"Non-food Crops-to-Industry schemes in EU27"

WP1. Non-food crops

D1.1 Oil crops that can be produced in EU27

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Table of contents

INTRODUCTION

Approximately 30 million of metric tones of oil crops, mainly rapeseed, soybean and olive, are produced in the EU27 area. In recent years, the production is increased 3% year by year and this trend is likely to further increase in the next future, mianly for industrial purposes.

Alternative oil plants such as honesty (Lunaria spp.), cuphea (Cuphea spp.) and wild spurge (Euphorbia lagascae) have recently attracted increasing importance in North America and China. New interesting genotypes of the above crops have been developed to compete with conventional oil crops that could be profitably grown also in Europe.

The general target of WP1 is to explore the potential of non-food crops, which can be domestically grown in EU 27 countries, for selected industrial applications, namely oils, fibers, resins, pharmaceuticals and other specialty products.

The aim of this task is to gather information and reviewing novel oil species for industrial uses (lubricants, solvents and polymers) adapted to European lands. Literature on these plants will be critically revised in order to estimate their potential market in the light of the booming of bio-based market.

The reason for this task is that Europe is composed of different environments, which vary with factors like mean temperatures, rainfall and soil quality. No single plant species is optimal for all environments, so identifying promising plant species an EU-27 context, enhancing thus biodiversity will be necessary.

The steps undertaken so far are the following: i) preliminary review on crops originally included in the DoW; ii) revision of the original crop list to replace less suited crops to European climate conditions whit more adapted and promising species; iii) editing literature reviews on these crops that are being updated during the next period.

During the project meetings some crops can reveal to be worthy of major interest thus higher efforts will be dedicated to that crops.

<u>Task 1.1 Oil crops</u> (CRES, <u>ITERG</u>, UNIBO)

The main oil crops that have industrial uses are: rapeseed (*Brassica napus*), sunflower (*Helianthus annus*), Crambe (*Crambe abyssinica*), Linseed/flax (*Linun usitatissium*), cotton seed (*Gossypium*), Calendula/pot marigold (*Calendula officinalis*). The production of the last one is for personal care products, cosmetics and paints.

Research is being carried out in several oil crops at European level, such as for Ethiopian mustard (*Brassica carinata*), caper spurge (*Euphorbia lagascae*), Castor (*Riscimus communis*), Honesty (*Lunaria biennis*), cuphea (*Cuphea spp.*), safflower (*Carthamus tinctorius*), Jatropha (*Jatropha curcas*). The most important markets for the oil crops are: biodiesel production, lubricants, solvents, polymers, etc.

In this project the following crops are dealt:

1. Calendula/pot marigold (*Calendula officinalis*),
2. Caper spurge (*Euphorbia lagascae*),
3. Cardoon (*Cynara cardunculus*).
4. Castor (*Ricinus communis*),
5. Cotton seed (*Gossyium annum*),
6. Crambe (*Crambe abyssinica*),

7. cuphea (*Cuphea spp.)*
8. Ethiopean mustard (*Brassica carinata*),
9. Honesty (*Lunaria biennis*),
10. Jatropha (*Jatropha curcas*)
11. Linseed/flax (*Linum usitatissium*),
12. Rapeseed (*Brassica napus*),
13. Safflower (*Carthamus tinctorius*)
14. Sunflower (*Helianthus annus*)

CRES studied: **rapeseed** (*Brassica napus*), **ethiopean mustard** (*Brassica carinata*), **sunflower** (*Helianthus annus*) and **cardoon** (*Cynara cardunculus*).

ITERG studied the crops: **Crambe** (*Crambe abyssinica*), **Linseed/flax** (*Linum usitatissium*), **Calendula/pot marigold** (*Calendula officinalis*), **Honesty** (*Lunaria biennis*), **Jatropha** (*Jatropha curcas*)

UNIBO studied the crops: **Cotton seed** (*Gossyium annum*), **caper spurge** (*Euphorbia lagascae*), **castor** (*Ricinus communis*), **safflower** (*Carthamus tinctorius*) and **cuphea** (*Cuphea spp.)*

The information collected and evaluated by this task addresses the following topics:

- Plants anatomy
- Areas of origins and current cultivation
- Growing conditions-input requirements
- Logistics (harvesting-handling) until the industrial plant gate
- Yields
- Quality
- Applications: current-potential
- Research gaps

11. CALENDULA (*Calendula officinalis* L.) Fam. Asteraceae

1.1. Plant anatomy

Figure 11-1. *Calendula officinalis* L

Common names: Scotch-marigold, Calendula.
It is a herb reaching a height of 40-70 cm at maturity depending on cultivar. It has a deeply penetrating tap root. The leaves are elongated, spatulate, light green and tomentose hairy. The inflorescence is an orange, terminal capitulum of 4-7 cm in diameter. [2], [3]

1.2. Domestication and area of origin

The species *Calendula officinalis* or Pot Marigold is a native of the Mediterranean area (Earle et al., 1964) and in western Asia [2] but is grown widely across Europe [4], [5]. It has been cultivated for many years as an attractive garden plant.

1.3. Growing conditions

Calendula officinalis is a biennial, but is generally cultivated as an annual plant. It is hardy and well adapted to temperate climatic zones in Europe, although it is believed to have originated in Mediterranean. [3], [5]

Its environmental requirements are shown in the Table 11-1 below: [8]

Table 11-1. Environmental requirements

	Optimal		Absolute	
	Min	Max	Min	Max
Temperature requir.	16	26	8	30
Rainfall (annual)	500	800	300	2500
Latitude	30	25	50	60
Soil pH	5.5	7	4.5	8.3
Light intensity	Very bright	Very bright	Very bright	Clear skies
Soil depth	Medium (50-150 cm)		Shallow (20-50 cm)	
Soil texture	Medium, light		Medium, light	
Soil fertility	moderate		low	
Soil Al. tox				
Soil salinity	Low (<4 dS/m)		Low (<4 dS/m)	
Soil drainage	well (dry spells)		well (dry spells)	
Climate zone	Steppe or semi arid (Bs), subtropical dry summer (Cs), temperate oceanic (Do), temperate continental (Dc), temperate with humid winters (Df), temperate with dry winters (Dw)			
Killing temp. during rest	No input			

Like many plants, Calendula is seriously affected by competition for moisture, nutrients and sunlight, particularly in the period following emergence. [5]

Planting

The optimum sowing date is April. Calendula is less sensitive to frost than sugar beet, linseed or flax, but during cold springs, it is advisable to delay sowing until the second half of April. Rapid emergence is important for effective suppression of weeds. In good conditions emergence is rapid (5-15 days after sowing).

Calendula seed is small and irregularly shaped; this can cause considerable problems with drilling. A fine, firm seedbed with adequate moisture is required to achieve an even establishment. The target plant population is 60 plants/m², although good yields have been achieved from 40 plants/m². [3], [5]

The seed may germinate within 4-5 days. [2]. Germination percentages in good seed lots are 60-80 and field emergence is normally rapid and varies from 40 to 60%. [3], [5]

Sowing depth is important, particularly if residual soil acting herbicides are to be used and to ensure even crop establishment and maturity. [5] Because of the small seed size, Calendula should be sown at a depth of 1-2 cm similar to that for oilseed rape and linseed. Normal row spacing with commercial seed drills is 12-25 cm, although wider, 50 cm rows are used for mechanical weeding systems. Typical seed rates are 7-12 kg/ha. [5]

Crop management

Fertilizer recommendations are: 50-100 kg/ha nitrogen (N), 25-75 kg/ha phosphate (P2O5) and 50-100 kg/ha potassium (K2O). In some cases excess fertility has resulted in crop lodging. A light dressing of nitrogenous fertilizer (50 kg/ha) has been found to increase biomass but not necessarily directly affect seed yield. [3]

Pest and diseases

Few pests have been identified in Calendula*.* As the crop area expands, pests will develop, so growers should remain vigilant to new threats.

Botrytis has been reported in crops. This disease is favoured by humid conditions. Mildew has also been observed, particularly in late season, although its effect on seed yields is unknown. *Sclerotinia* has been reported in crops and *sclerotia* have been found in harvested seed lots. Vinclozolin (Ronilan) during flowering or Uprodione (Rovral) as the flower leafs start to fall off, can be used to control botrytis and *sclerotinia* respectively. In consideration of the risk from *sclerotinia*, cultural control can also be recommended. Calendula should not be grown more than once every 6 years in the same field and not as part of intensive rotations with other susceptible crops such as oilseed rape and sunflowers. [3], [5]

A number of pre-emergence residual herbicides were shown to be crop safe. Post-emergence phenmedipharm at full rate caused some adverse crop effects. Trifluralin and metazachlor gave the most consistent weed control over the spectrum experienced and would be the recommended materials. The use of a herbicide significantly increased crop yield.

1.4. Logistics: harvesting/handling

Flowering begins in mid June and seeds ripen in early August. Harvest date varies from early to mid August. The plant continues to flower until the autumn frosts. [5]

As Calendula is an in determinant plant species (it produces flowers over an extended period), the optimum harvest date is difficult to determine, yet critical to achieve optimum seed yields, as seed shedding is an issue. Growers usually apply diquat and with this product harvesting is typically 5-7 days after application. [5], [9]

The crop should be kept fully weed-free to avoid reduced yields and harvesting problems. [9]

Direct combining is the recommended harvest mfethod. Swathing is not recommended as seed shedding is a problem. The crop is also relatively short, so swathing would place the crop on or close to the soil surface. Research with oilseed rape has shown that is important to lay the swath on rape stubblesk and keep the swathed crop above the ground, improving air flow and keeping the crop dry if rain occurs. [5]

Post Harvest management: Some Calendula seeds may be shed before or during harvest. There is no evidence to suggest that Calendula will become a weed crop in other commercial crops. If it does emerge in other crops, such as cereals, it easily controlled using current broad leaved weed herbicides. [5]

1.5. Production-Yields

At present, seed yields of 1000 to 1500 kg/ha are obtained on a farm scale, but with improved production systems and selected varieties it is believed yields could double, making it an attractive industrial oilseed crop for European farmers. [5]

Yields are generally between 2.0 and 2.5 t/ha. [3]

Oil yields: 300 kg/ha. [10]

Average yield of dry petals is 200-300 kg/ha, while yields of complete inflorence may be 500-800 kg/ha. High humidity will increase the risk of infections of powdery mildew. [2]

Calendula officinalis is one of five species included in an **European Community AIR project** "Vegetable oils with specific fatty acids", which commenced in 1994 on 2 years on the agronomic evaluation of the crop in north west Europe.

The experiments reported suggest that the best of current cultivars should produce field yields in the range 2.0-2.5 t/ha-1. Early maturing genotypes appear to be most suitable for climatic conditions of North West Europe, allowing a more concentrated flowering period an easier harvesting. Oil content was disappointing, averaging only 16.3%, with the best accession achieving 19.2%. There would appear to be scope for further improvement in crop yield, agronomic characteristics and oil content. Plant density of 40 m^{-2} or more had little effect on crop development and yield. Lower densities, particularly of early maturing types, did not produce full ground cover or yield potential. It would therefore seem desirable, because of the uncertainty over establishment, to set the field target population slightly in excess of 40 plants m^2. [4]

1.6. Applications: current/potential

The plant has several uses. These include the essential oils and pigments from its flowers, the former being widely sold in topical medicinal products. There are also uses for its seed oil, which contains Calendic acid. [5]

Already in 1987, Calendula was proposed as new oil crop for the chemical industry. [6] In the EU project entitled "Calendula as Agronomic Raw Material for Industrial Applications" (CARMINA), the cultivation and usage was developed. It was reported that "alkyl paints with less volatile organic compounds (VOC) and non-fogging polyurethane foams (PUF) can be produced with calendula oil as raw material and their use would reduce VOC-emissions". [7]

Composition of oil content

Interest in *Calendula officinalis* L. as an industrial oil crop has developed from the discovery that the seed of Calendula contains 14-22% oil of which 55-60% is the very reactive C18:3 calendic fatty acid, a useful industrial feedstock. [4], [5], [9], [11]

Applications

The chemical structure of calendic acid, containing three reactive conjugated ethylenic bonds and an octatrienoic acid isomer, makes it a potentially useful compound within industrial products and for chemical modification. Market opportunities have been identified for Calendula oil as an ingredient for the production of reactive diluents and oil based alkyd resins which are applied in high solid paints and as a substitute for Tung oil, which is currently imported into the UE. Replacing imported tung oil would require at least 10 000 ha of Calendula to be grown in Europe. [5]

Table 11-2. Oil profile of Calendula officinalis L.

Fatty acid	Percentage [10]
C14:0	0.5
C16:0	4.2
C18:0	2
C18:1	3.8
C18:2	28.5
C18:3, 9c, 12c, 15c	1.1
C18:3, 8t, 10t, 12c	59.1
C20:0	0.4
C20:1	0.4

Potential applications of these types of oil are paint, varnish additives, cosmetics and some industrial nylon products; it may also have wound healing properties. [3], [4], [9]

The reduction or even the substitution of organic solvents in the coating processing by reactive diluents derived from renewable material would be an important contribution to the necessary reduction of VOC. [10], [12]

The flower heads are used for flavoring soups and stews, and they also have medicinal properties. The plant flowers throughout the season and is often cultivated as an ornamental. [2]

1.7. Restricting factors

Main restricting factors are: soil conditions, date of harvesting, dehulling and refining difficulties, oil storage and low production.

1.8. Research gaps

Processing, refinement and industrial applications

The extreme reactivity of calendic acid makes Calendula oil interesting for several industrial applications but at the same time causes difficulties in processes related to extraction and refinement. These problems can be overcome by using mild process techniques especially designed for the production of extremely reactive oils.

Development

Calendula genotypes investigated in the **VOSFA program** showed considerable diversity in flower structure and site stem branching crop height, flowering period and maturity. However, the results indicated systems, utilizing existing equipment. Several constraints remain to be solved before this crop can be grown economically. By applying modern breeding technology, performing crop physiology studies, studying genotype x environment interactions and investigating seed cleaning and processing systems capable of meeting the specifications of the oil extraction processes, improved cultivars and production systems will be developed for the main production areas of Europe. Furthermore, technology to meet the seed cleaning specification of oil extraction production will be developed.

More research is needed in order to obtain high-yield (seed and oil) types. In *Calendula officinalis* seed oil content could be improved by reducing the seed hull and increasing kernel mass. [14]

The lack of a safe post-emergence material limits weed control options in the crop. **[4]**

CARMINA project was directed towards the development of the best technology to process speciality oil (Calendula oil) from seeds. Refinement methods were investigated in order to produce different oils meeting the various requirements of the specific applications investigated in this program. Functional ingredients present in flower-head extracts may be of interest for application as food and/or feed ingredients. Based on the present knowledge further research activities were proposed to identify specific high value applications. In addition, the utilization of Calendula meal as livestock feed ingredient were investigated. Calendula oil was produced and tested in the VOSFA program. Only a limited use in paint formulations was possible due to sub-optimal quality of the oil. Major improvement is expected when oil will become available from mild extraction and refinement processes. In CARMINA these oils were made and tested. Other industrial research activities conducted in CARMINA was related to the synthesis and characterization of speciality surfactant for application in lubricants, pharmaceuticals, disinfectant, agrochemical and cleaning products. Finally, the production of high performance polyurethane foam products from Calendula oil were tested and evaluated. In CARMINA the production, processing and testing of Calendula oil were integrated through continuous quality monitoring, product evaluation and information feedback up the production chain. [13]

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12. CAPER / WILD SPURGE (Euphorbia lagascae SPRENG)

Fam: Euphorbiaceae

2.1. Plant anatomy

E. lagascae is a wild spurge, recently introduced as an energy crop.

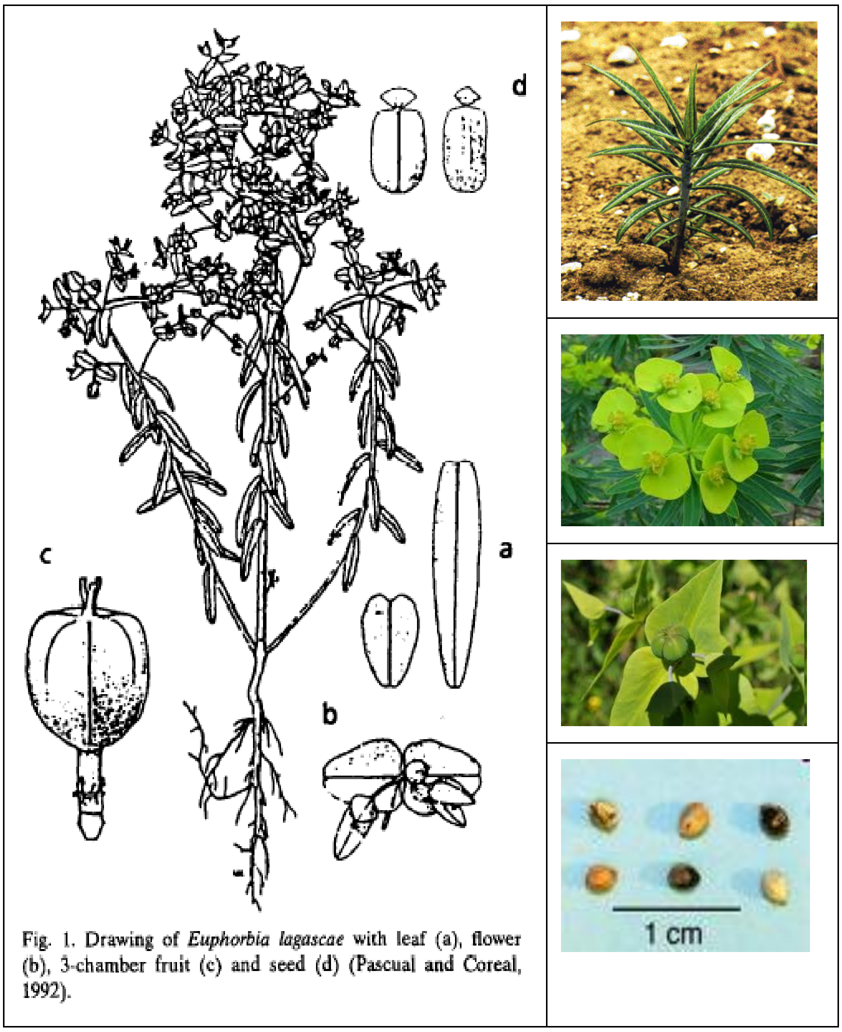

Fig. 1. Drawing of *Euphorbia lagascae* with leaf (a), flower (b), 3-chamber fruit (c) and seed (d) (Pascual and Coreal, 1992).

Figure 12-1. *Euphorbia lagascae*

Caper Spurge is annual, biennial and sometimes perennial. It is folkloristically called "moleplant" for its capacity to repel rodents, and it is often confused with *Euphorbia lathyris,* which can be also found in literature as caper spurge.

The plant can reach 1 m tall and has smooth light green stems about 0.3-0.5 m long. Its structure is mainly simple and grows erect, but if it is disturbed and the apical dominance inhibited, the plant grows branching producing big amount of white sticky latex. It is succulent and leaves surfaces can be glaucous, covered with a greyish waxy coating or glabrous, smooth and glossy, without trichomes.

The leaves are ovate-linear below and narrowly lanceolate above, simple, entire, one-nerved, opposite, apically acute, basally abruptly truncate, long up to 15 cm long. The leaves subtending flower clusters broader. The flowers are subcordate, ovate-lanceolate and triangle lanceolate and greenish yellow. The fruits are usually 3-lobed, subglobose, up to 1 cm long. The capsule can harbour three or four seeds and it is ovate, acutely ribbed and scarlet in varied shades. The seeds are ovoid, flattened, and long up to 6 mm, black marked or speckled and hard to crush. [7][5]

2.2. Domestication and area of origin

Native to the Mediterranean area, it is particularly present in Spain and Italy but less widespread than *E. lathyris* which can be found from Southern to Northern Europe, as well as in North America.

E. lagascae has been introduced in North America and North Europe. The majority of researches were in Germany and the Netherlands. It occurs in the arid southeast and in the entire coastal region of Cadiz and grows spontaneously in cultivated field around towns. In Italy can be found as wild species in Sardinia.

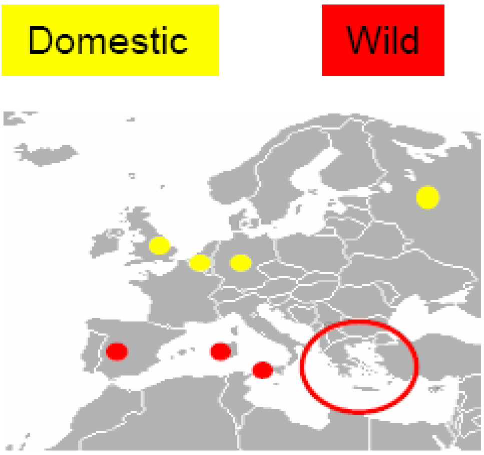

Figure 12-2. European distribution of *E. lagascae*.

2.3. Growing conditions

The optimal sowing time is April to May. The seeding rate vary from 10 to 30 Kg/ha, 30 cm row spaced. Seed production seems to benefit from early sowing time and wider row spacing. [15]

The plant grows better in fallow lands rich in nitrogen, while it does not grow in siliceous or in poor soils. It seems tolerant to damp sites of saline nature. [7]

Caper spurge can be considered a drought tolerant plant. Excess of irrigation water may generate too much greenness of stems, scalar seed maturation, massive release of latex and weed spreading. Otherwise, prolonged water stress periods may lead to vegetative re-growth in autumn when rainfall occurs more copiously. [12]

2.4. Logistics: harvesting/handling

Caper spurge presents significant problems at harvest due to the scalar maturation. These problems comprise indeterminate growth and consequently a long period to reach capsule dehiscence. [8] Moreover the foliage is rich in latex, that is vesicant and irritant and its handling can be critical, especially for the operators.

It is particularly important to define the right time of harvest. Common opinion is that harvest should be done when capsule ripening and seed dissemination has just started the third branch. Concerning the equipments, various field researches on the harvest of *Euphorbia lagascae* have tested the suitability of different harvesting machines. Combine harvester seems not feasible due to high moisture content at harvest time, nor did the application of pre-harvest desiccants appear practicable. The best machine was the pea harvester, caper spurge being fairly similar to green peas. To avoid the blockage of the threshing drum, the machine can be equipped with a special cutter-bar table. Thanks to this tool, the sticky latex do not cause problems and no gum build-up occurs. During threshing, even if the process is rough and designed for pulses crop, there are no evident sign of seed damage.

Another critical process related to harvesting are the impurities produced by the capsule chambers. To reduce this issue, harvest should be done in sunny and windy days because dried capsules split and shed their seeds appropriately.

After drying the organic matter up to a moisture content of 8%, the seeds can be cleaned through an air screen cleaner coupled with a brushing machine (Breemhar and Bauman, 1995).

