seed has been used and if, in addition, optimal warm and humid infection conditions are available for the fungus. All parts of the plant above the ground can be affected. Young plants leave the leaves hanging, in addition constrictions on the leaf stalks appear. These plants often die off. In older plants, the typical brownish, sunken “focal spots” are visible. In addition, the stems are twisted, leaves wilt, and leaf stalks bend. Burn marks are also visible on the pods, and they can also appear deformed. The fungus survives on and in the seeds. The sowing of these seeds causes primary infections in the crop.

3.1.3 Grey mould *(Botrytis cinerea)*
A grey mould infestation occurs in dense stands or in conditions with very high humidity and low air circulation, primarily in the late flowering period via infection of the dead petals or wounds. The conidia of the fungus spread mainly with the wind. The infested plant parts (leaves, stems, or pods) first turn greyish-green, and then the typical grey mould develops. Pod infestation in particular can lead to considerable harvest losses.

3.1.4 Control options for fungal diseases
In order to prevent and control fungal diseases in lupins, the use of healthy and dressed seed is the first priority. The active ingredient azoxystrobin is approved for the control of anthracnose. However, a severe infestation by anthracnose of yellow and white lupins has not been properly controlled.

A very heavy infestation with *Sclerotinia* by plant residues on the soil can be controlled with the parasitic fungus *Coniothyrium minitans* (commercial preparation: Contans WG) before sowing or directly after harvesting. The product is only effective if sufficient moisture is available.

3.2 Pests

3.2.1 Lupin weevils
The narrow-leaved and white lupins, both sweet and bitter varieties, are the preferred host plants of the weevil species *Charagmus gressorius* (synonym: *Sitona gressorius*) and *C. griseus* (synonym: *S. griseus*) (Fig. 3.2). These beetles can mainly be found on sandy sites. In a large number of trials, yield losses of 26–58% compared to non-infested stands could be determined (Ströcker et al., Arthropod-Plant Interactions 7,579–589, 2013). In spring, the beetles fly from their winter quarters into the emerging stands and cause the typical notches by feeding of leaf margins (Fig. 3.3). The resulting damage is often hardly noticed in the stand due to its insignificance. The serious economic damage

Fig.3.2: **Lupin leaf weevils *Sitona griseus* (left) and *S. gressorius* (right).** The common lupin weevil (left) appears in varying shades of colour between brown and grey; the large lupin weevil (right) is characterised by the bright centre line on the neck label.

results mainly from weevils feeding on root nodules (Fig. 3.4 and 3.5), which is caused by their larvae. This results in nitrogen loss and the creation of entry points for a number of fungal pests, which lead to root and stem rot (see above).

Control of the leaf beetles is only beneficial in the very early stage of the lupin development (up to about the 4-6 leaf stage) before the egg deposition. It is difficult to determine the actual infestation situation because the female beetles lay numerous eggs from which larvae can develop even if an only minor damage is done to the leaves; for this reason, the damage to the roots can be much more severe than that of the leaves.

Fig.3.3: Leaf notches caused by weevil feeding.

Fig.3.4: Root damage caused by nodule feeding of the lupin weevil larvae (left) and the secondary infestation with root rot fungi (right).

Fig.3.5: Detail of a lupin root with nodules eaten by larvae of lupin weevils.

3.2. Aphids

Three aphid species colonise lupins and can lead to yield losses: black bean aphid (*Aphis fabae*), green pea aphid (*Acyrthosiphon pisum*), and lupin aphid (*Macrosiphum albifrons*). Damage is caused, on the one hand, by assimilate deprivation and, on the other hand, by the released honeydew, which leads to the colonisation by fungi. Above all, however, aphids are important as vectors of various viroses. Control is only useful when colonies are formed.

4 Options for lupin utilization

Antje Priepke & Annett Gefrom

4.1 Utilisation of narrow-leaved lupins in animal feed

4.1.1 Feed value of narrow-leaved lupins

In feeding, narrow-leaved lupin is in direct competition with soya extraction meal (SEM, whose crude protein content of around 44% (in 88% dry matter (DM)) is not matched by any domestic grain legumes/pulses. If, however, imported soya is to be deliberately avoided, e.g. in the organic sector or the non-GMO market sector or if more emphasis is placed on regionally produced fodder, there is no way around domestic grain legumes.

The advantages of narrow-leaved lupin over other grain legumes are evident: with an average protein content of 30% (in 88% DM), it has the highest protein content of all grain legumes, ahead of field beans and peas. Yellow and white lupin reach even higher protein contents (on average 38 and 33%, respectively), but, as already emphasised in Chapter 1, the cultivation of these two species is very limited due to the anthracnose problem. New varieties of white lupin and novel breeding approaches to make yellow lupin suitable for cultivation again give hope that it will be possible to utilise these species again in the future.

The protein content of lupins can vary considerably depending on variety, location, and year of harvest, as shown by the grain legume monitoring of UFOP (2016) and evaluations of the LUPIN NETWORK (2019). The harvest samples analysed in four years from five federal states in Germany yielded average values of 32-34% for the narrow-leaved lupin in relation to 88% DM, whereby the range was very wide with values between 23-40%. For a protein supply in line with demand, it is therefore essential to use current analysis results when planning rations.