2.5. Production-Yields

Preliminary experiments on *Euphorbia lagascae* were carried out in Spain varying the date of sowing (autumn and spring), sowing density (36.000 to 143 000 plants ha^{-1}), location (winter mild coastal and cold winter inland areas), irrigation and nitrogen application.

Seed yield, was the highest in coastal locations with 0.4 to 1.6 t/ha [10] with an average oil content of 44% (63% of vernolic acid).

In experiments carried out in the Netherlands, harvested seeds were 1.2 t/ha but the seed lost was remarkable, up to 0.4 t/ha, mainly due to dehiscence (Breemhaar and Bouman, 1995). Serious concerns with seed shattering were also reported in North Dakota where in spite of considerable seed yield potentials the harvested seeds amounted to only 0.1-0.2 t/ha. [3]

Quality

The seed contains 46–52% of oil. The major fatty acid is vernolic acid (C18), which accounts from 60 to 75% of total oil content, mainly in triacylglycerols of seed cutin. It is the most known epoxy oleic acid from natural sources along with coronaric acid, that indeed is the principal fatty acid (up to 90%) of seed oil of *Bernardia pulchella* of the *Euphorbiaceae* family. Vernolic acid is an isomer of coronaric acid and both are biosynthetically related to linoleic acid. The epoxy acids are the best to produce paints and coatings, in fact vernolic acid is used as a drying solvent in alkyd resin paints, a plasticizer or additive in polyvinyl chloride (PVC) resins and possibly in pharmaceutical applications [2]. Paints formulated with vernolic acid would greatly reduce volatile organic compound (VOC) air pollution that now occurs with volatilization of alkyd resins in conventional paints. On the other hand, the main menace of the poisonous seed oil of *Euphorbiaceae* is the presence of the same vernolic acid. Indeed, along with coronaric, these epoxy fatty acids are defined as "leukotoxins", generally referred to the acid produced by leukocytes in inflammatory status and for their primary toxic action against endothelial cells.

In the human body a little amount of vernolic acid is formed after epoxydation catalysis by cytochrome P450 enzyme and accumulates in the lung, in the vascular system and in neutrophils, interfering with the regulation of vascular tone, homeostasis and blood pressure. At high dosage the toxic cardiovascular effect could lead to death. This happen for example after severe burn, when the patient's skin is burn and leukocytes accumulate massively to limit skin infection, producing high amount of leukotoxin hypoxic hydrolases. This action is exerted by vernolic acid by-products, like its hydrated product, that resulted more toxic than the oxidized form. It is reported that vernolic acid by-products are the agent of the development of Acute Respiratory Distress Syndromes. [16]

2.6. Applications: current/potential

Wild spurge has been grown for very different purposes, can be medicinal, ornamental or repellent for rodents in the orchards. [5] The oil is the marketable products of wild spurge, nonetheless its industrial use is still little known. Along with medicinal uses, studies dates back to 1976 by Nobel Prize M. Calvin suggested to use it for biofuels, oil composition of wild spurge being very close to that of diesel oil. Ten years later, Hirsinger (1989) corroborated this hypothesis.

The oil characterisation of *E. lagascae* revealed interesting potentialities for the production of soaps, detergents, lubricants, paints and cosmetics. The oil has high levels (up to 70%) of epoxy fatty acids, as vernolic acid, that make it suitable for epoxy coatings and resins. [11]

Table 12-1. Applications of main compounds extracted from different organs.

Organ/compound	Applications
Seeds *oleic acid* *vernolic acid*	Biofuels; adhesives; varnishes; paints; industrial coatings
Leaves *Quercetin* *p-coumaric acid* *ferulic acid*	Pharmaceuticals; medical nutrition
Latex *L-dopa* *β-sitosterol*	Pharmaceuticals; medical nutrition

Additional uses are in the treatment of skin diseases, ulcers and warts, as well as cancer tumors and intestinal parasites. [6] Some of the compounds of these plants are polycyclic and macrocyclic diterpenes with several biological effects such as, cytotoxic, antiviral [17], multi drug resistant reversing activity [4], antitumor [14], antileishmanial [4] and anti-inflammatory [13].

2.7. Restricting factors

It is a highly toxic plant due to a poisonous milky latex. This substance primarily contain oligocyclic, polyfunctional diterpene esters present both in the seed and in the latex. It is highly skin irritant as well as possessing carcinogenic properties. This issue prevents the plant being used on a large scale, although breeding programmes are under way to reduce content of these substances [1]. Due to the harmful nature of this specie for the presence of latex and other potentially irritating compounds in the stems and petioles, it will be important to understand which safety precautions are necessary during harvest and processing. Another important limitation for large scale production, that has hindered both breeding and agronomic research, is its massive seed shattering habit, making difficult to reduce seed losses during harvest and estimate and measure seed yield.

Moreover, the seed integrity is critical at harvest, because lipases activation within the seed change oil composition to the detriment of the epoxyoleic content. Last but not least, is the problem encountered with weeds. Indeed, weed control is a critical factor, because the common herbicides used are active even against cultivated wild spurge plants, resulting in vegetative damages and in lower seeds yield. [12]

2.8. Research gaps

Breeding activity is on this species is still in its infancy. Breeding programme should address towards limiting seed shattering, improving the resistance against herbicides and rising seed yields. In Spain, mutants with capsules harbouring up to five seeds at a time (in the wild type there are generally three seeds) and other mutants with up to nine main terminal branches per main stem crown have been grown. Although, the seed shattering trait has made progress, the availability of the non-shattering varieties will require much more breeding efforts.

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13. CARDOON (Cynara cardunculus L.). Fam. Compositae

3.1. Plant anatomy

Cynara is a perennial herb, often richly branched with a tap root. Its stems have a height of 20-180 cm and 17 mm wide.

Figure 13-1. Cardoon plantations at early stages of growth and at flowering stage (source: CRES).

An updated and full botanical description of the species *C. cardunculus* as it is presently recognized is found in Wiklund (1992). Thoroughtful cladistic analysis undertaken by Wiklund showed that the cultivars for artichoke and cardoon should be placed in a single species, *C. cardunculus.* Fernandez et al. (1998) [5] studied the expression of different characters in a collection of 18 populations of *C. cardunculus* selected for biomass production. The achenes produced were larger, 6.5-8.1 x 2.8-3.5mm, than previously reported by Wiklund. Other characters studied by the authors (unpublished data) showed that cardoon may reach heights of up to 3 m and that leaf segment shape is the most variable character; rosulate leaves of those populations exhibit leaf segment of up to 24-36 cm length and 10-19 cm wide. Most populations were spineless, and when any, they were very short and located on the intersection of the leaf segments. The central capitulum of the inflorescence (corymb-like) was generally larger than reported by Wiklund, about 9 x 11 cm average.

3.2. Domestication and area of origin

The distribution of the genus *Cynara* is mainly Mediterranean. Presently, the only accepted specific name for both artichoke and cardoon is *C. cardunculus* (see Hanelt and IPK, 2001). [10]

The cultivated cardoon and artichoke have originated from the Mediterranean westerly distributed *C. cardunculus* subsp. *flavescens*. Outside the Mediterranean region, there are also some naturalized cultivars -similar to *C. cardunculus* subsp. *flavescens*- in America (California, Mexico, and Argentina) and Australia.

The cultivation of cardoon as a vegetable (blanched petioles and young stems) dates back to the ancient Mediterranean cultures (Greece, Rome, Egypt) and hence, it has been a traditional crop in the Mediterranean region since then. In spite of its old origin and its good flavour the cardoon has never become a widespread crop. For instance in Spain, that is one of the countries where cardoon is mostly cultivated, there are only 1000 ha (96% irrigated lands) grown with this crop. Named varieties are difficult to find outside the Mediterranean region. Current catalogs report the following cultivars for the horticultural application of cardoon: *ardo LLeno Blanco, Cardo LLeno de España, Bianco Avorio, Bianco Avorio Gigante, Gigante de Lucca, Gigante Inerme, Gigante de Romagna, Large Smooth, White Improved*. These cultivars have been selected for the horticultural application of the crop. For this application, the crop is grown as a vegetable for only one season (May-December, in Spain). The cultivation of cardoon is usually carried out in irrigated conditions and it requires intensive crop management techniques.

3.3. Growing conditions

Cynara is a perennial herb with a development cycle fully adapted to Mediterranean climate conditions.

Cardoon, also known as cynara in the field of the energy crops, has been recently proposed as an energy crop and for this application the name 'cynara' is usually preferable. For this new application the species is grown as a crop field in rainfed conditions and the whole aboveground biomass produced by the crop over the full development cycle is used for energy purposes. Although much effort has been made for the past 20 years, the research and development of the crop for this new application is still under way. Screeening of cynara genotypes for biomass production has been performed (Fernández 1993 & 1998, Piscioneri et al 2000, and Foti et al. 1999). [4],[5],[8],[11] Over 40 different genotypes –wild genotypes, locally cultivated genotypes, mass seed selections- have been experimented for biomass production in the framework of several european projects. The prospects and experiments carried out suggest the good performance of the Spanish seed selection 'ETSIA' and so it is has been recognised by some authors (Gherbin et al. 2001 and Piscionery et al 2000). [11]

It is well known that the main characteristics of the Mediterranean climates are the rainfall regime -low annual rainfall irregularly distributed- and the long-lasting dry period -dry and hot summers-; furthermore, in some of these climates the winter is rather cold. In rainfed conditions the unfavorable season for plant growth in Mediterranean climates is the summer, in which the high temperatures coincide with the dry season. The way in which the cynara manages to survive summertime is the drought-escape strategy: cynara has an annual development cycle and completes its reproductive cycle before the dry season begins. Aboveground plant parts dry off in summertime but the underground plant part remains alive. When the climate conditions become more favorable the perennating buds on the underground parts of the plant sprout and a new development cycle starts.

The first growth cycle starts with the seed germination, commonly in early autumn. Firstly two freshly cotyledons emerge and soon after, several leaves grow gradually resulting in a leaf rosette. Plant growth is very dependent on the hardiness of the climate conditions. The leaf rosette usually grows in a rather slowly but steady way. At the rosette stage the plant passes through winter and early spring. By late spring the plant develops a leaf-branched floral scape which eventually bears several heads. After full blossoming the fruits ripen and the aerial biomass dries up. A new plant growth cycle starts with the growth of several sprouts from the perennating buds on the underground plant organs. The main phenological stages of the development cycle are: emergence/sprouting, rosette, stem (floral scape) elongation, blossom and ripeness.

As a perennial herb the shape of the plant changes as the development cycle advances. Leaf morphology depends on the position of the leaf. Leaves arising from the rosette are much larger than the leaves arising from the floral scape. Besides, the scape leaves are usually decurrent and tend to have less leaf segments.

Cynara will germinate whenever the soil moisture and temperature are favorable. Hence, the sowing time can be autumn or spring in the Mediterranean climates. If an autumn sowing is wanted, it should be done as soon as the sowing conditions allow it so that the plant can develop a leaf rosette large and strong enough to pass wintertime. At the end of this first cycle of growth the biomass production is usually low but in the next cycles the crop yield usually increases, depending mainly on the climate conditions.

In case of a cold autumn (early frosts) the spring sowing is recommended. It is advisable to accomplish the spring sowing as soon as period of frosts is over. In most cases, plants will reach summertime at the rosette stage; some leaves can be dried up as a result of the drought and the high temperatures. When the climate conditions are more favorable for the plant growth, the plant resumes their vegetative growth and the size of the leaf rosette increases. Plants complete the development cycle in the next summer; soon after the cycle is completed, the first harvest can be carried out.

3.4. Logistics: harvesting/handling

Cardoon is harvested in August-September every year. The machinery used for this purpose in Spain was: i) a combine harvester with a specially designed pickup to separately harvest the seeds, ii) a mower to cut the remained above ground biomass into pieces, iii) a rower to swath the biomass cut and iv) a rotobaler adapted for baling cardoon biomass. [7]

The trials of mechanical harvest of cynara with conventional machinery gave poor results in spite of the different implements and adjustments and showed that specific machinery should be developed for this energy crop. Some of the difficulties experimented in the harvesting were the following:

- Seed harvest: in order to harvest all the heads the height of the cut had to be set low, consequently the efficiency of the screens used to separate the seeds resulted very poor. On average the harvested material was 63% seeds, 16% broken seeds, and 21% head and biomass remains.
- Swather: the swather removed not only the biomass but also soil and stones; the biomass was mixed with soil particles given that the field was very dry at the harvest

date. As a result, the quality of the biomass was bad. Soil contamination was recorded as an increase of the ash content of the harvested material.

- Rotobaler: this operation resulted in a very poor efficiency. About 50% biomass could not be baled due to biomass losses through the machinery mesh. In some bales the stones accompanied the biomass.

In new trials carried out in the frame of the BIOCARD project, cardoon was harvested by prototype machinery in two steps: harvesting of tops by a specially-designed pick up for harvesting the heads of cardoon and separation of seeds (step 1) and harvesting of stems and baling (step 2).

3.5. Production-Yields

Studies conducted within the framework of R&D European projects showed that the biomass production of cynara ranges between 10 and 20 t dm ha^{-1} $year^{-1}$ if the crop is well established and rainfall is about 500 mm $year^{-1}$. [4][5] In some cases, productions of over 30 t dm ha^{-1} $year^{-1}$ have also been reported. [1][8] However, the irregular distribution of the rainfall that characterizes the Mediterranean climates is a limiting factor. As it usually happens for any other crop grown in rainfed conditions, the aerial biomass production of the cynara is strictly dependent on the water regime of the productive season. In a ten-year experiment carried out in central Spain in rainfed conditions, the biomass yield ranged between 3.4 t dm ha^{-1} $year^{-1}$ (280 mm rainfall) and 25.2 t dm ha^{-1} $year^{-1}$ (765 mm rainfall), and the 10-year mean, 14 t dm ha^{-1} $year^{-1}$(470 mm rainfall) (Fernández et al. 2000). The effect of the water regime is also noticed in the partitioning of the yield components. As an average, the aerial biomass (dry matter) is 92% lignocellulosic-type and 8% seeds (sensu stricto, achenes).

3.6. Applications: current/potential

The potential of the cynara as an energy crop mainly lies in its application as solid biofuel. The main characteristics of the crop that suggest this application are: (i) relatively low crop inputs, [9] (ii) large biomass productivity: about 14-20 t dm ha^{-1} $year^{-1}$ depending on the climate conditions, (iii) low moisture content (14%) of the biomass at harvest: 14-50%, it varies with the particular conditions of harvesting, (iv) biomass composition mainly lignocellulosic: values depends on the biomass partitioning into the different plant organs; the ranges of variation are approximately,16-27% hemicellulose, 24-60% cellulose and 3-13% lignin [9] and (v) high higher heating value: about 15 MJ kg^{-1} at equilibrium moisture. The potential of cynara as solid biofuel has been studied for several years (EU Projects) and pilot-scale experiments are under way (Dahl, Graz-Austria) [7].

The oil of cardoon is similar to the oils from sunflower and safflower in its composition. The main characteristics of the crop that suggest this application are: (i) seed productivity of cynara: about 1100 kg ha^{-1} $year^{-1}$ as average [6] (ii) seed oil content: 25% as average; 33% oil was the maximum figure reported by Curt et al (2002) (iii)oil composition similar to sunflower: 11% palmitic, 4% stearic, 25% oleic, 60% linoleic, as main fatty acids of the cynara oil and (iv) higher heating value: 22 MJ kg^{-1} at equilibrium moisture.

The oil from cynara seeds can be easily expelled by cool pressing (20/25 ºC) so that its composition does not be modified and is useful for food applications. Furthermore, another possible application of the oil is the production of biodiesel. Biodiesel production from cynara oil has been presented by several authors. [2][3] The most significant characteristics of the cynara oil for its application as biofuel are its high cetane number (≈51) and the low freezing point (≈-21ºC).

Cardoon has been investigated in European level in the following projects: AIR CT92 1089 (Cynara carduculus L. as a new crop for marginal and set-aside lands), ENK CT2001 00524 (Bioenergy chains) and recently in the BIOCARD project (just completed).

3.7. Research gaps

Being a perennial rain-fed crop that can be grown in marginal lands, its biomass productivity is highly variable, depending on the climate and soil conditions, as well as on the growing period. Thus cardoon cultivation still needs investigation over a longer period before commercial yields are defined.

Harvesting of the crop in order to separate the seeds from the whole plant is still under investigation.

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14. CRAMBE (*Crambe abyssinica* Hochst.ex R.E. Fries.). Fam. Brassicaceae

4.1. Plant anatomy

Figure 14-1. Crambe

Synonyms : Crambe hispanica A. Rich., non L.
Common names: Krambe, Crambe, crambe d'abyssinie, Abyssinian- kale, chou Abyssinie,colewort

General description [2], [3], [5], [6], [7], [8], [11]

Crambe belongs to the family Cruciferae or Brassicaceae. It's an erect annual branched cruciferous herb with large pinnately lobed leaves adapted as a spring crop. Plant heights vary between 1 and 2 m, depending on the season and the plant density. The penetrating tap root can reach depths of over 15 cm. This extensive root enables the plant to draw moisture from a considerable volume of soil, and thus relatively drought resistant in the wild. The main stem branches close the ground to form secondary stems which may number thirty or more, and these again branch to form tertiary branches. The extent of branching when cultivated is affected by cultivation methods, plant population, etc., and several hundred branches can be produced on individual plants under suitable conditions. Stem color is normally a typical "cabage green", becoming greenish-yellow to yellow when mature. Height varies with soil and rainfall, and is generally around 1 m when cultivated, although it can reach 2m.

The shape of the basal leaves is a species characteristic, and is stated to be the simplest method of distinguishing between *C. abyssinica* and *C. Hispanica)*. In *C. abyssinica* it is ovate. Flower buds develop from the ten to thirteen leaf stage, and the time when this occurs is mainly dependent on rainfall and temperature following emergence.

Flowers are generally self-pollinated, but out crossing in the range 7-10% has been recorded from plants 1m apart. The flowers are whitish, numerous, small and borne on long racemes. Typically the flowering period is approximately 3 weeks. Other publication announced the flowering period usually ends about 12-15 days before physiological maturity.

[3] High temperature at flowering, 30-35°C is believed to affect pollen fertility, since there can be a considerable reduction in seed set. Low temperatures, 12-13°C, for any period affects bud/flower development, and also reduce subsequent seed production.

The fruit is a capsule, initially pale green but becoming yellow with maturity, when it also becomes covered with a well-defined network of small ridges. The fruit is two parts, a terminal spherical capsule and a much smaller cylindrical lower segment by which it is attached to a relatively long pedicle. One plant may produce 530-1,840 fruits. Each capsule contains a single spherical seed, greenish brown or brown in color, although it appears that capsules usually have two embryos initially, only one developing into a mature seed. Seed size varies considerable in the range 0.8-2.6 mm in diameter, being mainly affected by the number of seeds per plant, soil fertility and rainfall. For this reason 1000 seed weight is most variable and can range from 25 to 50g.

4.2. Domestication and area of origin

"The genus Crambe contains some thirty species, mostly perennial herbs, although a few are shrubs or annuals, distributed mainly in the Mediterranean area, Euro-Siberia and the Turko Iranian region. The annual species occur mainly the Mediterranean region and Ethiopia to Tanzania, while shrubs are apparently confined to the Canary Island-Madeira area. One species occurs in Chile. The specie *C.abyssinica* is concerned by Ethiopia. The only member cultivated of the genus is *Crambe abyssinica.* From evaluation of the literature the most probable centre of origin of the genus is the Turko-Iranian area of S.W. Asia, despite the species *abyssinica*, with migration to the Mediterranean area during ancient periods of geological and climatological change". [8], [3], [6].

Domestication [5] [7], [8], [9], [10],[11], [13]

In comparison to the cultivation of rapeseed, which is usually dated to the 20th century BC, there are apparently no records of Crambe having been domesticated or grown for its oil on any scale prior to 1932 in the USSR [8], [7], but it reached some 25 000 ha in Poland after the Second World War. Crambe has been evaluated as a potential oilseed crop since about 1932 [9]. Since about 1932, Crambe has been tried in many parts of the world, including Canada, Denmark, Germany, Lithuania, Poland, Russia, Sweden, and Venezuela. These attempts produced low yields and lower crop prices-hardly an outcome that would generate long term R&D partnerships between scientists and industry. [13]

Since then Crambe has been subject of study and research in temperate and subtropical environments. Crambe seed was first officially introduced into USA in the early 1940s through a coordinated network of federal, state, and private interests, and improved Russian and Swedish strains in the late 1950s. A breeding and evaluation program has continued since then, albeit somewhat spasmodically. Interest first surfaced in the US in 1957 when the USAD began a program of systematically screening a large number of plant species as potential new crop. Among some 8.000 species evaluated by NCAUR between 1957 and 1983, Crambe merged as a promising oilseed crop due to its high content of erucic acid. North Dakota investigated Crambe at several research centers in the late 1960s and early 1970s. Crambe appeared drought tolerant, widely adapted, and among the most promising of several potential new crops. Crambe has been successfully grown in several areas of the United States. [11]

Current situation of growing in the world

Crambe has been grown in tropical and subtropical Africa, the Near East, Central and West Asia, Europe, United States, and South America. It can be grown at elevations between sea level and 2000 m or even up to 2500 m in Kenya. It has been grown commercially and experimentally on a wide climate range. [3]. Since about 1932, Crambe has been tried in many parts of the world, including Canada, Denmark, Germany, Lithuania, Poland, Russia, Sweden, and Venezuela. [13]. It can be grown as far south as Venezuela and as far north as Sweden. [12]

According to the publications, Crambe is well adapted to broad range of climates and adapted to marginal land areas with mild winters and hot and dry summers. [14]. Crambe is a spring-sown crop suitable for Northern European climates and can be cultivated in North and Atlantic Europe [16]. It has adapted to colder or drier areas and in Northern Europe it can be grown as a spring crop if sown once the risk of frost has passed [3]. Cold tolerance would increase the locations where Crambe can be successfully cultivated and may enable it to be grown as an overwintering crop. Therefore, the outlets for Crambe are well established. In addition, it has already been demonstrated that Crambe can be cultivated across Europe from the Baltic Sea to southern. [17]

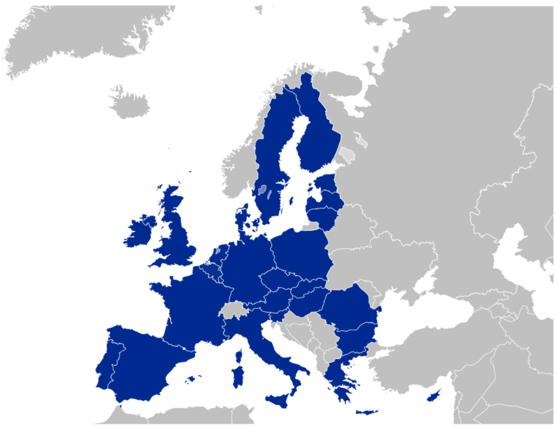

Figure 14-2. Favourable areas for growing Crambe in 27 European countries

Environmental requirements [2], [3], [6], [8], [12]

Crambe is a cool-season annual crop but does not possess a high level of frost resistance. Seedlings may survive -4 to -6°C [2] for short periods, but at all later stages of growth -1°C may kill the plant. A temperature range of 15-25°C is required over the main vegetative period [6]. It is a plant of moderate rainfall and its penetrating tap root which can reach depths of well over 15 cm enables the plant to be relatively drought resistant later in the season. The resistance of crambe to drought depends on the variety and this quality also can be enhanced by genetic selection [6].

Soil and water needs [3], [5],[8],[11],[12]

Crambe can grow on a variety of soil types with highest yields being obtained on sandy silt-loams, similar to those regions where it is found growing naturally [8],[12]. Heavy clays, sands and soil with an impacted layer which restricts root growth are unsuitable [11], [8]. Soils that have potential for crusting problems need to be managed carefully to prevent emergence problems. [5]

Crambe can withstand short periods of water logging, or grow in areas of high rainfall if the soil is permeable, but Crambe should not be grown on soils with inadequate drainage. When Crambe is grown on soil with poor internal drainage, good surface drainage is essential. [3] The plant grows and best on neutral to slightly alkaline soils, but below pH 6.0 growth and yield are usually adversely affected. However, reasonable crops have been obtained in Ethiopia on acid soils of pH 5,0 but in general such soils should not be the first choice. [8]

Tolerance of Crambe to saline soils is less than barley but greater or similar than wheat [3], [5]. Crambe seed is moderately tolerant to saline soils during germination over a range of soil temperature of 50 to 86 degrees F. As soil temperatures decrease below 50 degrees F in saline soils, Crambe seeds germination rate decreases. [5]
Crambe is independent of rainfall to a considerable extent, but there must be no water stress at flowering and pod formation. Moisture availability has a major effect on plant growth, particularly branching, and the number of racemes and subsequent fruit. Thus Crambe's "drought-resistant" properties are in fact an ability to draw on subsoil moisture, since in its absence or with lack of rain the plants remain stunted or die. As a commercial crop Crambe is not suited to arid areas of low water availability.

4.3. Growing conditions

Fertility management

Crambe's response to soil fertility is similar to that of small grains, mustard and canola. [5]. Fertilizer requirements are similar to other spring oilseed crops; best results may be achieved with around 150kg/N applied to seedbeds. [12]

Fertilizers: Reports of fertilizer trials on Crambe are rare, other than to establish whether or not fertilizers are necessary, and application levels, types and timing must be locally determined. Crambe can be deep-rooted, and thus draw on soil nutrients at depth. Additionally, if the main source of water is subsoil moisture, fertilizer placed on the soil surface or incorporated in the 10-20 cm horizon will be largely wasted. Fertilizers recommended for use on local small grains crops in the USA and USSR are also used on Crambe, and where there are large areas of grains and a small area of Crambe this is simple and economical solution. [8]

Planting [7], [8]

"The time of planting is important, since sowing outside the optimum period quickly reduces yield and can also affect seed-oil content. It is thus essential to determine this time by local trials, for Crambe's profitability is directly related to maximum seed yield. A delay of 10-14 days can be sufficient to reduce yield by 25%, therefore pre-planting and seeding operations must be well planned and quickly completed.

Two main factors are important when considering the time of sowing, and both have been previously mentioned. They are soil moisture and frost. In drier regions where soil moisture may not be high, rainfall prior to sowing will determine when this operation can be carried out to ensure a good stand. In regions where frosts limit the growing period, the time of sowing must ensure that plants have sufficient time to mature. Sowing may thus have to be delayed in those regions where there are late spring frosts, or advanced in others where there are autumn frosts. A period of 100 frost-free days should be available from planting to harvest". [8]

The seedbed for Crambe should be firm in order to place seed at a uniform and shallow depth. Seedlings are easily damaged by drifting soil. The seedbed should be prepared to avoid wind erosion". [5], [7].

Crambe can be sown by modern combine grain drills fitted with attachments recommended by the manufacturers, and some types of maize and cotton planters. Precision seeders, visually or electronically controlled, give accurate seed rates and planting depth, but unless they are already available are not essential. [8]

Seed should be sown 1.5-2.5 cm deep, but up to 4 cm is acceptable in loose soil, or to ensure the seed is sown into moist soil. A seed bed temperature around 10°C is preferable at sowing below this emergence is retarded, at 5°C normally inhibited and at 12-15°C accelerated. Seedlings normally emergence some 10-14 days after sowing when temperature is in the range 9-12°C, provided there is adequate soil moisture. [7],[8]

Crop management

Crambe crops are managed in the same way as Spring rapeseed crops. Machinery used for tillage, planting, spaying, and harvesting Crambe is similar to that used for small grains. Farmers producing small grains would not have to purchase additional machinery to produce Crambe. [11], [7]

Successful harvests have been obtained when Crambe is planted in rows 12-50 cm. Row widths of 12 to 30 cm give the best yield. Planting dept is important; it should be planted only deep enough to ensure sufficient moisture for rapid, even germination. This varies from 0.5 cm to 2.5 cm depending on the region. In North Western Europe, spring sowing is the only viable option with current material as there is a very high temperature dependence of field emergence. In Northern Europe sowing can only take place from beginning of April. A crop density of 75 -200 plants/m^2 is advisable for high yields (15-20 kg/ha).For autumn sowings in Italy, the optimum husbrandy is to sow 50 seeds/m^2. In the UK commercial sowing rates range from 10-20kg<ha depending on variety and thousand grain weight. **[**3], [7],[8]

Similar to rape, there are arguments in favour of wide or narrow rows, but row-width is most profitably related to the machinery available and method of harvesting. [8]

Pest and diseases

Young plants may be at risk from slugs depending on soil conditions and birds may cause seed losses at ripening. Seedlings may be attaked by flea beetle (Phylltrea cruciferae). Also pollen beetle (Meligethes aeneus) may attack young flower buds; a yield response has been observed where bee friendly insecticides were used. [12]

Crambe has been found to be susceptible to *Alternaria* and *sclerotinia* and a well-timed fungicide application at the mid-flowering stage has had a yield response (up to 1t/ha) and may also improve oil content. Fungicide dressed seed may also beneficial. Plants are susceptible to the same range and pests and diseases as those of oilseed rape including beet cyst nematode (Heterodera schachtii). [12]

Crambe was successfully commercialized, because of its inherent ability to compete with weeds, ward off insects, and escape diseases without help from pesticides. [9]

Herbicides

Herbicides labeled and used are much the same as those used with canola, with soil-applied dinitroanalines applied pre-plant the most popular. The most troublesome weeds are often those that mature late, once the Crambe crop is drying down. Though competition with these weeds may not directly reduce yield, it makes harvest more difficult.

4.4. Logistics: harvesting/handling

After flowering, Crambe matures rapidly (one to two weeks). Timely harvest is important to avoid high shattering losses. During warm dry weather the crop should be frequently monitored (daily or every other day) to determine correct harvest stage. Crambe is physiologically mature when 50 percent of the seeds have turned brown. According to E.A. WEISS, "Crambe is mature when the majority of leaves have fallen; the upper part of the stem is yellow, and when at least 75 per cent of the capsules have turned yellow. This is usually some 90-100 days after planting. [8] Attention should be directed to the seeds and seeds-bearing branches to determine the onset of harvest." [5]

Extensive branching is considered to be a disadvantage for mechanical harvesting, since inch terminates in a raceme. Thus, although branching may increase individual plant yield, by extending the flowering period it may increase loss from frost and pests or number of immature seeds harvested. [3], [6], [8]

Standard grain harvesters are suitable for combining of threshing Crambe, provided that the drum, concave and fan are correctly adjusted. No attempt should be made to separate the hulls from the seed during harvesting. [8]

Crambe can be swathed to dry in the field, but most growers prefer to harvest Crambe direct with combine headers commonly used with wheat. Unlike canola, Crambe cannot be swathed before the majority of the seeds are physiologically mature, since erucic acid content of the oil is lower in immature seeds. Crambe stubble is easily managed, and requires little fall tillage. The residue is valuable to reduce wind erosion and is an efficient snow trap during the winter. [9]

4.5. Production-Yields

Yields of 1,500- 2000 kg/ha have been reported in Europe and the USSR, slightly less than this in the USA; average yields of 2,500 kg/ha are most likely to be achieved [6], [8], [12], [13]. The oil production potential of Crambe is about 589 kilogram of oil per hectare. [10]

Production costs

Economically, Crambe has been advantageous. Certified seed costs are generally less than \$12 ha^{-1} for the typical 22 kg ha^{-1} seeding rate. The fertilizer requirements have been found to be no greater than wheat and herbicides are among the most inexpensive available. Insecticides are not required.

During a typical harvest, Crambe seed does not require drying. Investment in more equipment is not required either, since Crambe can be grown with equipment traditionally used to produce small grains.

4.6. Applications: current/potential

Composition of oil content

Crambe seed is composed mainly of oil, a nitrogen-free extract, and protein. [6]. Seeds contain oil in the range of 35-60 %, protein 20-40% and the erucic acid content of the oil ranges from 35 to 65%. Crambe abyssinica had the highest erucic acid content (Dolya et al., 1977). The oil can also contain up to 10% linoleic and 20% oleic acid. Interest in Crambe has resulted because its oil is high in erucic acid. [3], [6]

Table 14-1. Oil profile of crambe

Authors	CRAMBE (Abyssinian mustard) Last uptades : October 2005 **[3]**	AgGrow Oils LLC INFORM, Vol. 10, no.9 (september 1999) **[13]**	Donald L. Van Dyne, Melvin G.Blase, Kenneth D. Carlson, **[6]**	**[19]** Appelqvist and ohlson, 1972; Kramer et al., 1983; Princen and Rothfus, 1984.	**[20]** CETIOM, Oléoscope n°29- Septembre-Octobre 1995
Palmitic C16:0	1.8% of total		2		2.38-3.69
Stearic C18:0	0.7%				0.89-1.12
Oleic C18:1	17.2 %	16	15	17	17.88-22.21
Linoleic C18:2	8.7%	8	10	9	8.37-10.44
Linolenic C18:2	5.2%	5	7	6	6.05-6.78
Eicosanoic C20:1	3.4%		3	5	3.77-4.75
Behenic C22:0			2		1.71-2.16
Erucic C22:1	56.2% (58-66)	> 55	50-60	55	49.06-57.41
Brassidic C22:1	0.7%				
Tetracosanoic C24:0	0.7%				
Nervinic C24:1	1.6%				
Others:	2.5%				

The erucid acid content of oil in developing seed increases from approximately 25-30 per cent 14 days after fertilization to 40-45 per cent 1 week later, and reaches 55-60 per cent at maturity. [6]

Composition of expeller-pressed Crambe oil [13]
Free fatty acids: <0.5%
Iodine value: 85-90
Insoluble impurities: <0.01%
Sulfur (varies by specifications): 30-60 ppm.

Oil yield: 32-36% [13]

In seed with 30 to 45 percent oil by weight, 29-44 percent will be extracted [6]**.**

Applications

Interest in Crambe is three-fold (1) the seed oil is one of the richest known sources of erucic acid, (2) rapeseed oil, traditional erucic acid source, is being altered genetically to contain less erucic acid, and (3) Crambe appears to be a better potential domestic crop than rapeseed (Lessman and Anderson, 1981). Interest in Crambe oil originally focused on the high percentage of erucic acid, which had significant implications for industrial uses, specifically the plastics industry. Crambe oil's ability to withstand high temperatures and remain liquid at low temperatures make it a quality lubricant and transfer oil. Because it is a very effective lubricant and much more biodegradable than mineral oils, this oil may be used alone or as additives for the textile, steel and shipping industries. Recent experiments, carried out during the Concerted Action in co-operation with some private companies, showed that Crambe oil can effectively replace mineral oil in many mechanical industry processes, viz.Metal working, lubrication, quenching, cutting, etc. Crambe appears to be a promising crop because of the many possible uses of its seed (pharmaceuticals, detergents, cosmetic, ceramids nylon and perfumes etc.). [14]

More recently it is also being considered as an oil for use in biofuel production, because its oil content ranges from 35 to 60 percent with potential yields of over 2,000 pounds per acre. The oil production potential of Crambe is about 589 kilogram of oil per hectare”. [2], [7], [10], [15], [16]

Erucic acid is used mainly as erucamide, an effective on-stick agent in polyolefin films for wrapping food, plastic bags, shrink wraps, lubricants, plasticizers and foam suppressants etc. [9] It can also be converted to nylon 1313 (('Nylon 1313', a tough form of nylon used for molded plastic, for articles as bearings and heavy fibers in brushes, as an additive in plastic films to prevent sheets from sticking together, in plasticizers to keep them soft and flexible. [7]), or hydrogenated to behenic acid, which also has many applications in the manufacture of rubber, pharmaceuticals, cosmetics, fabric softeners, hair conditioners and rinses. [15]

“Processed seed meal can be used in animal feeds. Demand for Crambe oil has been seen rapid uptake of the crop recently in the UK”. [12]

Hull-free seeds contain about 26% protein. Crambe meal is used as plywood and rubber adhesive, as a source of protein isolates, and as an additive to waxes. Crambe meal, after unpalatable material is removed or made inactive, may be used as supplement for ruminants not to exceed one-third to one-half of the supplement; it is not recommended for pigs and poultry. The meal is also used as an insecticide. It is used in crop rotations for alleviating weed, pest and disease build-up”. [2], [7]

-Triglyceride (refined oil) : phamaceuticals, lubricants, heat transfer fluids, diemectric fluids, waxes, fish food coating agent;

-Erucic acid: Erucamide, plasticizers, antistats, corrosion, inhibitors;

-Behenic acid: behenamise, antifriction coatings, mold release agents, processing aids, flow improvers, cosmetics;

-Erucyl alcohol: Surfactants, slip and coating agents;

-Behenyl alcohol: Surfactants, slip and coating agents;

-Wax esters: lubricants, cosmetics;

-Fatty acids: existing markets for C18-C22 acids and their amides;

-Brassylic acid: Nylon, perfumes, plasticisers, synthetic lubricants, coatings, flavours;

-Pelargonic acid: Perfumes, palsticisers, synthetic lubricants, coatings, flavours. [3]

4.7. Restricting factors

Genetic variability in *C. abyssinica* appears to be restricted and other sources will probably be necessary to increase its potential and profitability. [8]

"A limiting factor would appear to be the narrow range of germplasm available. The high erucic acid content of the seed oil reduces its value for edible use (Cf.rape), but this is of secondary importance since it has many industrial applications". [8]

"Planting depth is a critical factor in obtaining good Crambe yields". [11]
"A critical phase of successful Crambe production is stand establishment". [5]

"Weed control is critical management factor in Crambe production. The crop is not a strong competitor with weeds during early vegetative development. Typically, three to four weeks is required for a 100 percent crop canopy to be formed after mergence. It is during this period that the biggest challenge for weed control exists" [5], [7]

Crambe, unlike rapeseed and most other crucifers, has each seed encapsulated in its own hull. This reduces test weight by more than 50%, to about 322 kg m^{-3} (25 lb bu^{-1}). Such a bulky commodity increases the cost of transportation from the farm gate to the processing facility, and misleads the grower in visually estimating dockage, or foreign material, in the harvested seed. [9]

4.8. Research gaps

Crambe is one of the sources of raw vegetable material with the most serious potential to compete with erucic rapeseed. Selection programs carried out in Canada on this species have opened up some very interesting perspectives.

Crambe has a higher erucic acid content than erucic rapeseed, but this is attenuated by its oil yield. Crambe oil shares the same properties. [21]

Competitive Products and Intensity

Rapeseed is the current oilseed of choice for erucic acid in national and international markets; however, Crambe oil typically yields 8 to 9 percent more usable oil. The limiting factor for expansion is lack of processors and market points to move the industry. When the USDA delisted Crambe, it reported only one commercial buyer of Crambe oil; the remainder was grown under contract for specific applications. In addition, supporting research and specific demand from end users will be essential for moving this industry forward. As an industrial lubricant, it must also compete against petroleum product alternatives.

Another consideration limiting widespread Crambe utilization is transportation costs. Because of its low test weight, the product cannot economically be hauled long distances. Additional processing infrastructure is needed to expand production; currently, processing facilities are extremely limited.

Restricting factors for Crambe growth:

- Germinative capacity of seeds (whether they are sown with or without their silicule) and Sowing density is limited. More research on plant spacing is required

-Yield levels remain low.

-The fertilization process is not fully understood, it appears to be sensitive to temperature. Seed production was very low in 1995 (due to high temperatures).

-Disease diagnosis needs to be undertaken (crown necrosis, wasting away: black and dry roots). It has been suggested that the plant may suffer from bouts of sensitivity to Phoma. **[22]**

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15. CUPHEA (Cuphea spp. L) Fam: Lythraceae

5.1. Plant anatomy

The genus *Cuphea* comprises more than 260 species, both perennial and annual, including herbaceous plants, with erect stems up to 1.5 m tall, and climbing species, mainly from tropical areas.

Figure 15-1 *Cuphea spp*.

Leaves are opposite and herbaceous, but tropical species have more leathery leaves adapted even to highlands with characteristics of xenomorphic adaptations, like thickened needle shaped and rolled leaves.

Inflorescences are collected in racemes that takes half or a third of the distal part of the whole stem and all ramifications. Inflorescences develop undetermined, namely they keep on growing and blooming for a prolonged period. The flower is calyx shaped and it is set up by six petals, with a bilateral symmetry. The colour of the petal are ranging from purple to yellow. The base of the calyx is humpy, as it is described in the etymology of the genus name, indeed *Cuphea* arise from the ancient Greek word "Kyphos", that means hump.

The fruit is a dehiscent capsule, that tend to slice through the dorsal part exposing the placenta harbouring from one to two hundred seeds. Glandular hairs excreting exudates or non viscous hairs are distributed all along both the vegetative part and the inflorescences. This feature made the plant particularly resistant to insects. [10] The plant reproduction strategies are mainly two: indeed, species with medium-sized flowers reproduce by cross pollination (*C. lanceolata, C. procumbens, C. laminuligera*), while small-sized flowers (*C. wrightii, C. tolucana, C. lutea, C. paucipetala, C. leptopoda*) by self pollination. [10]

5.2. Domestication and area of origin

Native to Americas with several species adapted to both temperate and tropical environments, ranging from the north-western states of USA to the fallow lands of southern Argentina. The genus *Cuphea*, the largest in the *Lythraceae*, comprises approximately 260 zygomorphic-flowered, herbaceous species, primarily of the New World tropics, which are assigned to two subgenera and fourteen sections. Cuphea is distinguished from the related genus *Lythrum* L. and *Pleurophora* Don. by a unique seed dispersal mechanism. The genus has two centers of species diversification, one in the south eastern Brazil and a secondary center in western Mexico. 41 annual species belongs to the section *Heterodon*, that is the most interesting for agronomy, and it predominantly comprises Mexican annuals. In this section, many species are common in roadside floras or occur in open, moist, disturbed habitats, but there are even many endemics of narrow distribution on the brick of extinction due to the conversion of their habitats to agricultural lands. [10]

Rapid speciation and expansion after introduction of the ancestral line from eastern South America into Mexico are believed to have been promoted by extensive orogenic and physiographic changes associated with mountain building during the Tertiary. For the *Heterodon* section, evolution apparently proceeded in two directions. A group had been generated from outcrossing perennials with medium-sized flowers to small-flowered, self-fertilizing annuals, whose seed oils are composed primarily of lauric acid. Another group had developed to large-flowered, outcrossing annuals whose seed oils are composed primarily of capric acid.

Generally, the plants of the genus had been used as ornamentals, but recently new insights on the nature and the products of the plants of this genus had been highlighted. Thanks to these studies, it has been possible to envisage the characteristic of the oil components of the seeds of several plants of this genus; up that nowadays the plant products have different application as industrial oils.

5.3. Growing conditions

A number of agronomic studies have been conducted to determine the adapted growing area, sowing date, seeding rate, row spacing, plant density, weed control, water requirements. [2][3][8]

The different species adapt to different types of soil, from sandy to clay with a tendency for lightly acid soils (pH from 5 to 6,5). The plant is well adapted to both conditions of high and low availability of water, thus the right species could be suitable for a dry culture. Anyway, we are not aware of any studies on seed and oil yield response to irrigation. Also, little information is on the effects of nitrogen fertilisation on seed yield, oil content and composition. Generally speaking it is recommended to apply 50 kg/ha of potassium sulphate along with 200 kg/ha of di-ammonium phosphate and 100 kg/ha of urea. These estimations were based upon crop mineral uptakes. [2]

Under the European environmental conditions the cycle length of Cuphea ranges from 100 to 130 days. The optimal sowing time is in late April, while the harvest is in late August. Cultivation density should be approximately of 30 plants/m^2 30 cm row spaced. Because of the low early competition of Cuphea weed control should be accurately done to favour the young plants growth.

Table 15-1 Ecological requirements for the cultivation of *Cuphea spp*.

Cuphea Ecology							
Growing period		**Seed germination T°**			**Precipitation**	**pH**
Seed	Harvest	Base	Optimum	Max	Range	Range
May	September/October	3-11 °C	18-24 °C	33-38 °C	10-60 dm	5-6.5

5.4. Logistics: harvesting/handling

More extensive research trials have been conducted in North America to determine the best harvest date, harvest methods [9], and post-harvest treatments [5]. At the opposite, in Europe this species has attracted very little interest by the research. The major bottlenecks of this crop are indehiscence and indeterminate growth that makes Cuphea very unsuitable to common harvesting systems present in the farms.

5.5. Production-Yields

Cuphea gives a seed yield range of 350 – 1500 kg/ha (mean 900 kg/ha) [2][3] [9][8] at with an oil content of 27 – 35% and oil yields 240 – 300 kg/ha. The seed contained 32% (dry basis, db) oil and 21% (db) crude protein. Glutelins and albumins accounted for 83.5% and 15.4%, respectively, of the total protein extracted.

In Europe, Cuphea has an established market for ornamental uses, whose breeding programs have generated several different hybrid lines. On the other hand, other applications of Cuphea (i.e. biofuels, resins, varnishes, fatty oils) still remain very little understood.