In contrast to the broad bean and pea, lupins contain little starch (polarimetric determination according to the VDLUFA method), which means there is no displacement of low-priced grain from the ration. By enzymatic analysis it could be shown that lupins are starch-free per se and that the classically reported starch belongs primarily to the non-starch polysaccharide (NSP) fraction.

Compared to the other grain legumes, lupin has a significantly higher content of crude fibre and neutral and acid detergent fibre (aNDFom and ADFom). Nevertheless, the crude fibre is highly digestible for ruminants due to its low lignification.

In the case of monogaster, the high content of non-starch polysaccharides (an average of 390 g/kg at 88% DM) is often described as restricting the use of the product, as these carbohydrates are enzymatically indigestible and can only be broken down in the large intestine to form gases. At the same time, they have the ability to coat nutrients, reduce digestibility and thus the energy content, as well as increase the viscosity of the digestion pulp. The NSP composition of lupin differs significantly from that of cereals. While the anti-nutritive effect of the less branched polysaccharides of cereals is known with regard to the increase in viscosity, there is less scientific evidence for the higher branched lupin NSP with regard to the effects in animals. In this case, negative effects on feed intake, nutrient digestibility, and energy supply capacity were primarily demonstrated in poultry. In contrast, the fibre supply in pigs is now assessed differently in terms of intestinal health and well-being than it was a few years ago. A certain amount of colon fermentable fibre can support a healthy intestinal flora.

It is also known that lupin fibres have a high water-binding and swelling capacity, which makes lupins interesting for human nutrition or industrial use. In pig feeding, this property leads to a higher volume of digestive slurry and longer satiation, which contributes in certain proportions to the well-being of the animal. Among the usual ration proportions, no negative effects of NSP can be assumed.

Another characteristic feature of lupin is its high fat content, which, on the one hand, has a positive effect on the energy content, but, on the other hand, must be considered when feeding lambs and dairy cows. The high content of unsaturated fatty acids (PUFA) is nutritionally advantageous and can also have a positive influence on the fatty acid pattern of the milk. With regard to meat quality, however, it must be considered in pig feeding if other components with high PUFA contents are fed. The nutrient content and digestibility of narrow-leaved lupin result in high energy values for pigs. In ruminants, the energy value even exceeds the soy extraction meal (SEM; Tab. 4.1), whereby in some cases even higher values of approximately 8.2 MJ NEL/kg and 9.2–9.4 MJ NEL/kg were determined for lupin in mutton trials. In contrast, the energy value for poultry is relatively low, mainly due to the high NSP content.

Tab. 4.1: **Comparison of the nutrient and energy content of protein feedingstuffs (kg in 88% DM)**

		SEM	Rape extraction meal (REM)	Narrow-leaved lupin	Broad bean	Pea
Raw ash	(g)	60	68	32	35	33
Raw protein	(g)	440	335	295	264	220
Raw fat	(g)	13	26	48	14	13
Raw fibre	(g)	60	114	143	77	57
aNDF om	(g)	167	275	223	135	92
ADF om	(g)	106	191	187	111	70
Starch	(g)	60	0	53	365	418
Sugar	(g)	95	71	49	35	53
ME_{Pig}	(MJ)	13.0	9.8	13.5	13.0	13.8
$ME_{Poultry}$	(MJ)	9.5	7.0	7.8	11.1	11.5
ME_{Cattle}	(MJ)	12.1	10.6	12.5	12.0	11.8
NEL_{Cattle}	(MJ)	7.6	6.5	7.8	7.6	7.5
UDP	(% XP)	30	35	20	15	15
nXP	(g)	259	222	193	171	163
RNB	(g)	+30	+18	+16	+15	+9
Calcium	(g)	3.0	7.7	1.8	1.2	0.9
Phosphorus	(g)	6.4	10.6	2.8	4.8	4.1
Sodium	(g)	0.2	0.5	0.4	0.2	0.2
Magnesium	(g)	2.7	5.2	1.7	1.4	1.3

- Nutrient content: DLG Futterwerttabelle Schwein 2014
- Nutrient digestibility in ruminants and UDP: DLG-Futterwerttabelle Wiederkäuer 1997 bzw. für REM und SEM updated (DLG 2011)
- ADF and aNDF of grain legumes: UFOP-Monitoring 2015

The mineral content of the grain legumes is characterised by lower calcium and phosphorus contents compared to the extraction meal. This is an advantage in P-reduced feeding methods. The UFOP grain legume monitoring (2015) shows higher Ca and P values as well as lower Na values for the narrow-leaved lupin than tabulated. This needs to be pursued further.

The protein value in ruminants is primarily determined by the degradability in the rumen (UDP = protein not degradable in the rumen). This is somewhat lower in narrow-leaved lupins than in peas and broad beans (UDP 20 and 15% of XP, respectively), although here, too, considerable ranges were found by laboratory analysis. In combination with the high energy content, the content of usable protein (nXP) of narrow-leaved lupin is also slightly higher than that of other domestic grain legumes, but significantly below the SEM. At high milk yields, the relatively low UDP and medium nXP content of untreated lupins can reduce performance. Furthermore, the high ruminal nitrogen balance (RNB) value has to be considered when calculating the ration.

In pig and poultry feed, protein quality is characterised by the amino acid composition and digestibility. Like all domestic grain legumes, lupin protein has a low content of sulphur-containing amino acids, which is why a combination with oilseed rape products makes sense. Considering the comparatively high protein content as well as the high praecaecal (pc) amino acid digestibility of the narrow-leaved lupin, the content of praecaecally digestible methionine+cystine, threonine, and tryptophan per kg (in 88% DM) is slightly higher than in other domestic grain legumes (Fig. 4.1) but significantly lower than in soybean meal (SEM). To replace 1 kg of SEM, about twice the amount of narrow-leaved lupin is needed for the equivalent replacement of lysine and sulphur-containing amino acids.

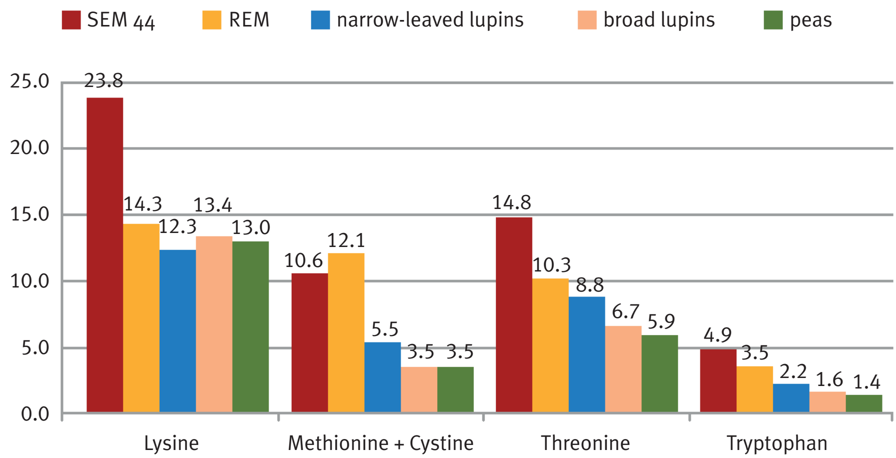

Fig. 4.1: Contents of praecaecally digestible amino acids of grain legumes (g/kg in 88% DM) (according to DLG Futterwerttabelle Schwein 2014, lysine REM from UFOP monitoring 2014).

When assessing the feed value and setting maximum limits for use, the content of specific anti-nutritive substances must be taken into consideration in addition to the nutrient and amino acid content. In addition to the already discussed NSP, the level of alkaloids has been significantly reduced to a point below of 0.05% in narrow-leaved lupin, making it possible to use this sweet lupin also in monogastric feeding. As already mentioned in Chapter 1, care should be taken when re-growing your own lupin as increased alkaloid contents cannot be excluded. Also, special annual or weathering effects seem to allow increased alkaloid content. In case of doubt, at least a simple, quick test (iodine-iodine-potassium test) should be carried out to exclude very high contents.

4.1.2 Conservation process

Uneven ripening is a common problem in lupin cultivation. With residual moisture contents of > 12–14%, mould may quickly develop, which is why preservation is necessary to maintain storage life.

The simplest, but often also one of the most cost-intensive variants, is drying, which can be carried out both in classic drying plants and using biogas waste heat. In addition, grain legumes can be preserved with the aid of acids, for which purpose propionic acid-containing agents are usually used, sometimes mixed with other acids. The dosing recommendations are usually only available for grain. A cautious estimate is that the recommended dosage can be applied to grain maize with an additional 20–30%. Preservation with sodium hydroxyde solution and feed urea is also possible, but similarly to acid treatment, it requires sensitivity and a Hazard Analysis Critical Control Point (HACCP) concept.

Lactic acid silage is also interesting in the context of on-farm utilisation. For this purpose, moisture contents of approximately 35% are recommended in order to ensure sufficient formation of stable lactic and fermentation acids. When harvesting at the end of dough ripening, no loss of feed quality is to be expected. It is also possible to rewet dry harvested material for ensiling later (Gefrom, Dissertation University Rostock, 2012). The method of tubular ensiling is preferred for ensiling dehydrated lupin grains.

The advantages and disadvantages of the respective processes are described in the UFOP practical information "Körnerleguminosen: Konservieren oder silieren?" (2014).

4.1.3 Treatment process

In addition to the pure preservation methods, there are a large number of treatment methods (see UFOP issue 33, 2007) that focus on increasing storage stability and improving the hygienic status. At the same time, the aim is to improve the feed value through reduced protein breakdown in the rumen, increased nutrient digestibility, and the breakdown of anti-nutritive substances.

In addition to chemical treatment, physical treatment processes such as toasting, roasting, extruding, expanding, micronising, or microwave processes are also available. The most extensive investigations have been done for toasting and expanding. A shift in the protein fractions, a reduced protein solubility, and, as a consequence, an increased UDP content of the raw protein could be detected. The reduction of anti-nutritive substances in grain legumes is also possible with the help of thermal processes as trypsin inhibitors, lectins are almost completely reduced during toasting, and tannins are partially reduced without protein damage. In contrast, the alkaloids of lupin are heat-stable and can hardly be reduced by thermal processes.