In the '90s, a number of studies were conducted in Germany, Spain and Portugal. Researches were made at preliminary level, involving plant adaptation studies, breeding programs and basic agronomy, but the outputs obtained were generally insufficient [11]. Parallel research studies were carried out in Italy by the University of Bologna and Pisa, however in both locations no promising results on the domestication of this plant were obtained using genotypes available at that time, not only for the low yields but also for the harvesting difficulties due to the inherent seed shattering. Anyway, according to that experiences, the most adapted species for Europe appeared *C. leptopoda*, *C. lanceolata*, *C. wrightii* and *C. laminuligera* . [10]

In contrast, Cuphea has been extensively studied in North America since '80s. According to the USDA Agricultural Research Service, the yields obtained for this crop to extract C:10 oils were generally not sufficient to allow this crop to compete with the higher yielding crops

Palm oil and Coconut. For example, in Central Illinois Cuphea yielded an average 0.2 t/ha of oil in front of a calculated break even yield of 0.5 t/ha. [2] At such low yields, the primary market for the crop can be restricted to specific high-value products such as cosmetic uses to which respect Cuphea seems to produce a very suitable oil (high solubility, dispersibility and oxidative stability).

It should be recognized that most of these experiences on Cuphea derives from North-American studies that in many cases refer to local and old genotypes which might not reflect the new potentialities of the recently selected lines. For example, the high-yielding hybrid *C. viscosissima* Jacq. X *C. lanceolata* WT can be expected to reach high yield in Europe as well as it did in USA.

Quality

Cuphea seed oils have an high content in medium chain triglycerides (i.e. capric acid, caprilic acid, lauric acid and myristic acid) very required for the industry of detergents and soaps. In particular, it is of great interest the content of lauric acid, for which the European market is dependent from the import from tropical countries, where lauric acid is extracted from palm and coconut oils. Besides, capric acid is very important to produce varnishes, resins and disinfectants, but the main source to produce is petroleum, thus there is a big need to find an alternatives origin for its extraction.

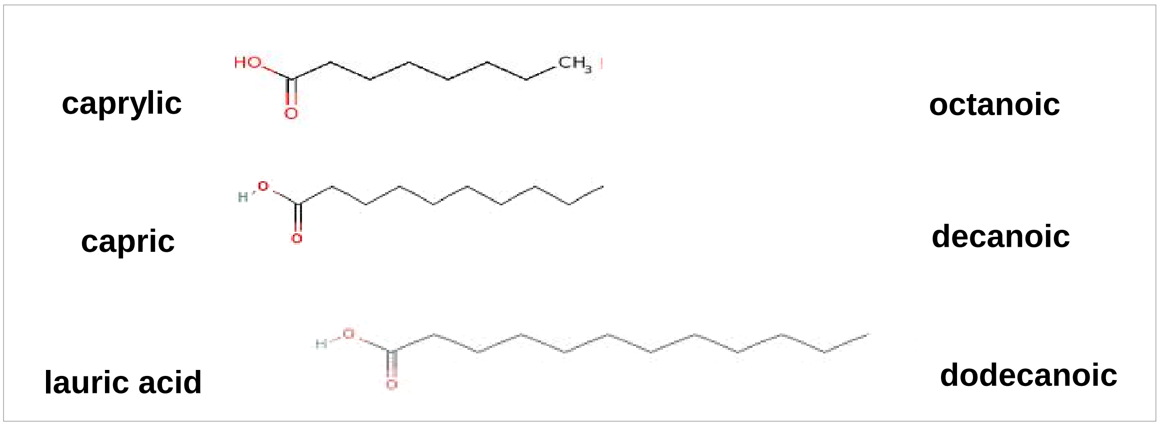

Figure 15-2 Major fatty acid compounds and their structure of the Cuphea oil

For instance, *Cuphea koehneana* seed oil is the richest source of capric acid, containing approximately up to 95% of the overall oil composition.

Cuphea seed oil (Table 2) is rich in medium-chain fatty acids (MCFA) such as caprylic (C8:0), capric (C10:0), lauric (C12:0), and myristic (C14:0). *C. lanceolata* has high capric acid (70%) and *C. llavea* has about the highest level of capric acid (92%) (Wolf, 1983). The typical fatty acid distribution includes 70% capric, 3% lauric, 4% myristic, 6% palmitic, 9% oleic, and 5% linoleic acids. Cuphea oil has an iodine value of 19.7, and a high oxidative stability of 157 hour at 110 °C which is comparable to that of coconut oil (*Cocos nucifera* L., Arecaceae). The content of free fatty acids (4.2%) and chlorophyll (200-260 mg/kg) in the crude oil are high (Berti et al, 2008).

Table 15-2 Major fatty acids in seeds of different species of *Cuphea.* (source: IENICA Project)

Species	8:0 Caprylic	10:0 Capric	12:0 Lauric	14:0 Myristic	Others
C. painteri	73.0	20.4	0.2	0.3	6.1
C. hookeriana	65.1	23.7	0.1	0.2	10.9
C. koehneana	0.2	95.3	1.0	0.3	3.2
C. lanceolata	87.5	2.1	1.4	9.0	0.0
C. viscosissima	9.1	75.5	3.0	1.3	11.1
C. carthagenensis	5.3	81.4	4.7	8.6	0.0
C. lamimuligera	17.1	62.6	9.5	10.8	0.0
C. wrightii	29.4	53.9	5.1	11.6	0.0
C. lutea	0.4	29.4	37.7	11.1	21.4
C. epilobiifolia	0.3	19.6	67.9	12.2	
C. stigulosa	0.9	18.3	13.8	45.2	21.8
Coconut	8.0	7.0	48.0	18.0	19.0

5.6. Applications: current/potential

The properties of cuphea oil make it ideal for biofuels, including jet fuel (Cermak and Isbell 2002). The addition of cuphea oil to jet fuel reduces the freezing point of the fuel avoiding fuel-gelling problems at –20 °C. Oil from *C. viscossisima* VS-320 has a low viscosity, greater than diesel fuel, but less than rapeseed oil (Berti et al., 2007). [2][3]

Medium-chain fatty acids can be used to replace saturated fatty acids and plasticizers in chewing gum.

Cuphea oil also performed successfully as flow carriers and solvents in the candy industry, and as defoaming agents and boosters in soap and detergent manufacturing. [2] Cuphea oil can be used in cosmetic products such as lipsticks, lotions, and creams and bath oils. The oil has a high oxidative stability, low to medium spreading with a low slip value which provides desirable non-slippery characteristics for sunscreen purposes. [3]

Table 15-3 Main applications of the three major fatty acid compounds of the oil of *Cuphea* spp**.**

Caprylic acid	**Capric acid**	**Lauric acid**
esters	perfumes	soaps
perfumes	lubricants	shampoos
dyes	greases	detergents
antimicrobials	rubber	surfactants
surface sanitizers	dyes	antimicrobial
disinfectants	plastics	heat storage
pesticide	food additives	
	pharmaceuticals	

5.7. Restricting factors

This review already stressed out the main constraints that have so far limited the development of cuphea. It should be recognized at least three major constrains: i) seed shattering trait, which can be helpful for wild propagation, but that created serious difficulties in harvesting a crop; ii) undetermined flowering; blooming occurs in three to four different periods, again making this plant difficult to be harvested in an economic way; iii) long term maturation and high moisture content, greater than 50%, at harvest. [5]

Another important issue to generate new hybrids is the difficult in 'typification' of the genus. [12] Even stickiness resulted in an important constraint, in particular this trait is negative for harvest mechanization as it may cause clogs.

Technology which would allow the cultivation and harvesting of cuphea using modern agricultural methods would have the potential to create a new, high-value, oil-seed crops for European industries. Nonetheless, some important agronomic and biological aspects such as seed shattering, stickiness and dormancy can limit drastically the development of these crops. Most of these issues are now being faced in the USA and Canada by plant breeders, while in Europe the research activity is still weak.

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16. ETHIOPIAN MUSTARD (*Brassica carinata* L.) Fam: Brassicaceae

6. 1 Plant anatomy

Brassica carinata L. Braun (Ethiopian mustard) is an annual crop, which is mainly grown in warm tropical regions. It belongs to the genus Brassica, of the large family of plants known as mustard (*Brassicaceae*). *Brassica carinata* is derived from a cross between *Brassica oleracea* and *Brassica nigra* L. Kock. It is related to rapeseed (*Brassica napus* L.).

Figure 16-1 Ethiopian mustard fields in Greece at several stages of growth (early stages of growth, flowering and harvesting time) [source: CRES]

It is a tall, leafy plant [8], well adapted in the Mediterranean climate. It can be grown either as winter or spring annual crop.

7.1. Domestication and area of origin

Brassica carinata is an amphidiploid with one genome from *Brassica nigra* (L.) Koch and the other from *Brassica oleracea* L. Ethiopia is the centre of genetic diversity of *Brassica carinata*, and its cultivation is thought to have started there about 4000 years BC. The cultivation of *Brassica carinata* as an oil crop is restricted to Ethiopia, but as a leafy vegetable it is often grown in East and southern Africa, less so in West and Central Africa [12]

It is originated from Ethiopia and its cultivation is limited to the Ethiopian Plateau and Kenya. Even though it is originated from Ethiopia, records from the Greek experiments and other

Mediterranean countries indicated that, selected varieties can adapt well resulting to satisfactory yields in the Mediterranean soil- climatic conditions. [5]

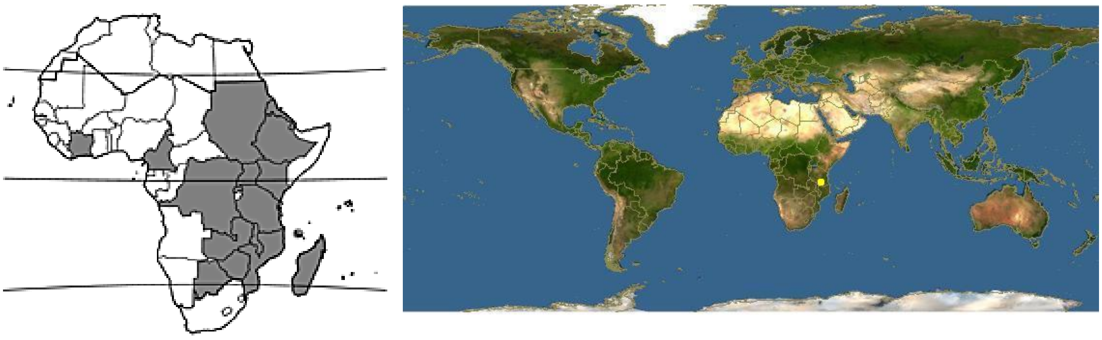

Figure 16-2 Brassica carrinata distribution ([12] on the left and [2] on the right)

7.2. Growing conditions

Vulnerability to cold temperatures at the initial growing stages has been observed, thus its cultivation is recommended only to areas free of severe winter conditions (FAIR CT96 1946). **[5]**

Several studies have shown that the seed-yield potential of different "genotype" of *B. carinata* is superior to that of rapeseed in Mediterranean and dry climates. [5][13][4][10]

B. carinata presents certain agronomic characteristics which make it suitable as a winter crop, alternative to cereals, in the Mediterranean countries. The most important are: 1) its well - developed root system, which is mainly the reason for its natural drought tolerance [11], 2) its high natural resistance to most of the prevailing diseases and pests, compared to other Brassica species, 3) low fertilisation requirements compared to conventional crops, d) non-dehiscent siliques, a fact which is very important since it is harvested under dry conditions [5], e) It's fast and exuberant growth allows the efficient interception of solar light [3] and f) the flower disposition in *B. carinata* does not shade the leaves as in other Brassica species. Thus, the photosynthesis continues during flowering and leaf senescence is not induced by shading.

The crop is at an experimental stage. There are two major types of ethiopean mustard: edible and industrial. *Brassica carinata* is widely used as food (especially the leaf) and edible oil. The industrial type contains both high erucic acid and glucosinolates unacceptable as a food or edible product.

Generally, Brassica varieties have a relatively small seed that varies widely in purity, colour & germination. The seeds of *Brassica carinata* as the other brassica genus are very small and contain about 40% oil which is extracted by crushing to leave a high protein containing meal. The meal is used as animal feed as well as fertilization.

Cultural practices are similar to conventional crops (winter cereals). Special attention should be given to the applied herbicides (pre-emergence and post-emergence) since the crop is very sensitive to weeds. This species may be treated as rapeseed. i.e., the tradition rapeseed techniques can be applied. As a general guide these are the general recommendation: a) planting rate about 200 seed/m^2; i.e., about 8 kg/ha, b) the soil depth should be 1 to 2 cm and c) the row spacing usually should be 30 cm and d) and should be planting either in autumn (first half of October in cold areas and second half of October or early November in mind areas) or in spring.

Brassica carinata can be grown on soils which vary from pH 5.5 to 8.0. Good drainage is essential. Winter sown in particular has a little tolerance for heavy, wet soils and a high water table. Wet soils can significantly reduce winter survival and contribute to root disease. Rape grows best in sandy loams, loams with high organic matter, and loam sands. Light soils are acceptable and even ideal when adequate moisture and nutrients are available.

7.3. Logistics: harvesting/handling

Harvest is a critical operation and losses can be heavy due to the small seeds and because the growth habit prevents all seeds in a crop maturing at the same time. Furthermore, early harvesting can reduce seed quality and late harvesting can enhance pod shuttering. The moisture content of *Brassica carinata* at harvest time of the seed must be around 7-9% and it's recommended for safe storage of rapeseed to be dried to less than 9%. [5]

7.4. Production-Yields

In Greece, experimental data indicate that fresh and dry seed yields could reach up to 1.42 t/ha and 1.21 t/ha, respectively. [3]

Concerning solid biomass production, dry matter yields ranged from 3 t/ha to 8 t/ha were recorded in central Greece, in fertile soils. In the view of the Brassica carinata project a large number of lines were tested and the biomass yields found to be 16t/ha in the wet areas and 10t/ha in the dry areas. It was found that it was not possible to obtain lines with low erucic acid and with oil content similar to rapeseed.

The Spanish Centre of Energy, Environment and Technology Research (CIEMAT) have compiled agricultural production data for Brassica carinata from 160 ha. The agricultural fields where B. carinata has been cultivated have been monitored using current agricultural productions procedures. As a consequence, the final results of the environmental and energetic performance can be extrapolated to other southern European regions with similar soil and climate conditions. [6]

It was found that the maximum seed and biomass yields for Brassica carinata when it was cultivated in the Mediterranean countries recorded when the sowing took place from middle of September to the middle of October. At sowing 8 kg/ha of seeds are needed for the good crop establishment and for yields maximisation. It was not found to be particular demanded crop in nitrogen, sulphur, due to its tap root that makes good uses of fertiliser remaining from previous crops. It was found that is a very interesting preceding crop for a cropping system of cereal, well adapted to soil with lower nutritional levels. [5]

7.5. Applications: current/potential

In comparison to Canola (zero erucic, low glucosinolates cultivars of Brassica spp.) oil types, present forms of zero erucic-acid Ethiopian mustard (Brassica carinata A. Braun) are characterised by a seed oil relatively low in oleic acid (mono-saturated) and rich in linoleic and linolenic acids (poly-unsaturated). The oil profile of zero erucic-acid Ethiopian mustard consists of 33% oleic, 37% linoleic and 21% linolenic acid [1][7][4] compared to 61% oleic, 21% linoleic and 11% linolenic acid in Canola [14]. The increase of oleic acid concentration and the simultaneous reduction of polyunsaturated fatty acid levels are important breeding objectives in Ethiopian mustard.

Two types of oil from B. carinata have been studied for the production of methyl esters by transesterification. One was characterised by a high content of erucic acid (HEAR) and the other was a low erucic acid type (LEAR). The presence of unsaturated fatty acids affects negatively the oxidation stability of biodiesel. Of the two B. carinata oil samples the behaviour of the low erucic acid oil (LEAR) was significantly worse than that of the rapeseed methyl esters. In contrast, the high erucic oil (HEAR) was similar in behaviour to the rapeseed methyl ester, with a lower iodine number, despite a difference lipid profile.

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17. HONESTY (Lunaria annua) Fam: Brassicaceae

7.1. Plant anatomy

Lunaria annua L., commonly known as honesty, belongs to *Brassicaceae* family. It has biennial cycle divided into a vegetative growth in the first year, and reproductive phases in the second year. It produces fruits that dry quickly. It is up to 1 m tall with erect stems, branched and stiffly hairy; the leaves are cordate-acuminate, coarsely toothed, triangle-shaped.

Figure 17-1 *Lunaria annua*

The flowers have four petals, each 1 cm in diameter, from purple to red up to whitish. The green seedpods are large, circular and flattened and are firmly attached to the stem. Seeds are large, strongly compressed in two rows. Each seedpod is ovate, up to 3 cm in diameter and harbours up to ten ovate seeds. A flat, thin-walled, translucent typical silicula is formed during the ripening process leaving a dry 'Silver Penny' which is used in floral compositions.

7.2. Domestication and area of origin

Honesty is a well-known ornamental plant that was introduced to Northern parts of Europe several centuries ago from its native areas in Southern Europe and West Asia. It has now become naturalised as a wild flower in some areas and is sometimes prominent during spring months in waste places, particularly by hedgerows.

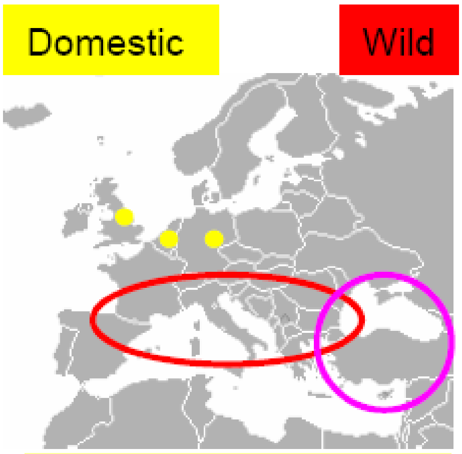


Figure 17-2 European distribution of *Lunaria annua*

7.3. Growing conditions

It is rustic and quite easy to grown though it prefers freshly soils set screened from direct light. It is well adapted to temperate climate. In ornamental gardens, plants shed their seeds in late autumn and seeds germinate in the very early spring. During the first year after germination, plants remain in a vegetative stage until early next spring. Thereafter it starts the reproductive phase blooming in April to May. After flowering disk shaped pods are produced containing up to six to ten flatten seeds. At the end of summertime, seeds get ripened and the pods turn its colour to whitish; then after removal of the pods outer layer a silver coloured false septum remains which is an appreciated ornamental value.

7.4. Logistics: harvesting/handling

Honesty often does not thrive in large open fields. At present commercial production of honesty is limited to seed multiplication for ornamentals.

The influence of sowing date on yield can be extracted from a recent research paper of Walker and colleagues [4], that had set up field trials of *L. annua* in Scotland, sowing on different periods. Sowings were made on May the 11th, June the 18th and July the 3rd, and the yields ranged from 1.1 to 1.9 t/ha, defining the best sowing date for Scottish latitudes in June. Different sowing dates did not affect the oil composition. Generally speaking, sowing must be done early enough to allow the plants to develop sufficiently before winter. Experiences in England suggest that July is the latest month for sowing honesty.

Some growers have attempted to minimise the consequent disruption to customary farming practice by under-sowing the crop in cereals. It is suggested that a suitable target plant density is about 50-60 plants per square metre, which should be obtained by the shallow sowing of 15-18 kg seed per ha, in narrow rows (10-15 cm). [1]

7.5. Production-Yields

The effect of agronomic inputs and yield data are very limited for honesty as the plant has been mainly used as ornamental so far. Some authors have reported in the '90s about current and potential seed yield in different area of cultivation including Germany and

England. It is reported that the maximum potential seed yield is 2.6 t/ha with a seed oil concentration of 36%. Studies conducted in Germany in that period reached a maximum seed yield of 1.2 t/ha, but those conducted later in south-western England achieved a seed yield in between 1.5 and 2.6 t/ha.

Quality

The potential of honesty as a new oil crop lies in its fatty acid composition and in its high caloric value as an hydrocarbon, moreover it has a very low flash point, high cetane rating and good lubrication qualities. Concerning the composition, it contains up to 40% of oil, which is rich in long chain fatty acids with high proportions of unsaturated fatty acid, as erucic and nervonic acids. The seed oil contains up to 40% of erucic acid (C22) and 20% of nervonic acid (C24). *Lunaria* spp. is a natural source of the spermidine alkaloids Lunarine, which possesses effects on the cardiovascular system, smooth muscle, carbohydrate metabolism, and glandular secretions.

Table 17-1 Seed oil composition of honesty

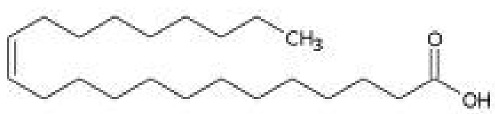
Name	Fatty acid	Range %
Palmitic acid	C16:0	1 – 3
Stearic acid	C18:0	1 – 2
Oleic acid	C 18:1	16 – 20
Linoleic acid	C18:2	8 – 10
Linolenic acid	C18:3	2 – 4
Erucic acid	C22:1	38 – 48
Nervonic acid	C24:1	22 – 25

7.6. Applications: current/potential

Honesty is an interesting oil plant. The composition of its seed oil is renown since 1960, and it is typical of the *Brassicaceae* family. The high content of erucic acid and its high tolerance to elevated temperatures makes the oil suitable for the production of transmission oils. Erucic acid is renowned to polymerise and dry readily, forming many organic compounds, for this it is employed in emulsions manufacture, for example in coating photographic films and papers. The oil is applied even for the production of erucamides, which are then used in the plastic film industry to resist each film to stick together and made the product stable. The high content of erucic acid makes the oil particular interesting for the industry of lubricants, paintings and engineering nylons. Moreover, due to the presence of erucic acid the oil is suitable to produce emollients, especially those to apply to human healthcare. The role of erucic acid on human health is still debated. The folkloristic medicine described it as protective agent against cardiovascular diseases, due to its ability to make the blood platelets less sticky. Otherwise, there are reported cases of lipodosis in rats fed with erucic acid and increased incidence of lung carcinoma through smoke emission under high heat of over heated oils with high erucic acid content.

Other compounds of the seed oil of *L. annua*, like "Lunarines" makes it suitable for some pharmaceutical preparations and are of general interest for their application in antimicrobials. The macrocyclic spermidine alkaloid "lunarine 1" from *Lunaria annua* is a competitive, time-dependent inhibitor of the protozoan oxidoreductase trypanothione reductase (TryR), a promising target in drug design against tropical parasitic diseases.

erucic acid

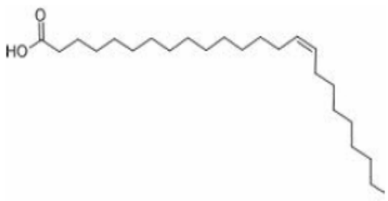


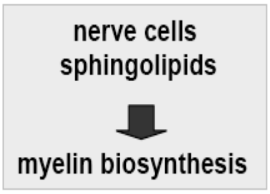
APPLICATIONS
transmission oils
paints
emulsions
emollients
surfactants
tribology
plastic films
biodiesel component

Figure 17-3 Main applications of erucic acid

Besides the importance of Nervonic acid has been recently outlined, and in North America, there are already on going research projects over its potential medical uses; the National Canadian Research Council had produced a line of hybrid rapeseed containing genetic elements from the nervonic acid pathway of *L. annua*.

nervonic acid





APPLICATIONS
pharmaceutical
medical nutrition
neurological disorders demyelination
•dementia
•Alzheimer' s
•multiple sclerosis
•adrenoleukodistrophy

Figure 17-4 Main applications of nervonic acid

Nervonic acid is an essential fatty acid which helps to maintain brain health by assisting in the biosynthesis and maintenance of nerve cell myelin. There is increasing interest in the use of nervonic acid for the treatment of neurological diseases associated with dementia, primarily; Alzheimer's, multiple sclerosis and adreno-leukodistrophy.