The effect of treatment methods on nutrient digestibility and performance is not uniform. Improvement in nutrient digestibility and energy content for ruminants could not be observed in the toasting process. Nevertheless, the use of toasted/expanded lupins in comparison to untreated material led in some cases to an increase in milk yield.

In pig farming, the toasting of a grain legume mixture led to an increase in digestible organic mass and energy content. However, an improvement in rearing or fattening performance could not be demonstrated using a thermally treated lupin or a legume.

Studies of poultry are somewhat different. In digestibility studies with laying hens, no significant improvement of the feed value (the content of convertible energy and praecaecally digestible amino acids) could be achieved with the thermal treatment of a legume mixture (LEGUMI-therm®). However, earlier studies on the use of thermally treated lupins showed higher fattening day gains in broilers. An improvement of the faeces consistency, however, could not be observed.

Therefore, thermal treatment is recommended especially for dairy cow feeding.

4.1.4 Practical applications of the narrow-leaved lupin

Lupins can be used in many different ways in feeding. In any case, it is important to calculate the exact ration based on the actual nutrient content and to avoid sudden feed changes.

Ruminants

Lupins can be used without any problems in ruminant feeding. While in the medium performance range of dairy cows lupins can be used as the sole protein supplement in concentrated feed, in the high-performance range of dairy cows the provision of non-degradable crude protein is a limiting factor. With increasing performance the demand for nXP increases. This must increasingly consist of rumen-stable protein (UDP) as the microbial protein production per MJ ME remains constant, and the energy intake is limited by the feed intake.
In combination with lupin and oilseed rape extraction meal, milk yields of > 40 kg per cow per day can be achieved if rations are optimised professionally

and the RNB values are considered. Special conditions apply under organic production conditions with high percentages of grass silage in the ration. Since here the possibility of feeding extraction grist with higher UDP contents in the protein is not given, the proportional replacement of silage by hay or dry green or the thermal treatment of lupin is a possibility to increase the UDP content. The cost-benefit ratio should be examined, and other alternative organic feedstuffs such as spent grains, slurry, and pomace should be included. A number of ration examples have been compiled in the UFOP brochure "Dairy cow feeding without soya extraction meal" and in the UFOP practical information "Field beans, feed peas and blue sweet lupins in cattle feeding". Amounts of up to 4 kg lupin/dairy cow per day can easily be used.

For calves and young cattle, there are also in principle no restrictions on use from the point of view of feed value; rather, the proportion in the ration is based on the requirements in the respective product range.

In cattle and lamb fattening, lupins should always be used as a high-quality supplement to other protein carriers. In bull fattening, application rates of up to 2 kg/day are possible, but their share in compound feed should not exceed 25%. In the case of lambs, their high demands for energy and protein supply for sufficient growth intensity and well-developed muscles should be considered. In combination with other protein sources (other grain legumes or extraction meal), it is recommended not to exceed 20% (Table 4.2).

Pigs

Pigs are particularly sensitive to elevated alkaloid levels. The ration should not exceed 0.02%, which does not occur in any practical feed ration with an alkaloid content of < 0.05% in the lupin grain. In the field of organic piglet rearing, hydrothermally treated grain legumes with proportions of up to 30% were tested and comparable performances were achieved. For lupins, application rates of up to 15% in piglet rearing are considered possible. Nevertheless, in accordance with literature results and practical experience, the UFOP recommends that piglets should only be accustomed to lupins from 20 kg live weight upwards and only at low proportions of 5%. In contrast, the use of 15–20% narrow-leaved lupin in pig fattening is possible without impairing feed intake or fattening and slaughtering performance, which has been confirmed by current feeding trials of the LWK Niedersachsen. Prerequisites are ration balancing based on the praecaecally digestible amino acids and a corresponding amino acid balance.

Poultry

The use in poultry feed is limited by the content of anti-nutritive substances. The high content of NSP has a negative effect on manure quality and litter hygiene. The oligosaccharides contained can also have anti-nutritive effects, especially in young animals or in higher ration shares, whereby modern breeds may react more quickly with growth depressions.

In addition, the low methionine content must always be considered in the ration design, e.g. by combining it with oilseed rape and sunflower products and if necessary by supplementing it with free amino acids. According to application recommendations, 10 % were derived for laying hen husbandry, 10–15% for broiler fattening, and 10–25% for turkey fattening.

Tab. 4.2: **Recommendations for the use of narrow-leaved lupin in feeding**

Animal species	Quantity used
Ruminants	
Dairy cow, calves, and young cattle	Without restrictions, aligned with the requirements in the respective section
Fattening bulls	1–2.5 kg/day, < 25% concentrate feed
Ewes/milk ewes	0.4 kg/day
Calves, lambs for fattening	Up to 20% concentrate feed
Pigs	
Piglets (< 20 kg/> 20 kg)	0% / 5%
Sow (carrying/laying)	8% /10%
Fattening (Start/End)	15% /20%
Poultry	
Laying hens (Egg, reproduction)	10%
Chickens/broilers	10% (Starter up to 4. LW), 15% (Fattening from 4. LW)
Turkeys for fattening	10% /15% (rearing), 25% (Fattening P 3–4), 20% (Fattening P 5–7)

Aquaculture
In aquaculture, narrow-leaved lupin is an interesting protein source as an alternative to fishmeal. Most of the experience has been gathered in the Asian and Australian regions. However, the importance of aquaculture and with it the interest to replace fishmeal as much as possible within the framework of sustainable production systems is also increasing in Europe.

While the saponins and lectins contained in soy extraction meal can cause intestinal damage in salmon, no similar effect was observed when feeding lupins. In the OLA (Optimization of lupin meal for aquaculture) project, feed formulations with increasing proportions of lupin seed meal as the main protein source for sea bass were tested. In addition, it was examined how fermentation processes based on phytase and xylanase enzyme preparations can be used to enzymatically digest indigestible substances such as phytic acid and the NSP to increase digestibility. Although fermentation led to a strong reduction of phytic acid in lupin meal, feeding experiments showed a positive effect on growth only in small animals under 15 g. With a proportionate fishmeal replacement by lupin seed meal fractions by up to 50%, comparable performances were achieved as with 65% of fishmeal. The excellent suitability of lupins as a supplementary alternative protein source and the great potential for exploitation in the aquaculture market were highlighted. Variations in supply, quality, and composition were highlighted as concerns for commercial implementation.

4.2 Lupin in human nutrition

Grain legumes from local cultivation areas offer a particularly high potential for innovation and added value in the food sector. Consumers in Germany are demanding GMO-free food, and there is a growing demand for food products that are produced regionally and sustainably, are traceable, of plant origin, and have a high health and wellness value. The increase in diet-related diseases in Western industrial societies also increases the urgency of designing preventive, innovative nutritional strategies based on health-promoting foods. These include vegetarian and vegan, as well as lactose-free and low-cholesterol products that are produced in the most environmentally friendly way possible. The influence of international cuisine also directs the focus on the utilisation potential of lupins. Grain legumes with their special ingredients offer a promising raw material basis for the development of such foods. Grain legumes,

including lupins, are a traditional source of protein and oil for human nutrition. Lupins have been valued in Mediterranean countries and in South America for more than 2000 years as a high-quality protein- and carbohydrate-rich staple food and are also traditionally eaten as a snack in the form of popped and salted lupin grains.
From the range of species, white lupin in particular has so far been used for human nutrition in Europe. Due to its anthracnose intolerance, white lupin is cultivated and marketed in very small quantities exclusively in organic quality. Some producers prefer it because of its neutral taste. Grains with a protein content of 40% in the dry matter are used for processing. Whole grains, lupin flour, or grits are used to make products such as flour, coffee, or spread. *Lupinus pilosus* has also gained regional importance as the basis for the so-called "Anterivo coffee" (Heistinger & Pistrick, Genet Resour Crop Evol 54, 1623–1630, 2007). In South America, the Andean lupin (*L. mutabilis*) is a traditional food plant. Especially in Germany, narrow-leaved lupin has gained importance in the past 10 years as a source of protein and dietary fibres for food applications.

The original accessions of lupins are characterised by high contents of bitter-tasting and toxic alkaloids, which do not readily permit their consumption by humans and animals. While the bitter substance content can be reduced by extensive watering of the seeds, there are other so-called "sweet" lupin varieties available, which, as a result of plant breeding efforts, have very low bitter substance contents. In the language of the breeders, low alkaloid is used to denote lupins with alkaloid content below 0.05% and alkaloid-free – below 0.02% in dry matter (DM). Nevertheless, the alkaloid content should be kept in mind as an important quality criterion, as it can fluctuate due to environmental influences, such as the pH value of the soil and heat stress during seed development, or increase due to the presence of individual bitter seeds in the crop. This is particularly the case if, as mentioned in Chapter 1, parts of the consumer harvest are used for future sowings instead of certified seed without further quality control (re-growing). It is common practice to require low alkaloid lupins for animal feed and, due to toxicological considerations, lupins free of alkaloids for food use. Not all varieties have low alkaloid values. Therefore, the selection of varieties is mainly based on protein content, alkaloid content, shell content, and susceptibility to diseases (e.g. anthracnose).

Other quality requirements imposed by the processors include the quality of the harvested material:

- water content < 14%
- max. impurities 3%, no soil and stones
- colour of seeds: as light as possible
- a low percentage of testa
- pre-cleaning via sieves (6.5 mm),
- avoid shell cracks (drying, gentle storage)
- little broken grain (< 5%) and stocking (< 4%)
- alkaloid values < 200 ppm
- residues according to guide values BNN (Association of Organic Processors, Wholesalers and Retailers, Germany).

Lupins can be used to produce gluten-, cholesterol-, and lactose-free non-genetically modified (non-GMO) products for human nutrition. In this context, the excellent processing technological properties of protein isolates from narrow-leaved lupins, for example, with regard to emulsification ability and stability (see Table 4.4), should be emphasised. These properties were made possible by the development of an innovative fractionation process at the Fraunhofer Institute for Process Engineering and Packaging (IVV), Freising. With this process, undesirable substances such as low-molecular sugars and alkaloids can be removed. The lupin seed can then be fractionated into protein concentrate, isolate with 65% or > 90% protein content, oil, fibre and shell fractions, which can then be used specifically for the production of food products (Fig. 4.2: Patented fractionation, Tab. 4.3).