Nervonic acid is a natural component of human breast milk and is currently being used as a supplement for infant formula to aid cerebral development in children under the age of five.

7.7. Restricting factors

The plant does not thrive in open field for agronomic purposes, thus a further breeding to avoid this trait should be investigated. Even if the plant is resistant to seed shattering, an important trait for mechanical harvesting, the few pilot experiments done so far indicate that the plant is poorly suitable to mechanical harvesting.

Another restriction is due to the difficult in seed cleaning, that do not adapt to the traditional machine and need special modification with consequently increase the operational costs.

Vernalisation requirement is a also big constraint for honesty, that however could be reduced through sowing it in late wintertime or early spring.

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18. JATROPHA (*Jatropha curcas* L.) Fam: : Euphorbiaceae

8.1 Plant anatomy

Figure 18-1 *Jatropha curcas L*

Jatropha curcas L. was first described by Swedish botanist Carl Linnaeus in 1753. It is one of many species of the genus Jatropha, a member of the large and diverse *Euphorbiaceae* family. The genus name Jatropha derives from the Greek *jatros* (doctor), *trophé* (food), which implies medicinal uses. There are some 170 known species of Jatropha, mostly native to the New World, although 66 species have been identified as originating in the Old World (Heller, 1996). [3], [4]

Jatropha, a succulent perennial shrub or small tree, can attain heights of 2 to 10 meters, depending on the growing conditions. [4], [5] Seedlings generally form a central tap root, four lateral roots and many secondary roots. As with other members of this family, the vascular tissues of the stems and branches contain white latex, causes brown stains, which are very difficult to remove. The branches and stems are hollow and the soft wood is of little value. [3], [4]

Jatropha is monoecious, meaning it carries separate male and female flowers on the same plant. The ratio of male to female flowers averages 29:1 but this is highly variable and may range from 25-93 male flowers to 1-5 female flowers produced on each inflorescence. It also has been reported that the male-to-female flower ratio declines as the plant ages suggesting that fruiting capacity may increase with age. [3] The unisexual flowers of Jatropha depend of pollination by insects, including bees, flies, ants and thrips. One inflorescence will normally produce approximately 5 fruits. [2], [3], [5] On average, the seeds contain 35 percent of non-edible oil. [3]

The Jatropha plant may produce several harvests during the year if soil moisture is good and temperatures are sufficiently high. Fruits are mature and ready to harvest around 60 to 90 days after flowering. [5],[6]

The seeds weight (per 1000) is about 727 g, this are 1375 seeds per kg in the average. The life-span of the *Jatropha curcas* plant is more than 50 years. [4], [6]

Varieties and toxicity

The seeds are toxic to humans and many animals. They contain toxic substances mainly curcin (related to ricin), which is highly poisonous at low doses (3 or 4 seeds are toxic for a child of 7 or 8 and adults) phorbol esters, and also phytate and saponin and trypsin inhibitors. **[7], [5]** The presence of phorbol ester in some plants of agroeconomic importance, such as Jatropha limits their use as animal feed. [6], [8] Although research has been carried out by several laboratories in order to develop a process to detoxify seeds, these processes have not yet been finalized and costs are prohibitive. [5]
A non-toxic variety was found in Mexico that was free of phorbol esters. This variety could allow the use of Jatropha oil and cakes for human consumption. [4]

9.1. Domestication and area of origin

Jatropha is an ancient plant. Fossils dating from the tertiary era have been discovered in Peru. The source of *J. curcas* remains controversial, but it is highly probable that the centre of origin is Mexico and Central America. From the Caribbean, the species was probably distributed by Portuguese seafarers via the Cape Verde islands and former Portuguese Guinea (now Guinea-Bissau) to other countries in Africa and Asia.It is now naturalized and widespread throughout the tropics. **[3], [5], [9], [10]**

Jatropha is well known to farmers as a living fence, because it is not eaten by animals, and as medicinal plant. **[6]** After the energy crisis in the 1970s a serious discussion on renewable energies started in the industrialized countries. This led to the decision of the governments of the big industrialized countries (G7) at their summit in Cancun, Mexico, to support the developing countries. The German government started a "Special energy Program, SEP" to apply renewable energy technologies. In 1987 the SEP-Mali was asked by the Division of Agricultural Mechanization to look into the use of Jatropha oil as fuel. The French colonialists in Mali in the "Office du Niger", made already tests with Jatropha oil as fuel in the years before 1939. Then these tests were stopped by order of the French governor of Dakar, because "plant oil is too precious to be used as fuel in the colonies, it has to be shipped to the metropoles". There Jatropha oil from seeds from Madagascar, Dahomey (now Benin) and Guinea became the raw material for the famous "savon de Marseille". From the 50s onward, the production of chemical tensides reduced the importance of plant oil for soap production.

Jatropha seeds of Cape Verde Islands were exported to Lisbon (about 35 000 tons per year) after the Second World War. **[3]** Roland PIROT of the CIRAD claims this figure of 35 000 tons is underestimated**. [8]**

Jatropha oil does not have drying properties. Therefore, it cannot be used in paints. During the Second World War it was mixed with tung oil (Aleurites fordii) for railroad maintenance. It was also used for making varnish, tarpaulins, linoleum and printing ink.

In 2007, the rising price of fuel generated new interest in this plant as a biodiesel. **[5]**

Distribution

Figure 18-2 Distribution of *Jatropha curcas* L. [5]

The plant is widely distributed in wild or semi cultivated stands in Central and South America, Africa, India and South East Asia and in the tropical and subtropical part of the world. In South Africa, Tanzania, Zambia, Zimbabwe and Malawi, there are large populations of Jatropha, whereas in Ethiopia, there are only small amounts. Large parts of the world are not suitable for Jatropha, either because it is too cold, or there is not enough water (rainfall). [4],[6]

Environmental requirements

Jatropha likes high temperatures like in the tropics and subtropics. Optimal temperature ranges between 20 and 28°C, but the tree can tolerate temperatures between 11 and 28°C. Very high temperatures can depress yields. Frost hardiness is probably a varietal property and the different ecotypes do not share the same sensitivity. [8]

There is a possibility of cultivate successfully the crop in southern Greece, Italy and Spain if the selected genotypes are resistant to Mediterranean winter". M. PIROT of the CIRAD explains: "Current Jatropha varieties are sensitive to frost and therefore cannot be grown in Europe and certain areas of North Africa."

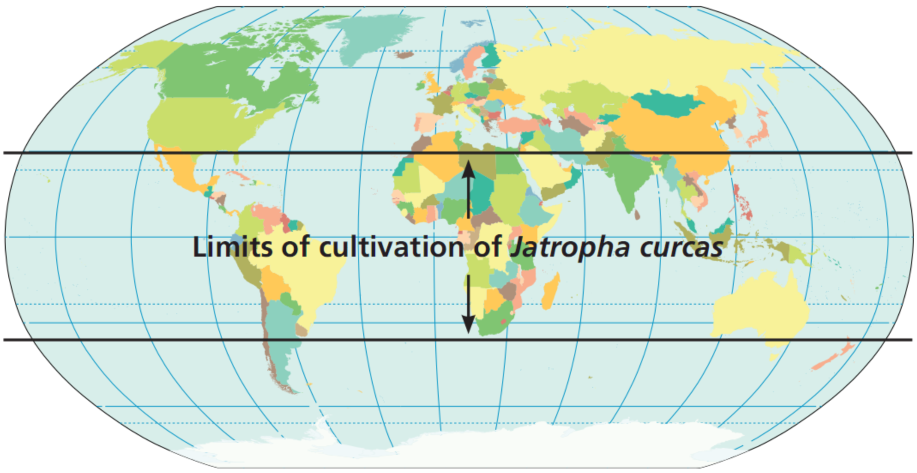


Figure 18-3 Cultivation limits of *Jatropha curcas*

Jatropha has a cultivation limits at 30°N and 35°S. It also grows in lower altitudes of 0-500 meters above sea level. Jatropha is not sensitive to day length (flowering is independent of latitude) and may flower at any time of the year. [3]

Soil and water needs

J. curcas is a highly adaptable species: very tolerant and thrives under a wide range of climatic and edaphic conditions. The plant resists to long periods of drought (7 to 8 months in Mali). [9],[11]

It is a succulent shrub that sheds its leaves during the dry season, with deep roots that make it well suited to semi-arid conditions. *Jatropha curcas* L. grows well with more than 600 mm of rainfall per year, and it withstands long drought periods. With less than 600 mm it cannot grow except in special conditions like on Cape Verde Islands, where the rainfall is only 250 mm, but the humidity of the air is very high (rain harvesting).

Other studies have shown that under 600 mm, the plant can live on but without developing. [8]

Rainfall is a determining factor in terms of yield. The optimum rainfall for seed production is considered between 1 000 and 1500 mm (FACT, 2007), which corresponds to subhumid ecologies. While Jatropha has been observed growing with 3 000 mm of rainfall (Foidl, 1996, cited Achten, 2008), higher precipitation is likely to cause fungal attack and restrict root growth in all but the most free-draining soils. [3], [4]

Rainfall induces flowering and, in areas of unimodal rainfall, flowering is continuous throughout most of the year. After short (one month) periods of drought, rain will induce flowering. Thus, the cycle of flowering can be excessive at the expense of seed production if too much water is applied, for example with continuous drip irrigation. The plant is well adapted to conditions of high light intensity and is unsuited to growing in shade. [3]

Jatropha grows well in gravely, sandy, well drained soils. It does not stand standing water. In some reports is it said, that Jatropha can grow in saline soils, but it is not known, to which extend it can support irrigation by salty water. It can even grow in the crevices of rocks. Its water requirement is extremely low (min.600 mm, but for seed production the water requirements are higher, about 800 to 1000 mm) and it can stand long periods of drought by shedding most of its leaves to reduce transpiration loss. Jatropha is also suitable for preventing soil erosion and shifting of sand dunes (if enough water is available, drip irrigation, irrigation with waste water).

8.2 Growing conditions

Planting

Hot and humid weather is preferred for good germination of seed and plant growth. [12]

According to Münch (1986), germination is induced by rising humidity levels in the atmosphere after a drought. The germination of seeds is very different, depending on the time of harvest, the origin of the seeds and their storage. [6]

Jatropha is planted at densities ranging from 1100 to 2500 plants per ha. Yield per tree is likely to increase with wider spacing but with a decline in yield per ha. Spacing decisions should be based on the environment. Semi-arid, low-input systems should use wider spacing such as 3.0 x 2.0, 3.0 x 2.5 or 3.0 x 3.0 meters. Planting holes of 30-45 cm wide and deep should be prepared and organic matter incorporated before planting. The seedlings may require irrigation for the first two to three months after planting. Seedlings are susceptible to competition from weeds during their early development. Therefore weed control, either mechanical or with herbicides, is required during the establishment phase. [3], [6], [9]

Crop management

The optimum levels of inorganic fertilizers have been to vary with the age of the tree (Achten, 2008). Site-specific fertilizer trials need to be established for trees of different ages and over a number of seasons. An analysis of the nutrient value of harvested fruit indicates the application rate of nutrients required to maintain soil fertility levels, assuming all other biomass is retained in the field. From the nutrient composition calculated by Jongschaap et al. (2007), the fruit equivalent of 1.0 ton of dry seed per ha removes 14.3-34.3 kg of N, 0.7-7.0 kg of P, and 14.3-31.6 kg of K per ha. [3]

Pest and diseases

Contrary to popular belief, the insecticide and toxic properties of *Jatropha Curcas* do not immunize it against insect attacks which affect yield.

Large-scale Jatropha monoculture is naturally prone to attacks. There is a real risk of latent pests and diseases developing and becoming more destructive.

The insect causing the greatest damage is *Agonosoma trilineatum*. This insect feeds on the fruit by injecting it with a liquid which dissolves its seed.

Other pests identified in South America, include *Pachycoris klugii* (damage to fruit) and *Leptoglossus zonatus.* In India, the two main pests are *Scutella nobilis* (which causes flowers to fall off, prevents fruit from growing and generates seed malformation) and *Pempelia morosalis* (which attacks inflorescences and capsules). [5], [14]

9.2. Logistics: harvesting/handling

Flowering-growing period

Flowering starts at the end of dry season. [6] It begins with the rain season. Flowers grow on newly grown branches and are pruned at the end of the dry season. [8]

In the regions where there is an alternation of dry and humid seasons, flowering appears to be brought on by the beginning of the rain season. A single branch can bear ripe fruit at its base, unripe fruit in its middle and flowers at its extremities, which interferes with mechanized harvesting. Male flowers open for 8 to 10 days, while female flowers only open for 2 to 4 days. [5]

Seeds are produced in the first or second year of growth. [3]. A stabilized yield is reached during the 4th or 5th year. [8] Mature seeds are produced 90 days after flowering. [14]

Seeds are ready for harvesting around 90 days after flowering when the fruits have changed from green to yellow-brown. In wetter climates, fruiting is continuous throughout the year, while the harvest may be confined to two months in semi-arid regions. Even then, the fruits do not ripen together, requiring weekly picking and making the harvest labour intensive and difficult to mechanize.

The yellow and crown fruits are harvested by beating the branches with sticks to knock them to the ground, or by hand picking. [3].This process damages the fruit and complicates harvesting. A better option consists in pruning the trees so the fruit can be hand-picked. [8] The fruits are dried and the seeds removed from the fruit shells by hand, by crushing with a

wooden board or by using a mechanical decorticator. Work rates for harvesting are given by Henning (2008a) as 24 kg per workday while India's National Oilseeds and Vegetable Oils development Board (NOVOD) gives a rate of 50 kg of seed per workday (NOVOD, 2007). The seeds are shade dried for sowing but dried in the sun for oil production to reduce moisture content to around 6-10 percent. If kept dry and ventilated, the seeds may be stored for up to 12 months without loss of germination or oil content, although there may be losses to pests in storage. [3]
Preserving germination and seed oil content are two separate issues. [8]

Brazilian researchers (Saturnino and al., 2005) report the possibility of using fruit tree harvesting vibrators, such as those used for harvesting olives and coffee.

The economic feasibility of Jatropha oil production depends very much on the manual work needed to harvest the fruits (seeds). Under conditions of a long rainy season, harvesting has to be done manually, because fruits are continuously ripening-a problem for any mechanical harvesting. However, if water availability can be controlled a more uniform ripening can be achieved; eventually mechanical harvesting like with coffee in Brazil could be an option. Roland PIROT of the CIRAD claims that "this isn't possible for current varieties of Jatropha and that coffee harvested under these conditions is 'poor quality ». [8]

Harvesting operations are much more efficient with high yielding varieties; much more fruits can be collected per working hour. [11]

8.3 Production-Yields

The yield of a plant depends mainly on the number of branches and on the genetics of the plant. The number of branches is important, because the inflorescences develop only at the end of branches. To improve the number of branches, the plant has to be pruned. If a branch is cut back, 3 to 5 new shoots will be developed below the cutting. This process can be repeated all 6 to 8 weeks in the first 2 to 3 years. The result will be a very bushy plant with many branches and many fruits, if the genetic basis of the plant allows. [11]

However preliminary trials show that this isn't necessarily true, as the plant can only bring a limited amount of fruit to maturity. [8]

Because of the wild nature of the plant, productivity reports vary considerably from less than 100 kg to more than 10 000 kg of seeds per ha. [15] According to Roland PIROT of the CIRAD, this figure of 10,000 tons is unrealistic today. [8]

In Nicaragua the yield of a Jatropha plantation was said to be 5.000 kg per ha (N.Foidl, personal communication). The real figure was in fact 1160 kg/ha of dry seeds. [8]

In India, the DaimlerChrysler project mentions a yield of 2.500 kg and year (on waste land) (G. Francis, personal communication). [6]

At present, there is not enough available data to accurately determine Jatropha yield. Past data must be studied and new data must be collected from current plantations.

During the Wageningen conference (March 2007), researchers studied worldwide Jatropha plantations and determined a yield scale ranging from 3 to 5 tons/ha/year. However, one cannot define yield without considering environmental pedoclimatic conditions. It would be more appropriate to define a potential yield for a given pedoclimatic environment. The optimal tree density is close to 1300 plants per ha. A density of 2500, as is often mentioned, appears to be too high. [6], [11] A study carried out by the IFEU (Reinhardt, 2008), based on data from the Central Salt and Marine Chemicals Research Institute (India) and the University of Hohenheim (Germany), forecasts 3 possible crop yields for dry seeds based on different production methods: a standard yield based on current yield, an 'optimized' yield and an 'ideal' yield. This study shows that a yield of 5 tons/ha of dry seeds, often deemed as easy to achieve, ought in fact to be considered as an 'optimized' yield requiring advanced cultivation practices and ecotypes that are adapted to the geographical area of production. [5]

8.4 Applications: current/potential

Composition of oil content

- Fruit [3]

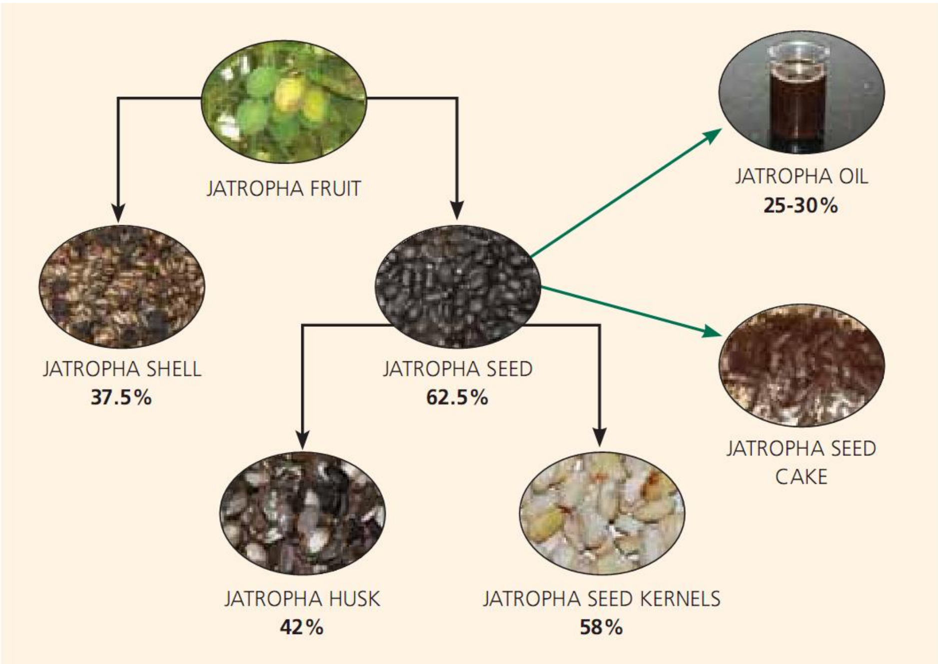


Figure 18-4 Composition of Jatropha fruit

- Oil content [3], [5], [6],[16],[17],[18]

The seeds of *J. curcas* weight on average from 0.69 to 0.86g depending on the variety. The oil content of the seeds varies between 30 and 35%. There don't exist high oil yielding varieties up to now. It is reported that Jatropha seeds contain about 30% to 40% of oil (Kandpal & Madan, 1995).

Table 18-1. Oil profile - Various compositions of *Jatropha curcas* L.

Origin	Brazil	India	Mexico	Thailand	Mali	Mali	Togo	Zaire	Egypt
Authors	Tapanes 2007	Nasirullah 1987	Kpoviessi 2004	Chedchant 2004	Liennard 1994	Henry Malotte, 1996	Kpoviessi 2004	Gaydou 1982	Reyadh
Saturated fatty acids									
Lauric C12:0									
Myristic C14:0									
Palmitic C16:0	16 max	12-17	15.2	14.7	15.2	15.6	15	28.4	4.2
Stearic C18:0	6-7	5-6	9.1	6.9	6.6	6.7	6	3.9	6.9
Arachidic C20:0					0.2				
Behenic C22:0									
Mono-unsaturated fatty acids									
Palmitoleic C16:1	0-3.5			0.8				1.5	
Oleic C18:1	42.43.5	37-63	37.6	42.6	44	42.6	44	35.7	43.1
Erucic C22:1					0.1				
Poly-unsaturated fatty acids									
Linoleic C18:2	33-34.4	19-40	38	35.2	32.6	33.9	35	30.1	34.3
A-Linolenic C18:3	>0.8				0.7	1.3			
Others acids									1.4

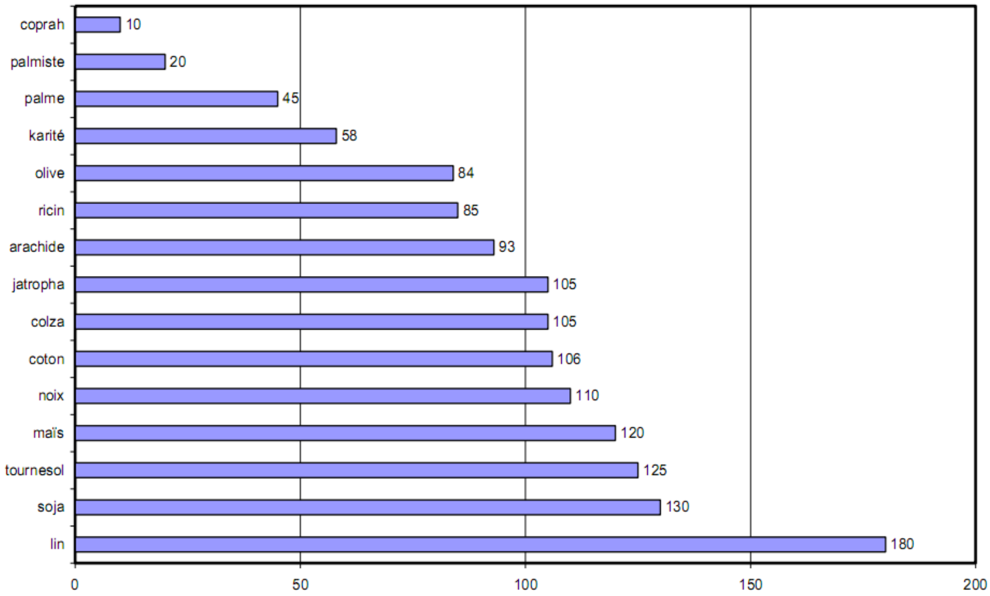
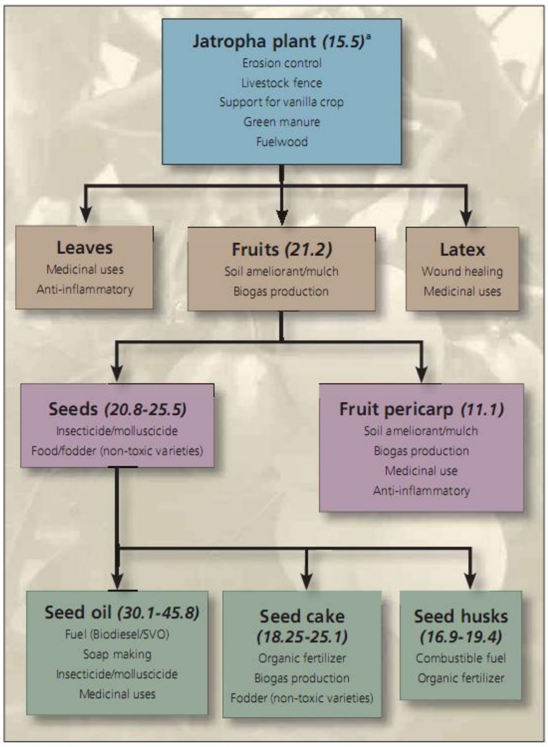


Figure 18-5 Iodine values for different vegetable oils

Applications

Figure 18-6 The uses of Jatropha curcas and the energy values of its components



[a] Energy values of the components are given in MJ kg^{-1}.

- Seed Oil [3], [5]

Traditional medicine:

Consumed at low doses Jatropha oil has purgative properties and can be used to treat certain skin diseases and relieve rheumatism. It is also used for manufacturing traditional soap or as a fuel in oil lamps. Jatropha latex used on wounds is believed to have antiseptic and anticoagulant properties.

Industrial applications:

- Use as a lubricant

In spite of what certain studies have claimed, and unlike castor oil, Jatropha oil cannot be used as a lubricant because of its low viscosity, and a high risk of resin exudation, due to its high content in unsaturated fatty acids.

- Use as a biofuel

Vegetable oils have a high flashpoint, and although Jatropha oil has a low flashpoint compared to most of them, it is still difficult to vaporize and requires a source of heat above 500°C within the combustion chamber, in order to prevent deposits.

The more an oil is saturated, the more it makes a good biofuel (low iodine value).

Based on these observations, Vaitilingom (2007) defined the ideal composition of vegetable oil for use as diesel (or biodiesel). Jatropha oil is closer to this ideal oil than rapeseed oil (whose content in unsaturated fat is too high). **[5]**

- Jatropha biodiesel

Depending on oil type and conditions of use, vegetable oils cannot always be used as alternative fuels. In order to overcome these difficulties, a new process has been developed for treating vegetable oil so it shares the same properties as diesel and can be used by standard car motors. This process, where oil reacts with alcohol, is known as transesterification (or alcoholysis) and produces an ester. This process makes it possible to reduce molecular mass to approx 1/3 of that of oil, as well as lower viscosity and density. **[5]**

Oil quality and consistency are important for producing biodiesel. The physical and chemical content of Jatropha oil can be extremely variable. Oil characteristics appear to be influenced by environment and genetic interaction, as are seed size, weight and oil content. The maturity of the fruits also can affect the fatty acid composition of the oil, and processing and storage further affect oil quality (Raina and Gaikwad, 1987, cited Achten et al., 2008). **[3]**

Table 18-2 The properties of Jatropha methyl ester

Methyl ester	Auteur	Densité	Viscosité	Indice cétane	Point de trouble	Point éclair	PCI
MEC[1]	Vaitilingom 2007	0,880	7 (20°)	52	-4°	183	41
MEJ[2]	**Foidl 1996**	**0,879**	**5,8 (30°)**	**51**		**191**	
MEJ²	**Tiwari 2007**	**0,880**	**4,8 (15°)**		**2°**	**135**	**40**
MEJ²	**Sarin 2007**		**4,4 (40°)**	**57**	**3°**	**163**	
MEJ²	**Kaul 2007**	**0,879**	**4,3 (40°)**	**58**	**4°**	**135**	
Gazole	Vaitilingom 2007	0.880	6 (20°)	50	-9°	93	44

1 : Méthyl Ester de colza
2 : Méthyl Ester de Jatropha

Tableau 24 : propriétés des méthyl esters de Jatropha, par rapport à celles du colza et du gazole

The properties of Jatropha methyl ester, mainly its cloud point, mean it is better adapted for use in countries where winters are cold compared to rapeseed esters. [5]

- Use for soap manufacturing

For a long time, the Cape Verde Islands produced Jatropha oil which was exported to Europe for manufacturing soap. In 1930, approx. 3000 tons of oil were exported. Jatropha oil was also produced in a number of French colonies and was used for manufacturing Marseille soap (Cunha de Silveira, 1934).

Jatropha oil was traditionally used to manufacture soap in many countries.

However, Jatropha oil used on its own is not adapted for soap manufacturing. There are several reasons for this (Cossel and al., 1982):

-the soap it produces is not hard enough,

-it is prone to secondary oxidation,

-does not stand storage,

-it has low washing properties.

Jatropha oil content must be limited to 30%. Tallow and coconut oil are generally added.

After studies showed that Jatropha oil contained different toxic substances, soap manufacturers stopped using this oil. It is more than probable that Jatropha oil will not be used for manufacturing soap, except for traditional soap making, until an affordable process has been developed for removing toxic substances. [5]

- Use as lamp oil

Lighting is a basic necessity in rural areas and as lamp oil is not always available, Jatropha can be used as an alternative lamp oil (Henning, 2005).

Insecticide properties

Several studies and tests were carried out on different insect pests. The experiments that were carried out attempted to demonstrate the advantages of using Jatropha oil – which has no impact on the environment - instead of chemical insecticides. All the parts of the plant were studied: leaves, bark and mostly its oil. The author of this study claims that Jatropha fatty acids have natural insecticide properties and that these could be used instead of chemical insecticides. [5]

8.5 Restricting factors

Temperature: sensitive to frost.

Storage problems :

The oil has to be stored in the absence of oxygen (air), because the oxygen leads to a polymerization (gel) of the oil molecules. If the containers are always, filled to the edge and no air can access the oil, a long storage is possible. Otherwise the gaseous upper part of the container has to be filled with an inert gas like $CO2$ or Nitrogen which does not react with oil. [6]

"An FAO/FIDA study found that since only limited improvements have been brought to Jatropha crops, their seed yield, oil content and quality are extremely variable. The majority of Jatropha crops currently grown are toxic. They cannot be used in animal feed and are hazardous for humans. This report stresses that research must be encouraged in order to develop non-toxic Jatropha, seed quality and agronomic practices, including conservation agriculture, integrated pest and nutrient management.".[19]

8.6 Research gaps

Patrick CARRE Interview, Cetiom 23/07/2010 :

"The main problem with Jatropha is seed toxicity. The seeds are highly toxic as most of them contain Phorbol esters. This toxicity prevents them being used for making oilseed cakes (which are rich in proteins) for animal feed. Instead, they are used as fertilizers.

There may be a problem linked with seed storage promoting mould growth and affecting seed quality. One of the explanations for this problem could be poor harvesting practices.

The hulls which make up 1/3 of the seed are used as a combustible material.

Seed crushing does not present any difficulties, even when seeds are dehulled.

An interesting option might be to develop a process for detoxifying these seeds which would then have a higher market value".

The focus on *Jatropha curcas* has never been on oil production so far. At the moment, there is a clear lack of descriptions (genetic variability (G), Environment (E) and Performance (GxE)). Furthermore, there is a need for integration of the available scattered knowledge on, and experiences with, crop performance of different *J.curcas* provenances in different environmental settings and under different management interventions.
It is assumed that current research issues comprise the search for elite (high production) *J.curcas* accessions, a search for agronomic optimizations and genetic improvement for specific locations. At the moment, there is no scientific evidence (available) for the existence and performance of elite (high producing) *J. curcas* accessions. Current (advanced?) research is not visible and not publicly available, but apparently owned by a few private companies who have no intention sharing it. [11]

FAO Cautious on Jatropha

Using Jatropha for biodiesel production could benefit poor farmers, particularly in semi-arid and remote areas of developing countries, according to a report published by the United Nations'Food and Agriculture Organization (FAO) and the International Fund for Agricultural Development. But the report stresses that Jatropha is still essentially a wild plant sorely in need of crop improvement. Expecting Jatropha to substitute significantly for oil imports in developing countries is unrealistic. "Many of the actual investments and policy decisions on developing Jatropha as an oil crop have been made without the backing of sufficient science-based knowledge", the report said. "Realizing the true potential of Jatropha requires separating facts from the claims and half-truths".

In 2008, Jatropha was planted on an estimated 900 000 hectares (ha) globally-760 000 ha in asia, 120 000 ha in Africa, and 20 000 ha in Latin America. By 2015, it is estimated that Jatropha will be planted on 12.8 million ha. The largest producing country I Asia will be Indonesia. In Africa, Ghana and Madagascar will be the largest producers, in latin America it will be brazil. [20]

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19. LINSEED (Linum usitatissimum L.). Fam. Linaceae

9.1 Plant anatomy

Table 19-1 Linum usitatissimum L

Flax, *Linum_usitatissimum* L., is a member of the family Linaceae that includes ten genera and 150 or more species. Owing to criteria used for selection, *Linum usitatissimum* L. mainly includes varieties that are either used for their fibers or their seeds. Flax is an annual crop. [3] The average height of fibre flax ranges between 0.8 and 1.2 meters with a crown diameter of 1 to 2 millimeters. Seed flax has a shorter stem (45 to 75 cm) as it has been bred for its high seed yield. [4]

Flax flowers are terminal in position, perfect, regular, hypogenous and tetracyclic. The main stem branches to form a cymose inflorescence or panicle with 80 à 100 sheets. [5] The fruit is a septicidal capsule 8-15 mm high and 10-12 mm in diameter. Each capsule contains 10 seeds rich in oil. [4] The surface of the seed is smooth, highly polished small, light, and varies in color from dark brown to yellow. [3], [7]

9.2 Domestication and area of origin

Flax (*Linum usitatissimum* L.) is one of the oldest known crops in our temperate climate countries, cultivated for its cellulose-rich fibers (fiber flax) and its seeds, rich in polyunsaturated fatty acids (seed flax) (Deyholos, 2007). [8] The history of flax can be traced back over thousands of years. The first probable use of flaxseed as food may have been as an ingredient in breads and a laxative. [9]

Flax was first introduced into North America as a fiber crop, but its value and importance as an oil source quickly became apparent. Initially the same variety was used for both fiber and oil production. As a result of breeding and selection, distinct fiber and oil seed varieties and presently recognized. [11] In most countries, with the exception of North America, flax is known as *Linum usitatissimum* (the most useful flax). In Europe, long fiber flax varieties used for their fiber by the textile industry are known as fiber flax, while short fiber varieties used for producing oil and oilseed cake are known as seed flax.

Linum usitatissimum L. is widely grown also as a fiber crop in Europe. [13] Flaxseed is grown approximately 50 countries most of which are in the Northern Hemisphere. [8] In Canada, seed flax (short fibers) accounts for the majority of crops grown in the Prairie Provinces, Saskatchewan, Manitoba and to a lesser extent, Alberta. [10]

9.3 Growing conditions

Seed flax is grown in areas where temperatures are not too high and days are longer during the plant's growing cycle, optimizing seed oil content and iodine. The cool temperatures and long hours of daylight in the high latitudes of Western Canada mean this area is perfectly adapted for growing Flax. [10]

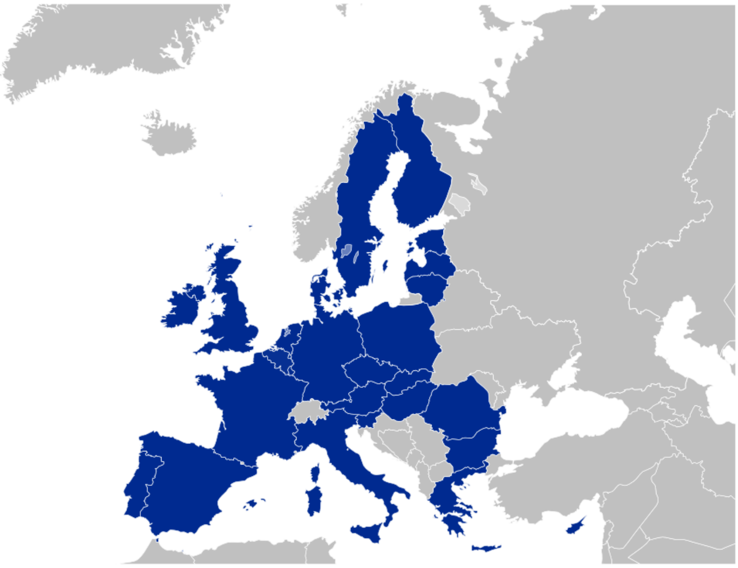

Figure 19-1 Favourable areas for growing Flax in 27 European countries

Environmental requirements

Linseed is a cool temperate annual herb. [3] Oil content, fatty acid distribution in flaxseed can be affected by environmental conditions. Significantly lower oil contents and a darken oil from frost-damaged immature seeds, higher concentrations of palmitic (P), linoleic (La), and Linolenic (Ln) acids and lower oleic (O) acid where observed in damaged seed compared to normal seeds. [9]

Soil and water needs

Linseed, like rape, is sensitive to seed bed conditions, and best emergence comes from a fine tilt. The crop can be very slow to establish in cold weather. Evidence from work in field trials shows that small seeded varieties are less vigorous, and with this avoidance of early drilling is particularly important. Winter varieties of linseed have now been developed and perform well providing the crop is well established prior to onset of winter. Weed control in the young crop is essential. [3]

Fertility management

Soil phosphate and potassium requirements are the same as for linseed production. Nitrogen applications for fiber production should be much reduced compared to that of Linseed. [13] Flax is one of the crops which require the lowest use of plant protection products. Half of its nitrogen requirements are supplied by the soil, which means Flax is appropriate for sustainable farming. [12]

Flax can grow roots as deep as 1.5 meters under appropriate soil conditions.

It has low nitrogen requirements, helps boost minerals, and half of the nutrients it needs are supplied by the soil. Flax is one of the crops which require the lowest use of plant protection products. On average, flax crops are treated three times during their growth cycle, mainly with herbicides while cotton crops are treated ten times more often! [4]

Seed flax requires 90 to 110 nitrogen units/ha, half as much as other crops. The total amount of active pesticide ingredients is also significantly lower than for other crops:

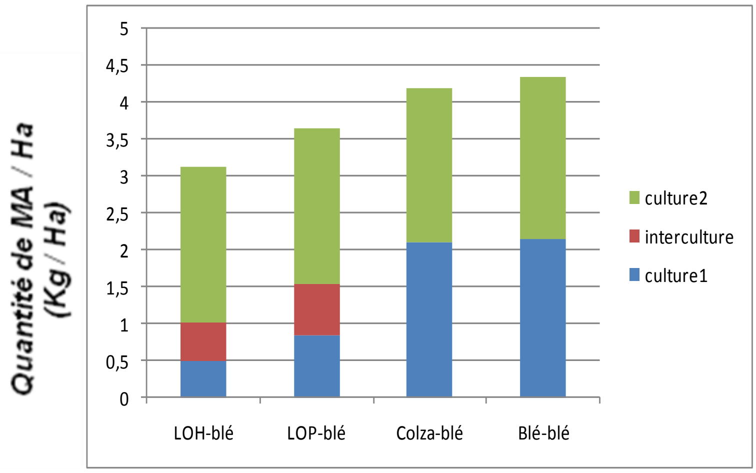

Figure 19-2. Amount of active ingredient/ha: Winter Seed Flax < Spring Seed Flax < Rapeseed < Wheat preceding Flax < Wheat preceding Rapeseed < continuous wheat cropping system. [SOURCE: Data published by the economic department of the Oise in collaboration with the department of agriculture of the Oise in 2006]

This figure shows that winter seed flax requires 0.5 kg / ha active pesticide ingredients compared to 2 kg / ha for wheat, whereas Spring seed flax requires 0.75 kg / ha active pesticide ingredients, a significantly lower amount than rapeseed and wheat.

One of the agronomic advantages of including flax in crop rotations is that it lowers pest pressure on other crops and so helps reduce the amount of pesticides needed to protect subsequent crops. [8]

9.4 Growing conditions

Due to its growth cycle (sowing from 15 March to 10 April, harvest: 15-20 August), Spring seed flax is sensitive to soil and weather conditions. This particular sensitivity strongly impacts the quality of production. On the other hand, new Winter seed flax varieties are a lot less sensitive than Spring seed flax due to their longer growth cycle which prevents them suffering from hydric stress (sowing: 15 September, harvest: 10-25 July according to geographic area).

The choice of a Seed flax variety for growing a successful crop should be based on its response to soil and weather conditions, and the strength of its stem. Available flax cultivars include: 'Winter' varieties (available for sowing in the Autumn) and 'Spring' varieties (the most common (>20)). The 5 most common varieties represent 90% of crops. [4]

Flowering last up to 15 days, however, the flowers only last for a couple of hours. [4]

During germination, the primary root is the first structure to emerge from the seed. As the hypocotyls hook elongates, the seed coat and cotyledons generally are pulled above the soil surface. The cotyledons break free of the seed coat, expand, develop chlorophyll, and function as photosynthetic organs. [14]

Flax seeds are very small and only have a limited reserve of nutrients. This specificity means the farmer has to prepare the soil so it promotes fast seed germination and root growth. Depending on the geographical area, winter flax is sown between mid September and end of October, whereas Spring flax is sown between the end of February and the end of March.

Seed flax must be evenly sown so as to achieve optimum crop density – improving quality and yield. Ideally, population density should equal 450 stems per square meter. This density increases yield, promotes resistance to lodging and improves seed production. [4]

Traditionally sown at high density: 400 seeds/m2 for winter seed flax and 650 to 700 seeds / m² for Spring seed flax. [4]

9.5 Logistics: harvesting/handling

Harvesting can be a major problem with linseed, particularly if the crop is late, incompletely desiccated or lodged. Lodging can be serious in linseed but crops often recover if lodging occurs early in the season. Late lodging severely impedes harvest, with very little bulk in the crop to support itself and allow room for the combine, and great care must be very well desiccated at harvest to avoid wrapping in the combine, and great care must be taken to ensure thorough penetration of the desiccant into the crop**.** [3]

Winter flax is harvested around 20 July (in the North of France / early July for the South), a month before Spring flax harvest. When seeds turn dark brown, they are harvested by cutting and threshing. [4]

Producing high quality seeds requires that producers pay careful attention and invest time and effort in harvesting. [4]

Diseases affecting affecting cultivars for flax production are the same as for linseed (see earlier). However the higher plant densities used may increase vulnerability to these diseases. [13]

Linseed is an excellent head of rotation to short cycle (approximately 140 days for the Spring seed flax) which allows advantageous ruptures in cereal and beet rotations. It does not lodge the nematode of beet and is not sensitive to the diseases of cereals, nor with the vermin such as taupins. It is a healthy, productive, respectful culture of the environment, offering many diversified outlets [15].

9.6 Production-Yields

The table below shows international figures for seed flax production, yield and areas of production.

Table 19-2. International figures for seed flax production

LINSEED : World Production (1000T), Yields (T/ha) and Harvested Area (1000ha)

		PRODUCTION				YIELD				HARVEST'D AREA			
	HARVEST(a)	09-oct	08-sept	07-août	04/05-08-sept	09-oct	08-sept	07-août	04/05-08-sept	09-oct	08-sept	07-août	04/05-08-sept
EU - 27		103	77	95	128	1.36	1.33	1.32	1.27	75	58	72	101
Thereof:													
Belgium-Lux	Aug-Sep(1)	9	9	10	10	.69	.73	.70	.63	13	12	14	16
France	Aug-Sep(1)	18	15	34	26	1.86	2.06	1.99	2.17	10	7	17	12
Sweden	Aug-Sep(1)	8*	8	7	11	1.60	1.60	1.56	1.57	5	5	4	7
U.K	Aug-Sep(1)	50	29	23	48	1.72	1.80	1.84	1.66	29	16	13	29
Ukraine	Aug-Oct(1)	54	21	35	32	1.11	1.09	1.45	1.21	48	19	24	27
Russia	Aug-Oct(1)	103	93	80	73	1.12	1.09	1.08	.96	92	85	74	76
Ethiopia	Oct-Jan	135	156	140	136	.79	.86	.92	.69	170	181	152	196
Canada	Aug-Oct(1)	1030	950	720	894	1.47	1.36	1.20	1.17	700	700	600	762
U.S.A	Jly-Sep(1)	189	145	150	264	1.48	1.06	1.06	1.11	127	138	141	237
Argentina	Dec-Jan	50	19	13	32	1.32	1.14	1.33	1.19	38	17	10	27
China,PR	Aug-Sep(1)	440	475	480	474	.96	.99	1.00	.97	460	480	480	487
India(b)	Jan-Apr(2)	160	150	190	190	.35	.32	.35	.34	460	470	550	567
Oth countries		111	96	88	96	.60	.50	.51	.54	181	191	172	178
WORLD		2375	2182	1991	2319	1.01	.93	.88	.87	2354	2339	2275	2658

(a)Bulk of harvesting time, i.e. first of the split years in the case of (1) and second in the case of (2). (b) All rabi/summer crops.

Source Oil World, Feb 2010

According to the figures above, French seed flax production is approx. 20 quintals/ha. These figures show that yield varies depending on whether farmers have access to technical assistance.

In areas supervised by SARL OLEO-LIN (filial LINEA / LIN-2000), yield for 7,000 ha was 2.6 T / ha in 2009 and 2.9 T in 2008. Providing technical assistance to farmers is the key for success.

In 2009, flaxseed production reached 2,375 million tons, after a steady increase in the last three year (1,991 million tons harvested in 2007). Frédérique Lucas, France Agrimer oilseed crops analyst explains: "Since 2006, flax world production has fluctuated between 2 and 2.5 Mt as the market is essentially based on sown acreage in Canada". [16]

Canada is undeniably the world's leading producer with 1,030 million tons. China comes in second position (440,000 T) followed by the United States (189,000 T), India (160,000 T), Ethiopia (135,000 T) and Russia (103,000 T). Another source [16] quotes 1 million tons/year for Canada and 500,000 tons/year for China.