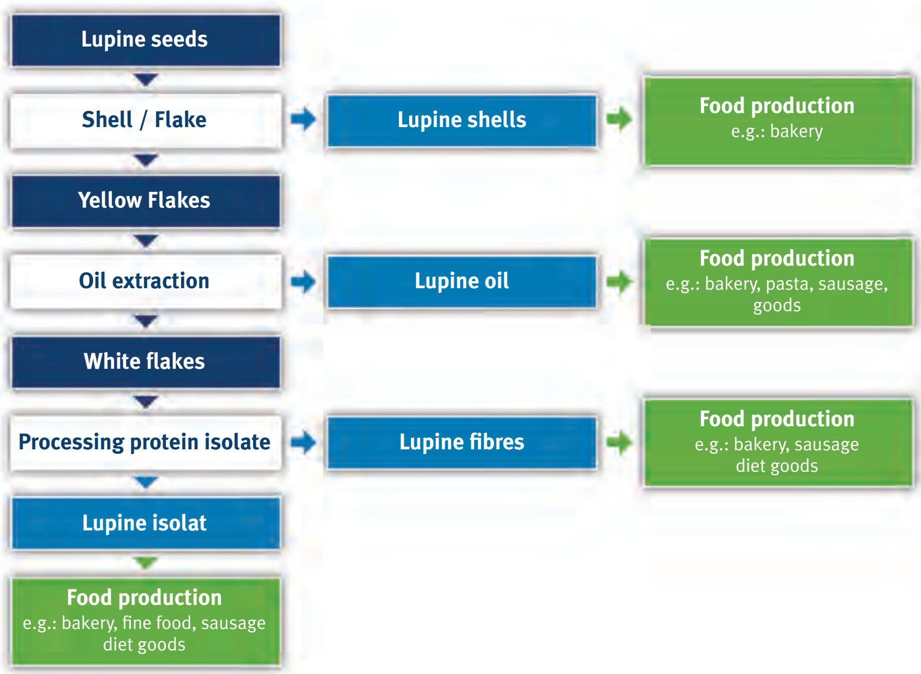

Fig. 4.2: **Technical implementation at Prolupin GmbH.** Patented fractionation results in four novel food ingredients: shell, oil, fibre, and protein isolate (Source: www.prolupin.com).

Lupins and their constituents are added to numerous food products (Table 4.3) such as tofu, sausages, liquid seasonings, cutlets, roast meat, spreads, quark, mayonnaise, noodles, all types of baked goods and coffee substitutes. Lupin flour has a high water-binding capacity, gives the food yellow colour (carotenoids), has good emulsifier properties, and ensures fine-pored baked goods that do not dry out quickly. Due to its high protein content and nutty taste, lupin meal is often used to improve the taste of baked goods. Studies have shown that bread enriched with lupin flour leads to a faster feeling of satiety and thus contributes to eating less due to its high protein content.

The partial replacement of pork by lupin protein concentrate can be used for fat and calorie-reduced sausage products (reduction of the fat content from 25% to 11% in Wiener sausages and liver sausage).

Tab. 4.3: **Examples of lupin use in human nutrition**

	Narrow-leaved lupin			White lupin
Application	Isolate from 90% protein	Concentrate from 65% protein	Inner fibre	Whole grains
Whole lupin seeds for germination or cooking				x
Meat and sausage products - alternative or admixture for fat reduction				
Sausages, liver sausages	x	x	x	x
Hamburger	x	x		
Cooked ham	x			
Roasts, cutlets, gyros		x	x	x
Bakery products, confectionery				
Bread, biscuits, crackers	x	x	x	x
Cake, doughnuts		x	x	x
Baking mixtures, pancakes, waffles		x	x	x
Sweets, fat foams, chocolate coating		x		
Pasta, delicatessen				
Noodles and similar products	x			
Breakfast cereals		x	x	
Spreads	x	x	x	x
Mayonnaise	x	x		
Diet food, baby food	x	x	x	
Sports nutrition	x			
Flavour carrier			x	
Beverages				
Coffee whitener	x			
Coffee from seeds	x	x		x
Grain spirit with roasted narrow-leaved sweet lupin				
Milk alternatives				
Lupin drink	x			x
Yoghurt	x			
Cream cheese, processed cheese	x	x		
Dessert	x			x
Tofu		x		x

Numerous studies have shown that the combination of lupin protein with cereal or maize protein results in an almost ideal protein composition (FAO). Lupins are characterised by high protein contents (narrow-leaved lupin 33% XP in DM; white lupin 37% XP in DM) in the seed. The nutritionally high-quality protein with a high proportion of storage protein is rich in the amino acid lysine, which is an important component of human connective tissue. Lupin grains are also rich in fat (4–7%; narrow-leaved lupin 5.5% in DM, white lupin 8.7% in DM) and the oil contains valuable unsaturated fatty acids. White lupins have a high proportion of oleic acid, followed by linoleic acid (Erbas et al., Food Chemistry 89, 341–145, 2005), while narrow-leaved lupins have more linoleic than oleic acid. Beyer et al. (J. appl. Bot. Food Qual. 88, 192–196, 2015) state the fatty acid composition of narrow-leaved lupins as follows: 19.5% saturated fatty acids, 32.4% monounsaturated, and 48.1% polyunsaturated fatty acids. In addition, lupins are rich in dietary fibres, which are better tolerated compared to other legumes because they have a less flatulent effect. The low glycaemic index (slow release of carbohydrates) slows down an increase in blood sugar levels and is therefore beneficial for people with diabetes. Dietary fibre promotes intestinal passage and can prevent colon cancer.