European production is approx. 75,000 tons. The two biggest European producers are England (50,000 tons) and France (18,000 tons). In France, total crop acreage was approx. 10,055 ha in 2009 with plenty more available acreage for increasing production. French flaxseed production represented 1% of world production and 20% of European production for the 2009-2010 agricultural year. In 2010, production is expected to reach 40,000 tons. [8]

According to the study published by Mathilde Carpentier, European production represents 4% of world production. "United Kingdom is the biggest European producer with 40,000 tons, while France has the highest yield with 1.8 tons/ha". [16]

About a third of international production is exported worldwide. Exports reached 900,000 tons in 2009, with Canadian-produced flaxseed (approx. 700,000 tons) accounting for 80% of total exports. Ukraine and Russia produce approx. 100,000 tons. However these two countries have not developed oilseed processing. In terms of market demand, Belgium imports 400,000 tons of seed flax, while the United States imports between 140,000 and 150,000 tons and China, 100,000 tons. For this reason, oilseed processing businesses are mainly located in Belgium, the United States, China, India and Ethiopia. [16]

Crop production is crucial for the industry. EU demand has reached 150,000 tons a year, which is to say 450,000 tons of seeds. The oil processing industry imports mostly Canadian seeds. This means extra costs and irregular supply.

The oil processing industry wishes to develop European production. The need for local production is even greater for seeds whose quality and traceability need to be guaranteed. It is difficult to motivate farmers even when agreed prices are higher than market prices. Further research needs to be developed, and to this day the available quantity of seeds is not high enough for the oilseed processing industry. [4]

9.7 Applications: current/potential

Composition of oil content

The International Flax Institute as well as Thomas P. Freeman, [7] claim that flaxseed contains as much as 35 to 50% oil, which can be used in a wide range of applications. [4]

Other sources claim similar values:
Flaxseed oil content ranges between 38 and 45% depending on geographical area, cultivars, and environmental conditions (Daun *and al.,* 2003; Oomah and Mazza, 1997). Kozlowska (1989) reported an average oil content of 41.4% for Polish cultivars and 31.9% to 37.8% for North Dakota cultivars (Hettiarachchy *and al*., 1990). As for cultivars grown in Ethiopia, Wakjira and al. (2004) reported an oil content ranging between 29.1% and 35.9%. [9]

The table below shows available data on the fatty acid content of flaxseed oil.

Table 19-3. Fatty acid content of flaxseed oil

		Fatty acids (%)						
References	Oil (%)	Palmitic	Stearic	Oleic	Linoleic	α-Linolenic	Arachidic	Other
[17] Declerq et al. a)	41.2	5.3	3.3	20.3	14.6	56.4	/	/
[18] Declerq et al. b)	43.3	5.2	3	16.9	14.6	58.8	/	/
[19] Hettiarachchy et al. c)	35.2	5.4	4.7	25.6	15.9	48.4	/	/
[20] Oomah and Mazza d)	43	/	/	/	/	/	/	/
[21] Solin	/	6	2.5	19	24.1	47.4	0.5	0.2
Institut technique du lin	35-50	4-6	2-3	10-22	12-18	56-71	/	<1

Note:

linseed meal to flaxseed

b) Mean of 495 samples of No.1 Canada Western flaxseed

c) Mean of 11 cultivars grown in North Dakota, United States

d) Mean of 31 cultivars grown at Morden for 3 years (1987-90)

The fatty acid composition of linseed oil is dominated by C18 fatty acids C18:2 (16% of oil) C18:3 (50% of oil) (Turner, 1987).
a) Mean of 441 samples of No.1 Canada Western flaxseed; protein converted from

Applications

The specific properties of flaxseed set it apart from other oilseed crops used for industrial applications or for human and animal nutrition. [8]
Uses for linseed:

- **Seeds** are used in animal feed and human food (425,000 tons), added in bread and toasted rolls...[8]
- **Linseed oil** is widely used in industrial applications as a binder in paint and in printing inks 740,000 tons. In the future, REACH Regulations will further promote the use of Linseed oil.

The demand for flaxseed is growing worldwide for many different reasons:

Since REACH regulations have restricted the use of certain ingredients in lipochemistry applications, flaxseed oil has regained interest because of its drying properties.

As flaxseed oil is rich in Omega-3, it offers considerable health benefits when it is added to human food and animal feed.

- **Flaxseed oil cake**, is used in animal feed as a source of protein,

  1,208,000 tons in 2009. [12]
- Flaxseed by-products are used in a wide range of applications: Flaxseed lignans are used by the cosmetic and pharmaceutical industry, flaxseed fibres are used to make paper and flax straw is used for manufacturing composite building materials (insulation) or as bio combustible material... There is a growing interest in flax straw which can be used to feed biomass boilers to heat public buildings (flax straw has a high calorific value), producing electricity or insulating buildings.

Linseed straw also has application in biomass energy burners. [3]

Uses for linseed

Animal feed

The use of flaxseed is being developed for a wide range of applications. The main market for flaxseed is animal feed. Clinical studies show that flaxseed does more than simply improve animal health: when cows and hens are fed with flaxseed, the milk, eggs and meat they produce offer higher benefits for the health of consumers because of the higher Omega-3 polyunsaturated fatty acid content provided by flaxseed oil. [4]

There is a market for linseed meal as animal feed, also poultry feed as it increases levels of omega 3 fatty acid in eggs. Whole seed is used in the baking and confectionery industries where is healthy benefits are recognized. [3]

In the last few years, the French Flaxseed Industry has become more competitive. It has developed a higher level of quality and improved its technical and economic skills on a national and European scale. This was made possible thanks to the Bleu Blanc Coeur network which aims to develop new markets in the agri-food sector. The French Flaxseed industry is currently working to open up to new markets and is about to launch a large scale research project, certified by the 'Industrial and Agricultural Resources' (IAR) competitive cluster. [12]

60% of French flaxseed production is consumed as animal feed marketed through the Bleu Blanc Cœur Network. 20% is consumed as flaxseed oil and 20% is used for different applications in human nutrition and cosmetics. [12]

Human nutrition

History shows that flaxseed has been used as a ingredient in breakfast cereals and breads; however, since the 1990s, a number of products containing flaxseed have been developed primarily for the health food market. The renewed interest in flaxseed as a food source is due to findings that suggest the flaxseed can provide a variety of health benefits (Thompson and Cunnane, 2003). The components that contribute the health benefits include lignans (secoisolariciresinol diglucoside [SDG] being the predominant form), alpha-linolenic acid (ALA), and nonstarch polysaccharides (i.e., gum or fiber). Flaxseed is an oilseed that contains roughly 38-45% oil. ALA, a polyunsaturated lipid, accounts for 52% of the fatty acids in the oil. Flaxseed is also a rich source of plant lignans (up to 13 mg/g flaxseed). The interest in ALA and lignans as food ingredients has opened opportunities for the utilization of flaxseed in foods. In contrast, the same level of interest has not been observed for other flaxseed components, such as protein and dietary fiber, which account for 20% and 28% of the flaxseed, respectively (Carter, 1993). This chapter will provide a general overview of flaxseed research completed over the past 50 years with the major focus being on data from 1990 to 2006. It will highlight the basic composition, health benefits, and finally the processing and application of flaxseed. [9]

A growing market has been identified for whole seed linseed, in baking and in health foods and for this the traditional "high linolenic" varieties are suitable, as it is only their extracted oil that lacks the keeping qualities for culinary use. [3]

Flaxseed is very rich in Omega-3 fatty acids which are essential for human health and preventing cardiovascular disease... Flaxseed contains compounds which have therapeutic (lignans,…), emulsifying, moisturizing and absorbent (mucilage,…) properties, and are rich in amino acids. This is the reason why flax acreage has doubled in the last 6 years. [8]

- **Uses for linseed oil**

Non-food applications

Linseed oil is traditionally used in paints and coatings because of its drying properties. It is also used for manufacturing linoleum, printing ink, soap, putty and industrial lubricants. [4]

Currently Linseed is predominantly grown as a source of oil for industrial use in the manufacture of paints, varnished and linoleum. [3]

Because of its high linolenic acid content, Flaxseed is also commonly used in paints, varnishes, and more recently, in polymer and oleochemical products. [8]
Long fibers are used for weaving, spinning into yarn and geotextiles. Shorter flax fibers are used for packaging materials and plastic alternatives. Dual purpose cultivars are being introduced whereby the crop is harvested and the resulting straw is processed into specialist paper product, composite materials and biodegradable matting. Yields from fiber flax may exceed 1t/ha. [13]

Traditionally, Linseed has been grown for its oil, which is used in the manufacture of paints, varnishes and linoleum, because of its drying and hardening properties when exposed to the air and sunlight. Tests have indicated that these also have a range of industrial applications including specialist oils and inks. [3]

Oil: drying agents. The high linolenic acid (C18:3) content of linseed makes the oil an excellent drying agent for example in paints, resins, inks, soaps, varnishes, wood treatments, linoleum. It is also being investigated for use in the building and construction industry. [3]

Linoleum: Linoleum is made of natural materials: linseed oil, resins, wood, cork, powder, calcium, vegetable pigments and hessian (jute). There are new interests in this material and the European market is expected to increase from 36 million m² in 1995 to 56 million m² in 2003. Linoleum has particular benefits in "high-tech" situations in being anti-static. One kg of linseed oil is required for each 1 m² of linoleum. [3]

Human nutrition

Regulations for food-grade linseed oil

In accordance with the decree n°2008-184 dated 26 February 2008, relating to edible fats and oils, the conditions of use of flaxseed oil in food is supervised by the ministry in charge of food and agriculture.

In accordance with the decree dated 4 December 2008, which determines the conditions of use of flaxseed oil in food, refined flaxseed oil is authorized as an ingredient in edible oil blends and fat spreads. The lipid fraction of these products must not contain more than 15% of alpha linolenic acid. The quantity of flaxseed oil added to food must not make it possible for the final consumer to ingest more than 2 g of alpha linolenic acid a day. The total content of alpha and gamma tocopherols in food containing flaxseed oil must not exceed 3 mg/per g of alpha linolenic acid.

AFSSA recommendations regarding the evaluation of risks linked to consuming food-grade virgin flaxseed oil, referral n° 2008-SA-0392, referral n°200-SA-0409

The AFSSA has deemed that there is no valid reason for banning the sale of virgin flaxseed oil in France. Flaxseed oil is a source of important nutrients such as alpha linolenic acid. It has been available for many years in a number of other countries (Germany, Canada, China) without showing any negative side effects. However, in the case of flaxseed oil, packaging, storage and conditions of use must meet stricter rules than those applied to other vegetable oils in order to minimize the risk of oxidation:

-Batches must be identified to ensure traceability from the time of seed crushing to packaging for optimizing shelf life (must no exceed a year including use),

-Packaging volume must not exceed 250 ml

-Injection of inert nitrogen gas during the bottling process,

-Opaque packaging,

-Best-before date must not exceed 9 months.

In compliance with AFSSA recommendations, the following information should figure on the label:

-To be used as salad dressing only,

-Do not heat,

-Keep away from heat after opening,

-Do not keep for more than 3 months after opening,

-Not suitable for children under 3 years old.

Not subject to regulations.

Flaxseed oil is essentially rich in Omega-3 polyunsaturated fatty acids. These fatty acids contribute to phospholipid synthesis and improve cell membrane structure compared to cholesterol which hardens cell walls. Humans and animals rely on the food they eat for these fatty acids. Most of the time, our diet fails to provide these nutrients, except for Cretan and Japanese diets based on fatty fish rich in alpha linolenic acid (ALA). Flaxseed oil vegetable ALA is the precursor of Omega-3 fats synthetized by animals. Since they are not destroyed by heat, they are naturally transmitted through the food chain to humans. Besides their benefits for the cardiovascular system, they have antioxidant and immuno-stimulant properties, they also contribute to protecting cerebral tissue. They play a decisive role in the longevity of Mediterranean and fish-eating populations. This is why Omega 3-rich flaxseed should be incorporated in animal feed and why the raw material we chose to use can really make a difference when it comes to improving nutrition.

The iodine value expressing the drying properties of flaxseed oil is one of the highest compared to other oils, approx. 190 units. This means flaxseed oil dries very fast when in contact with air (oxidation). [4]

Uses for linseed oil cake

-In Europe, oilseed cake has been in competition with extruded flaxseed (Valorex France patent) for the last twelve years. Flaxseed is heated and after extrusion the final product contains more oil than standard oilseed cake. Animals fed with extruded flaxseed retain the benefits of Omega-3 fatty acids contained in this oil. 5,000 tons of extruded flaxseed are produced in France every year.

The Bleu Blanc Coeur network has been approved by the Ministry of Agriculture, Health and Ecology in accordance with the PNNS (National Health and Nutrition Plan)

This program which was initially launched in France is now being implemented in other European countries (Germany, Portugal, United Kingdom…) as well as in North America and Asia (China/India).

Linseed breeding

Seed flax breeding in France [12]

1995, a breakthrough in flax breeding: the first winter variety. In 1960, Inra launched a flax breeding programme including plant lines from all over the world, tested for their winter hardiness. In 1980, these genotypes were crossed to create new 'WINTER' varieties. Fifteen years later, OLIVER was developed by Inra and the LIN 2000 cooperative. This cultivar opened new perspectives for flax farming and production compared to Spring flax. Because flowering takes place a month earlier in May, hydric stress, which occurs towards the end of the growth cycle, is avoided, stabilizing production and guaranteeing a higher yield. Traditionally farmed in the northen regions of la Loire, these winter varieties can also be grown in the South of France. Another advantage is that winter flax has a high and stable Omega-3 fatty acid content as opposed to Spring flax, whose Omega-3 content may vary if weather conditions are too mild towards the end of its growth cycle.

Breeding technology transfer to a professional body

Inra transferred the genetic material, used for breeding new varieties, to the LIN 2000 cooperative for developing and marketing new varieties. Further research on flax breeding was carried out by GIE LINEA, in collaboration with LIN 2000 and three scutching cooperatives. In 2003, two new winter varieties were developed: EVEREST and ALASKA.

In addition to increasing yield, breeding aims to improve winter hardiness, oil content (by increasing seed size) and fatty acid profile.

The latest winter flax varieties, developed by GIE LINEA, are Banquise (registered in January 2008), Iceberg (registered in January 2009) and Cristalin (registered in January 2010). The yield of these new varieties is 3 to 4 times higher than that of OLIVER, the first winter flax variety. This yield gain means that seed flax is now as competitive as rapeseed.

Flax cultivars developed by LINEA-INRA are the leading flax varieties in France

The genetic improvement achieved through breeding has helped to develop new markets. Ten years ago, Spring flax was the most widespread flax crop, today it hardly represents 20% of total flax crops. This opportunist market has been prompted by the high yields of winter flax crops in Canada, the world's leading flaxseed producer.

Winter flax varieties represent 80% of crops in France, 90% of this market has been taken over by the four main varieties developed by INRA-LINEA: ALASKA, Banquise, Iceberg and Cristalin. Flax was introduced in France after the Second World War. In the 90's, Flax acreage ranged between 5000 and 40 000 ha, nowadays, thanks to the Bleu Blanc Coeur network, which works to develop new markets for French producers, acreage has reached 18 000-20 000 ha (compared to 1 000 000 ha in Canada).

NOVANOL, a research project for developing a national flaxseed production network

The NOVANOL project (5.8 M€) has been launched by the Industrial and Agricultural Resource Competitive Cluster (Champagne Ardennes). Headed by the companies LABOULET and LINEA-LIN 2000 working in partnership with ten scientific and technological institutes, including Inra, this project aims to add value to seed flax crops and their by-products by integrating them in new applications for biolubricants, composite materials, inks and bioenergy.

Divided in four parts, this project tackles the different issues connected with setting up a new production network, ranging from the initial phase of sowing, farming, and final processing. GIE LINEA is mainly responsible for coordinating the 'AMELIOFI' program for improving seed flax cropping and launching a new production network in Picardie. The Inra 'Seed Molecular Physiology' laboratory in Angers and the Inra 'AGROCLIM' unit in Avignon are also involved in this project. The long term objective consists in finding ways of adding value to flaxseed crops and their by-products, and launching a national flaxseed production network. Economically speaking, Winter flax deserves to be included in crop rotations. The low increase in acreage is due to competition with other crops, mainly rapeseed. Compared to sunflower and barley, flax is a competitive crop, but it is not as competitive as rapeseed and corn. Current research aims to find new ways of adding value to the whole flax plant in order to make it become more competitive than rapeseed: this means adding value to flax straw (unsuitable for use in textile manufacturing) by integrating it in new industrial applications. [12]

STANLUB project:

The STANLUB project **Development of new bio-lubricants and coatings using standoils from linseed, castor and tung oils** lasted 2 years.

The objectives of the project were to develop "green" raw materials and related production processes from renewable sources: standoils from linseed oil, castor oil and tung oil for two applications which are bio-lubricants and solvent for coatings.

The main interests of the project were:

- The implementation of a low cost process with few reaction steps that could be used easily at SME scale,
- To provide SMEs with cost-effective raw materials with high quality standards, good mechanical and physical properties (at least 20% cheaper than traditional raw materials),
- To valorise all the standoils derivatives from linseed, castor and tung oil. The main one (dimer) was used for bio-lubricant production and the reaction by-product (monomer) for the coating industry.

The main innovations of this project resided in the following points:

- To develop a new product and a new process: the bio-lubricants are not currently based on standoil derivatives that are cheaper and will offer different mechanical and physical properties. The developed process had a reduced step number and was easily transferable to SMEs.
- To compete the traditional mineral lubricants by developing a cheaper and more environmentally friendly raw material with high biodegradability for a large range of applications (releasing, sawing,…..).
- To synthesize bio-lubricants with physical and chemical characteristics different from the current bio-lubricants based on vegetable oils. Development of bio-lubricants with better

properties at low temperature normally because of the presence of double bond in higher quantity on the final product.

- To give a high added value to the different fractions of standoils produced by chemical and thermal treatment of linseed oil and to create a new valorization pathway for these products (lubricants and solvents for coatings).

9.8 Restricting factors

In addition to oil content, fatty acid distribution in flaxseed can be affected by environmental conditions (Taylor and Morrice 1991). Growing conditions and variety can influence the unsaturated fatty acid content in flaxseed (Daun et al., 2003). In contrast, the environment may also have an undesired impact on flaxseed composition. Early and late frosts, heat damage, and drought could have detrimental effects on flaxseed quality (Daun et al., 2003). Significantly lower oil contents and a darken oil from frost-damaged immature seeds was reported by Gubbels et al. (1994). In addition, higher concentrations of palmitic (P), linoleic (La), and Linolenic(Ln) acids and lower oleic (O) acid where observed in damaged seed compared to normal seeds. [9]

9.9 Research gaps

In September, the market was in upheaval after banned GM FP967 Flaxseed was discovered in imported Canadian seed flax intended for the European market. The suspension of Canadian imports caused prices to rocket. In Belgium, the oilseed processing industry tried to source new suppliers, mainly in the area of the Black Sea, but flaxseed production there is limited.

Flaxseed prices have recently stabilized. Frédérique Lucas comments "*In September and October, the price of flaxseed oil, flaxseed and flaxseed oil cakes increased dramatically. However, economic losses are significant and the surplus of flaxseed on the market won't help improve the situation*". Prices soared because of the unavailability of flaxseed.

At the end of the agricultural year, Canada will be left with surplus Flaxseed stocks. Moreover, as the prices paid to Canadian farmers are low, this could discourage farmers from producing flax which in turn could have a negative impact on the European market. Canada is currently seeking new markets, like China, for the flaxseed it cannot sell on the European market or which cannot be delivered on time because of stricter import procedures. The price of flaxseed remains high and the cumulated effect of recent events should encourage European farmers to turn to flaxseed production especially as '*the leading producer will no longer be dominating the European market.'* [16]

In order to improve the quality of seed flax (oil content, improved fatty acid profile,..) several studies are being carried out on the biological process leading to the filling of seeds (Gutierrez and al., 2006; Troufflard and al., 2007). As for new breeding programs (regional program : RECOLIN), further research is being carried out to understand the biological factors which trigger high levels of linolenic fatty acids (45-65% Omega-3 fatty acids) in traditional varieties and low levels (2%) in Solin or Linola cultivars (Spence and al., 2003; Sørensen and al., 2005; ANR program : GENOLIN and PT-Flax). [8]

Synthesis
The seed industry is working to develop new uses for flaxseed in animal feed and human food, improve plant properties (already acknowledge as a nutritional source of Alpha Linolenic Acid) and select new breeds capable of producing high quality oil with an optimal nutritional content. [15]

Criteria and uses:

-High protein content for added value oilseed cake (lysine);

-High linolenic acid content so flaxseed can be added to animal feed rations for producing low fat and high protein eggs, milk, butter and meat, naturally rich in unsaturated fatty acids;

-Flaxseed can also be added to food: waffles, salads, bread, cereals, energy bars, cake mixes, soup, ground flaxseeds…

Flaxseed and its elemental components, Omega-3 precursors and phytoestrogens (lignans), can be added to human food to meet consumer expectations in terms of:

-Preserving the environment and ecological balance, nature, sustainable values;

-Promoting a balanced and healthy diet for animals and humans: blood profile, low blood lipids (cholesterol, triglycerids), preventing cardiovascular disease, and providing benefits for type 2 diabetes…

-Sensorial pleasure, flavour and taste;

-Traceability throughout the production chain and compliance with food safety standards. [15]
Many research projects have been or are being carried out on Flaxseed:

NOVANOL-AMELIOFI (2006-2008) IAR Research Cluster for adding value to flaxseed crops.

Projects for developing molecular tools certified by the IAR cluster, GENOLIN and PT Flax sponsored by the ANR, and RECOLIN sponsored by the Picardie region.

In Canada = plant genome sequencing

OLEOMA (ITERG)

STANLUB project

Although flax is a minor crop, several fundamental and applied research projects (within research clusters) are being carried out to study this plant = this is due to the fact that, unlike most other plants, the whole of the flax plant can be used, increasing added value. Flax has the potential for becoming a major crop in Europe as long as French and European interprofessional oilseed organizations do more to promote this crop.

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10. RAPESEED (*Brassica napus* L.) Fam. Brasicaceae

10.1 Plant anatomy

Rapeseed belongs to Brassicaceae family, along with 3,000 other species and is related to broccoli, cabbage and cauliflower (Johnson and Croissant, no 0.110).

Figure 10-1 Rapeseed plantations at several stages of growth (vegetative phase, flowering and maturity phase)

The seeds reach the maturity almost two months from the pollination of the flowers. The crop at flowering has a height that varied from 60 cm to 150 cm depends on the variety and cultivation site. The flowers are yellow and have four petals. The pods are 2.5 to 3.8 mm long and around 30 mm wide. Rapeseed has a deep taproot and a fibrous, near surface root system.

Soon after the harvesting the seeds should carefully stored before the oil is extracted (UFOP 2007). Its seeds have an oil content of 40-45%. There are two main categories of rapeseed varieties; the varieties that are for human consumption and the ones that are for industrial uses (HEAR). In the first category the rapeseed oil has high values of unsaturated fatty acids that are very helpful to the health, while in the oil of the industrial varieties there is high percentage of erucic acid and glucosinolates that are toxic for human and animal consumption.