It is also known that lupin fibres have a high water-binding and swelling capacity. The high contents of minerals (K, Ca, Mg, Fe), carotenoids, vitamins A and B1, and health-promoting secondary ingredients have further nutritional advantages, as do the comparatively low contents of uric acid-forming purines (beneficial for rheumatic diseases) and phytoestrogens (Ibieta et al., J. Biosci. 60c, 649–656, 2005). Lupins contain no gluten and are therefore well suited for people with celiac disease (hypersensitivity to gliadin protein from cereals). Human intervention studies have shown an LDL-cholesterol-lowering effect in people with high cholesterol levels, good tolerability, and high sensory acceptance of foods fortified with soluble dietary fibres from the seeds of narrow-leaved lupin (Weiße et al., Eur. J. Nutr. 49, 65–71, 2010; Fechner & Jahreis, Atherosclerosis Suppl. 11, 150, 2010). With their diverse physiological effects and favourable processing properties, such ingredients offer perspectives for the nutritional prevention of colon cancer and coronary heart disease.

As lupin contains certain proteins that are similar to the proteins of peanuts, which are also legumes, allergy sufferers who react to peanuts should exercise caution when consuming lupin; cross-allergies could occur. Because of their allergenic potential, lupin ingredients in food must be labelled on the packaging.

Tab. 4.4: **Functional properties, nutritional benefits, and health aspects of Lupins**

Protein properties/functional properties
Emulsifying capacity
Protein solubility
Water binding, oil/grease binding
Thermofixable foams and foam stabilisation
Gel formation

Nutritional benefits
High protein value (PDCAAS) of 0.9 (comparison: milk, chicken protein 1.0)
Essential amino acids
Saturating
Rich in secondary ingredients (protease trypsin inhibitors)
Positive content of B vitamins (thiamine, riboflavin)
Prebiotic – supports the formation of a good intestinal flora

Health aspects
Appetite regulation – protein is a highly satiating nutrient
Cholesterol reduction – γ-Conglutin controls LDL-receptors
Cardiovascular protection – reduces vascular diseases
Angiotensin-converting enzyme (ACE) inhibition – blood pressure reduction (the effect is probably due to the high proportion of amino acids)

The increasing demand for plant-based and sustainably produced food from regional production and the trend towards health-conscious nutrition opens up possibilities for wider use of lupins in human nutrition in the future. More and more companies are producing a wide variety of different products and recipes from the seeds of white and narrow-leaved sweet lupin (Fig. 4.3), which are free of genetic modification (Table 4.3). Nevertheless, the potential of using lupin in innovative nutritional strategies needs to be researched in detail and developed for practical application and the market for these products needs to be expanded. This requires, on the one hand, an increase in the area under cultivation and the optimisation of product flows.

For a successful entry and long-term survival of farmers in the innovative field of lupin cultivation for human nutrition, a site-specific development of cultivation methods in a dialogue between science and practice is necessary in order to meet the quality requirements of the producers.

Fig. 4.3: Food products from sweet lupins

5 Economic efficiency of lupin cultivation

Matthias Dietze

The production of lupins and other large-grain legumes has been significantly expanded in recent years as the reform of the Common Agricultural Policy (CAP) has considered legume growing at different levels. Further research in the field of breeding, cultivation, and utilisation, as well as a stronger focus on consulting and knowledge transfer, shall contribute to increase the competitiveness of legume cultivation.

When assessing economic viability, there is an agreement that the value of grain legumes cannot be measured solely in terms of yield. The benefits beyond the yield, which can be directly measured and monetised, are summarised under the term 'preceding crop value'. Further ecosystem services, such as the expansion of biodiversity in the agricultural landscape or the promotion of phytosanitary stable crop rotations, which contribute to more sustainable agricultural production but cannot be assigned a direct monetary value (in the short term and at farm level), are not included in the calculation.

In the present calculation, various services in the previous crop value are considered, which also considered the market environment. If the yield of the subsequent crop after lupins is up to 10 dt/ha higher, the producer price for wheat or rye is a second important variable. On average over the years 2008 to 2016, the prices for wheat and rye were 179 and 163 €/t, respectively (Table 5.1). The nitrogen fixation of the lupin as well as savings in labour costs are further variables that are included in the estimation of previous crop value.
Depending on the location, the subsequent crop and the producer price level, a previous crop value of 123 to 232 €/ha is assumed as a long-term average (Table 5.2).

Table 5.1: **Substitution value of lupins according to utilisation**

			Substitution value lupin on basis	
	Wheat	SEM 44%	pev. Lysin/MJ ME €/t	nXP/MJ NEL €/t
On average over the years 2008-2016	179	332	**249**	**229**
min.	126	280	208	182
max.	236	413	311	291

			Substitution value lupin on basis	
	Rye	REM	pev. Lysin/MJ ME €/t	nXP/MJ NEL €/t
On average over the years 2008-2016	163	207	**233**	**197**
min.	106	138	166	135
max.	232	264	306	267

nXP RES, SES calculated according to updated UDP contents.

Price statistics for conventionally produced lupins are rarely gathered, so it is common practice to take the substitution value (value of the feed replaced in a feed mix) as the price. Depending on the feedstuff and the intended use (milk production or pig fattening), this lies in the long-term average between 197 and 249 €/t (Table 5.1). For use in milk production, the usable crude protein (nXP) and the net energy lactation (MJ NEL) of the feed components are decisive. In pig fattening, the substitution value is calculated on the basis of the praecaecally digestible lysine (pev. lysine) and the convertible energy (MJ ME). As a rule, it is assumed that soya extraction meal (SEM) and wheat are displaced by lupins in the feed ration. In a cost-optimised feed ration, however, feeds such as rape extraction meal (REM) and rye could be used. For cattle feeding, the positive effect of thermal treatment has been proven. Assuming a doubling of the non-degradable protein (UDP content), the usable crude protein increases by 20%. The substitution value of the lupins is then, under otherwise identical conditions, 302 €/t on a wheat/SEM basis or 236 €/t on a rye/REM basis before deduction of the additional treatment and transport costs.

When the previous crop value and the substitution value are considered, the calculation shows a positive contribution margin for all locations (see Table 5.2). The range in the contribution margins of the individual locations illustrates the value of lupin feeding depending on the animal species. It is essential to observe the limits of use of lupin feeding.

Table 5.2: **Calculation of contribution margin for lupin cultivation**

		conventional			organic
Income assumption	dt/ha	18	25	35	20
Substitution value/market price	€/t	197–249	197–249	197–249	44
Previous crop value	€/ha	123	185	232	
Performance	€/ha	478–571	678–808	922–1104	880
Various costs	€/ha	–442	–454	–469	–376
Contribution margin	€/ha	36–129	224–354	453–635	504

In the second step, competitiveness is examined (Table 5.3). The utilisation costs show the lost contribution margin of the displaced market crop at the respective location, which lies in the long-term average between 214 and 663 €/ha. It becomes clear that the minimum price that would have to be achieved in order to grow lupins profitably for use in animal feed decreases with increasing profitability of the location and approaches the substitution value used in the contribution margin calculation. If the long-term average of the market data used is taken as a basis, the minimum price is between 257 and 296 €/t, depending on the location.

The high market prices for lupins in organic farming reflect the specific requirements for this type of farming. The inclusion of a previous crop in the form shown here is not appropriate for organic farming. The central question here is probably whether the location and utilisation or marketing possibilities speak in favour of a small-grain or large-grain legume as an anabolic fruit in a systemically more diverse crop rotation. After deduction of the processing costs in this abridged calculation, the contribution margin for lupin in organic farming is 504 €/ha.

Table 5.3: **Competitiveness of lupin cultivation**

		conventional		
Income assumption	dt/ha	18	25	35
Previous crop value	€/ha	123	185	232
Various costs	dt/ha	−442	−454	−469
Costs of use	€/ha	−214	−382	−663
Minimum price	€/t	296	260	257

To sum up, the inclusion of a previous crop has a positive effect on the evaluation of lupin cultivation but is not sufficient to establish a level playing field with competing crops.

If, from an agricultural policy point of view, importance is attached to other ecosystem services of lupins, the difference in competitiveness would be the basis for the assessment of support for legume cultivation.

Attachment

Plant growth stages for lupin (Modified and supplemented from: Lupin Development Guide. M. Dracup & E. J. M. Kirby, University of Western Australia Press, 1996.)

Code	Description
0	**Germination**
00	Dry seed
01	Soaked seed (water absorption)
03	Radicle (root) protruding through the testa (seed coat)
05	Radicula 5 mm long (germination)
07	Hypocotyl protruding through the seed coat (hypocotyl is half as long as the grain)
10	**Leaf Emergence**
11	Cotyledons emerge at the soil surface
15	Cotyledons unfolded
20	**Rosette stage**
21	First and second leaf unfolded
23	Third and 4. leaf unfolded
25	5. leaf unfolded
29	End of rosette development (First internode longer than 1 cm)
30	**Stem development**
31	6. leaf unfolded
33	7. leaf unfolded
35	8. leaf unfolded
37	9. leaf unfolded
38	10. leaf unfolded
39	11. and more leaves unfolded

Code	Description
50	**Bud formation**
53	Flower bud visible at the tip of the shoot (1 cm long)
57	First petals visible
60	**Flowering**
61	First flowers are blooming
63	75% of flowers are blooming
65	First flowers loose their characteristical colour
69	All flowers faded
70	**Pod development**
71	First pods are visible (pods longer than 2 cm)
73	75% of the pods visible
77	First pods are fully grown (seed profile visible to all sides, pods lighter green, moisture between cotyledons)
79	75% of the pods are fully grown
80	**Maturity, seed ripening**
81	Green maturity: No more moisture visible between the green cotyledons
83	First pods are brown
87	Yellow maturity: All pods are brown, seed is scratchable with fingernail, cotyledons are yellow
89	Maturity: seeds are no longer scratchable with fingernail
90	**Dying off**
92	Complete straw ripeness, stem dry

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