10.2 Domestication and area of origin

Oilseed rape (*Brassica napus L. var. oleifera*) is a very old cultivated plant originating from Asia and the Mediterranean area. Rapeseed has been important to Europe since the 13th century as a source of food and oil for fuel. Rapeseed production became popular in North America during World War II as a source of lubricants. Its oil has the property of adhering well to moist metal, making it an ideal lubricant for marine engines (Oplinger et al, 1989).

In the early 1960s, Canadian plant breeders isolated single lines free of erucic acid and began programs to develop double low varieties. Double low indicates that the processed oil contains less than 2% erucic acid and the meal less than 3 mg/g of glucosinolates. Erucic acid is a fatty acid that has been related to heart disease. Glucosinolates have breakdown products that are toxic to animals. Both characteristics make rapeseed products poor candidates for animal consumption (Oplinger et al, 1989).

It is widely distributed in the cool temperate climates of EU27, as well as in Canada and China. EU accounts for nearly 17% of the world production and Canada for 15%. In Canada it is also called 'canola'. Rape seed ranks 5th in production among the world's oilseed crops following soybeans, sunflowers, peanuts and cottonseed

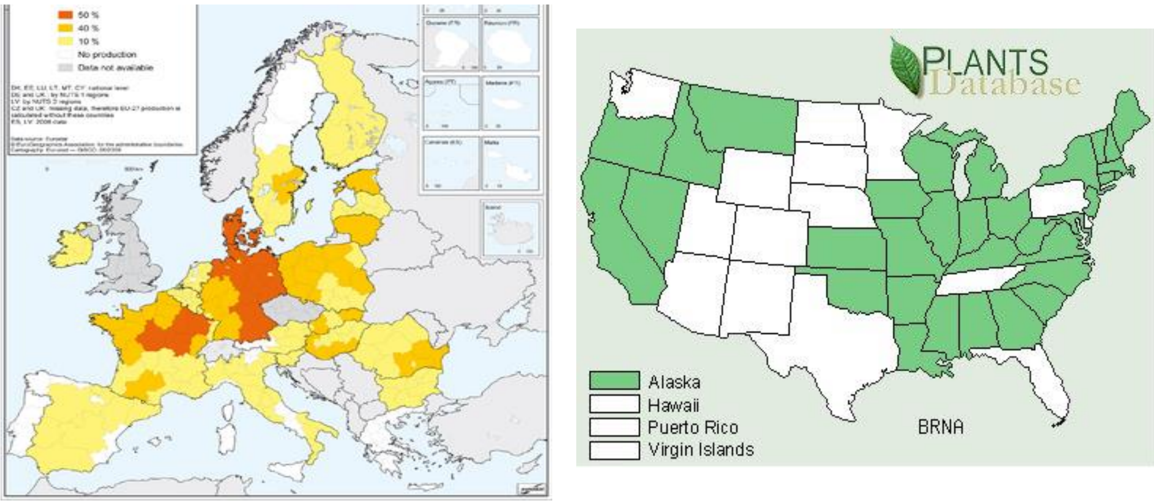

Figure 10-2 Oilseed rape distribution in EU27 and Canada (Sources: FAO on the left and http://www.livingcropmuseum.info/CropDetail/Canola /canola_distribution_map.jpg on the right)

10.3 Growing conditions

Rapeseed is an annual crop that can be cultivated as winter or spring crop. In northern Europe rapeseed is cultivated as winter oilseed rape, sown in August or/and early September. In South Europe can be cultivated either as annual or spring crop. In all cases the crop is flowering in May and the final harvest take place from June to July depends on the specific climatic conditions of the cultivated area.

Rapeseed is widely adapted to cool temperate zones. Seeds can germinate and emerge with soil temperatures at 5-10 ^{0}C. The germinating seedling may take from 4 to 10 days to emerge, depending on soil temperature and moisture, seed soil contact, and depth of planting.

It prefers medium textured, well drained soils, but it tolerates pH as low as 5.5 and saline conditions. Because of its tolerance to salinity, canola has been used as the first crop on newly drained dikes in the Netherlands.

The crop responds well to nitrogen fertilizer, with optimum yields occurring around 90-112 kg N/ha. Rapeseed is also a heavy user of sulfur (Oplinger et al, 1989).

10.4 Logistics: harvesting/handling

Rapeseed is prone to shattering which can account for significant crop losses at harvest and also can pose problems to the subsequent crops in crop rotation systems. Its timely harvest is critical to prevent shattering. Harvest maturity can only be determined by observing the color of the seed. In canola that stands well, 30 to 40% of the seed on the main stem needs to be brownish-red in color prior to swathing. This corresponds to about 30 to 35% seed moisture.

Canola does have a tendency to lodge, particularly with over-fertilization.

Stems should be cut high and left to dry near 10% moisture before combined. Canola that is to be stored for six months or more must be dried to near 8% moisture. Rapeseed must be handled and stored carefully. Tight storage bins are required. Seed can sweat in storage even at 9 to 20% moisture content. Inspection is required to prevent heating and spoilage in the bin. The small seed restricts air flow, so thin layers are necessary for drying wet seed (Oplinger et al, 1989)

10.5 Production-Yields

Today, winter oilseed rape is the most important oil crop in northern Europe. In 2007 the harvested area in EU27 was 6.501 million ha. The largest harvested area was for the first time in France (1.577 million ha) and the second largest in Germany (1.548 million ha). Until 2006 the largest area for rapeseed was located always in Germany. Quite big harvested area was also measured in Poland (0.797 million ha) and in UK (0.681 million ha). The yields (kg/ha) in the countries belongs to EU27 presented in Table 3. The variation in yields is quite big; from 1178 kg/ha (Romania) to 3890 kg/ha (Ireland). The mean seed yields for EU-27 (in 2007) was 2539 kg seeds/ha. It should be mentioned that in France that the largest area of rapeseed was established the seed yields were lower compared to the corresponding value in Germany (2888 kg/ha versus 3437 kg/ha).

In Germany in 2007 the harvested area for rapeseed cultivation was two times higher compared to the area recorded 15 years ago (1.5 millions ha). Over a period of years, rapeseed is always cultivated in rotation with cereals and other crops and this fact is that rapeseed can be characterized anything but monocrop plant.

According to IENICA report for rapeseed the yields were 2.71 t/ha in Austria, 2.69 t/ha in Belgium, 5.27 t/ha in Denmark, 1.38 in Finland, 2.92 in France, 3.31 t/ha in Germany, 1.92 t/ha in Ireland, 0.96 t/ha in Italy, 4 t/ha in the Netherlands, 1.58 t/ha in Spain, 2.45 t/ha in Sweden and 2.81 in UK.

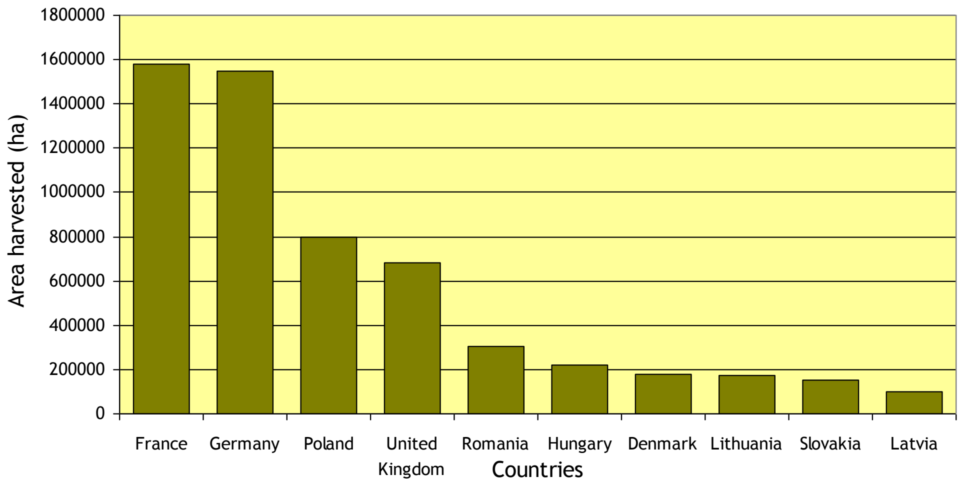

Table 10-1 Area harvested (ha), yields (kg/ha), production quantity (tones) and seed yields (tn) in the EU-27 countries for rapeseed (source: FAOSTAT).

Country	Area harvested (ha)	Yields (kg/ha)	Production quantity (tones)	Seed yields (tones)
Austria	48509	2983	144706	269
Belgium	10776	3570	38470	
Bulgaria	53999	1723	93018	1137
Croatia	13069	3009	39330	130
Czech Republic	337571	3057	1031920	3569
Denmark	179200	3328	596300	8960
Estonia	74000	1805	133600	
Finland	89500	1268	113500	
France	1577000	2888	4554000	7885
Germany	1548177	3437	5320518	6000
Greece	4000	1500	6000*	
Hungary	223000	2234	498200	2000
Ireland	8200	3890	31900	50
Italy	7200	2078	14962	100
Latvia	99200	1985	196900	750
Lithuania	174400	1788	311900	26700
Luxembourg	5394	3393	18302	
Netherlands	4000	3250	13000	56
Poland	796751	2673	2129873	77106
Romania	306771	1178	361500	3574
Slovakia	153830	2087	321100	54
Slovenia	5400	2722	14700	
Spain	16800	1935	32500	235
Sweden	83310	2594	216100	
United Kingdom	681000	3096	2108000	7776
EU-27	6501057	2539	18334299	8131

10.6 Applications: current/potential

The oil of oilseed rape has various food applications, including bottled oils or/and margarines where it is valued because it is high in monounsaturates (UFOP, 2007). The Brassica napus oilseed fatty acid profiles are presented in the Table below.

Canola and rapeseed are the most important oilseed crops in the world. Until the early 1970s both crops covered by the name "rapeseed". At that time, the Canadian scientists through its breeding programme create the "double low" varieties that had low or zero erucic acid and glucosinolates. For these varieties was adopted the name "canola". 00-rapeseed is now exclusively cultivated and used for nutritional purposes because of its excellent oil composition of unsaturated fatty acids (UFOP, 2007).

A second type of rapeseed varieties are the "high erucic acid varieties (HEAR)" which are grown specifically for their high erucic acid (C22:1) content, which is typically 50-55% of the oil.

Canola is now more important than rapeseed in countries such as Canada mainly because it produces two acceptable products, an edible vegetable oil and a proteinaceous concentrate for feedstock. Nowadays, most of the canola varieties cultivated in Canada and USA are genetic modified ones.

Table 10-2 Brassica oilseed fatty acid profiles

	C16	C18	18:1	C18:2	C18:3	C20:1	C22:1
B. napus cv. Tobin	4.3	1.7	52.7	24.5	14.2	1.2	0.6
B. napus	3.8	1.6	39.2	20.5	9.2	11.7	14.9
B. napus	3.0	0.8	9.9	13.5	9.8	6.8	53.6
B. napus	10.0	1.0	51.0	19.0	13.0	1.0	trace
B. napus Stellar (Io 18:3)	5.0	2.0	64.0	24.0	<3.0	1.0	trace
B. napus VHOAR mutant	3.0	1.6	85.4	3.6	3.9	1.3	0.0
B. napus Tobin	3.8	1.2	58.3	24.0	10.3	1.0	0.3
B. napus Echo	2.5	1.0	32.5	18.8	8.9	12.0	23.5
B. napus R-500	2.5	1.0	13.0	13.5	10.1	5.5	51.1

Source: www.ienica.net

Worldwide rapeseed occupies the third rank on the world oilseed production after soybean and palm oil. Vegetables oils are primary used in the food industry.

The industrial markets of the rapeseed oils are: Biofuels, lubricants, surface coatings, polymers and medicinal.

In addition to the oil markets, rapeseed meal can be used in Bioplastics. Adhesives. Cosmetics, encapsulation agents, lawn care products, combustion materials. Its straw can be used as animal bedding or for feed.

The Biodiesel market

According to UFOP (Extracts from the 2008/9 UFOP report) 83% of the worldwide vegetable oils production (127 million tons) is used for foodstuff, 10% in industry and 7% for biodiesel. In 2007/2008 173 millions tons of rapeseed production (worldwide) is for feedstuff utilization, 14 million tons for foodstuff and 6 million tons for industry (4.1 million tons for biodiesel production).

Biodiesel production uses today approximately 3,000,000 hectares of arable land in EU27, according to estimations of EBB (European Biodiesel Board). Of the major oilseeds cultivated today, soybean is far the world's largest, followed by rapeseed and cottonseed (*WWI, 2006*). But, in Europe nearly 85% of biodiesel comes from rapeseed, followed by sunflower seed oil, soybean oil and palm oil (*Mittelbach and Remschnidt, 2004*). In temperate regions, oilseeds crops typically produce lower yields per hectare than starchy cereal feedstock such as corn and wheat, whereas when grown in tropical areas oil crops can be very productive (*WWI, 2006*).

The total rapeseed production in EU27 is expected to increase in the marketing year 2007/08. The increase will be almost 14% mainly due to higher acreage in most member states and the total production around 16.68 million MMT, whereas the rapeseed oil is expected to continue to increase to 7.5 MMT. The entrance of Romania, which is a considerable rapeseed producer, is expected to help keeping the record levels of rapeseed production in Europe. It is also reported that more than half of the EU27 production is located in Germany, France and Benelux (Belgium, Netherlands and Luxemburg), whereas EU imports rapeseed oil mainly from Canada and United States, China and the United Arab Emirates. Roughly two thirds of the EU27 rapeseed oil production is used for biodiesel, while the remaining third goes to food and staple use.

Rapeseeds are characterized by high contents of monounsaturated oleic acid and low levels of both saturated and polyunsaturated acids and thus have the ideal combustion characteristics, oxidative stability and cold temperature behaviour.

The lubricants market

According to the IENICA project, in 2000 the European lubricants market produced 5.3 MT lubricants from vegetable oils.

Rapeseed oil can be used as a lubricant because of its favorable natural properties:

- High viscosity index
- The structure endures mechanical stresses
- Low friction coefficient means only slight heating of the oil during use
- Due to its polarity, the oil adheres o metal surfaces and provides good protection against corrosion
- Liquid even at temperatures below -35 ^{0}C.

A number of major players in the lubricant market have prepared vegetable-oil-derived substances for current fossil petrochemical derived lubricants, like the companies Fuchs, Shell/BP, Elf Aquitaine/Total/Fina, Lubrizol International, Novance, Castrol, croda, OMV.

Restricting factors for the lubricants market development are:

- The high price, that cannot compete with the mineral oils
- Will not withstand long-term use at temperatures above 100 ^{0}C, even with additives
- Reduction in the efficiency of oil soaked brakes
- Stubborn staining

Very high oleic oils seem to offer the best compromise in terms of technical characteristics. As a result, high oleic varieties of rapeseed oil are beginning to find users where higher oxidative stability is required but commercialization is still a long way off.

The surface coating market

Although soy-based vegetable oils are used as ‘vehicles’ in printing inks, rapeseed oils are also used in a smaller extent. However, they cannot compete on price with mineral oils and any increase on their use highly depends on environmentally based legislation.

The market of polymers

Rapeseed oils are used in the manufacture of functional additives (stabilizers, processing aids, flame returdants, etc), in the manufacture of reactive ingredients for polyamids, polyesters and polyurethanes, as well as for the direct production of polymers.

Rapeseed oils are used as having properties preventing cancer, etc)

10.7 Restricting factors and research gaps

Many applications are identified now for erucic acid, both in industry than cosmetics. The market remains small and for the European Union hardly exceeds the production of 40 000 hectares (witch represent at least 120 000 tons of seeds). Acreages in France account for half of this production (A. Merien, 2011).

Two major sources are identified for the production of erucic acid: the erucic rapeseed and the crambe. However, up to now, only the erucic rapeseed leads to a significant production. Crambe crops are currently at the stage of testing.

In the case of erucic rapeseed (HEAR), levels of erucic acid oil are on average around 50 % of total FA. In the case of crambe, references show higher concentrations up to 55 to 60 %.

As for the other fatty acids, the enzymatic activity involved in the biosynthesis is temperature sensitive and therefore governs much of the balance of fatty acids in the oil.

The quality of production and especially erucic acid imperatively requires control of volunteer oilseed "00" in plots of erucic rapeseed. Isolation between rapeseed "00" and erucic is also required, which complicates rotation crops. To resolve this problem, cooperatives now devote entire area for the production of erucic rapeseed. More difficult is the situation of crambe, whose technical and economic interest has yet to be demonstrated. The plant also benefits very little research effort.

The achievement levels are far from the economic threshold required under the potential of erucic rapeseed.

The glucosinolates content of seeds leads to dedicated the cake to fertilization instead of of animal feed uses.

Regarding the production of HEAR, the main limiting factors reside mainly in the narrow genetic variability in the level of performance of varieties and especially in erucic acid content in the oil capped at 50% today. However, the latest entries varieties now allow the cultivation of varieties (winter type) with low glucosinolates, no definite improvement for enhancing the meal.

There are only 2-3 varieties of HEAR available (Palmedor, Zeruca) and they are grown in limited areas; around 40,000 ha are grown with high erucic varieties in EU, half of them located in France.

Cultivars available for farmers are unfortunately susceptible to phoma linguam and require fungicides in autumn, difficult to target in terms of the biology of the pathogen.

The establishment of the stand is a real weak point to difficulty of seed germination (the seed is sown with the pod walls, one seed per pod).

Seed shattering is a major drawback of rapeseed cultivation. Crop development studies involving the development of new types as well as visual markers for each crop type would contribute to achieve higher yields at lower production costs.

Despite the fact that this crop is the most important oil crop for biodiesel production in Europe better adapted varieties should be developed for the Mediterranean region.

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11. SAFFLOWER (*Carthamus tinctorius* L.)

11.1 Plant anatomy

Safflower (Carthamus tinctorius L.) is a broadleaf, annual oilseed crop primarily adapted to grow in the western Great Plains. In the same family as sunflower, it is a thistle-like plant with a strong central branch stem and a varying number of branches. Each branch usually has one to five flower heads and each of those heads contains 15 to 20 seeds. Safflower has a taproot system that can penetrate deep making the plant more tolerant to drought than small grains. Stiff spines develop on leaf margins of most varieties at about the flower bud stage.

Figure 11-1 Carthamus tinctorius L. Safflower

Branches usually produce one to five flower heads. Flower heads, about one inch in diameter, are usually yellow or orange in colour, although some varieties have red or white flowers. Flower buds form in late June and flowering starts in mid- to late July, and continues for two to three weeks depending on environmental conditions, stand density, and varietal differences. [3]

11.2 Domestication and area of origin

Safflower is native to the Old World, and the genus occurs naturally in the Mediterranean region, northeastern Africa, and southwestern Asia to India. There are positively identified archaeological records of safflower from 4000-year-old Egyptian tombs, including a find of single safflower flowers wrapped in willow leaves that were placed with a mummy from the 18th Dynasty (ca. 1600 B.C.). The flowers of Carthamus are pale yellow to red-orange, tubular disk florets; there are no ray florets in this thistle-like head. Since ancient times, orange pigments have been obtained from safflower. In fact, the name safflower may be derived from another plant, saffron (Crocus sativus), which was a precious and very expensive yellowish dye obtained from the stigmas of freshly opened flowers. The name Carthamus is the latinized form of the Arabic word quartum or gurtum, which refers to the pigment color. The corolla as a water-soluble yellow dye (carthamidin, an anthocyanin) and a water-insoluble orange-red dye (carthamin), which is readily soluble in an alkaline solution.

Figure 11-2 Safflower distribution in Europe (Source Wikipedia)

11.3 Growing conditions

Safflower is an annual species in the same plant family as sunflower. This crop is adapted to dryland or irrigated cropping systems. Each seed germinates and produces a central stem that does not elongate for two to three weeks, and develops leaves near the ground in a rosette, similar to a young thistle. The slow growth of seedlings in early spring often results in a weedy crop. Each flower head produces 15 to 30 seeds with seed oil content usually between 30 to 45%. Seeds are enclosed in the head at maturity, which prevents shattering before harvest and delays somewhat the feeding loss from birds. Seeds usually mature in September, which is about four weeks after flowering ends. This crop usually needs 110 to 140 days to mature [3].

Safflower production is not recommended for areas with more than 15 in. of annual precipitation or growing seasons with fewer than 120 frost-free days and less than 2,200 growing degree days. Temperatures as low as 20°F are tolerated by plants while in the rosette stage, but safflower is very sensitive to frost injury after stem elongation until crop maturity. This crop does best in areas with warm temperatures and sunny, dry conditions during the flowering and seed-filling periods. Yields are lower under humid or rainy conditions since seed set is reduced and the occurrence of leaf spot and head rot diseases increases. Consequently, this crop is adapted to semiarid regions. Deep, fertile, well-drained soils that have a high water-holding capacity are those ideal for safflower. This crop is also productive on coarse-textured soils with low water-holding capacity when adequate rainfall or moisture distribution is present. Soils that crust easily can prevent good stand establishment. High levels of soil salinity can decrease the frequency of seed germination and lower seed yield and oil content. Safflower has approximately the same tolerance to soil salinity as barley [3].

Table 11-1 Safflower growth requirements

Safflower Ecology			
Temperature	**Precipitation**	**pH**	**Soil**
6 – 28 °C	2 -14 dm	5 - 8	sandy or clay loams

11.4 Logistics: harvesting/handling

Safflower is ready to harvest when most of the leaves turn a brown colour and very little green remains on the bracts of the latest flowering heads. The stems should be dry, but not brittle, and the seeds should be white and hand thresh easily. This crop should be harvested as soon as it matures in order to avoid the seed discoloration or sprouting in the head that can occur with fall rains.[3] Safflower is an excellent crop for direct combining since it stands well and does not shatter easily. Direct combining may require artificial drying or waiting until green weeds are killed by frosts. The crop can be windrowed to dry green weeds when moisture content of seed is as high as 25%. The time for harvesting safflower in Europe can vary from early to late September due to the environmental conditions during the growing season. The combine cylinder speed should be set low at 550 RPM to avoid cracking seed. The reel speed should be about 25% faster than the ground speed. To prevent clogging of the machine from plant residue, the shaker speed must be greater than speeds used for small grains. Air speed should be sufficient to remove most unfilled seeds, straw, and bulls. The combine radiator and air intake should be checked regularly to avoid blockages from the white fuzz of seed heads. Accumulations of this white fuzz can be a fire hazard. [3]

<u>Drying and Storage</u>. Quality safflower seed should have a white seed coat, and no sprouting. Safflower seed has recently been purchased on a clean basis with a desired oil content of 34 to 36%. Oil content above or below this level results respectively, in a premium or dockage on prices paid to growers. Moisture content of the cleaned seed should not exceed 8% for safe, long-term storage. [3]

<u>Weeding</u> is a logistic issue in safflower cultivation and can be done: mechanically or chemically For the mechanical, weeds frequently emerge before safflower and can be controlled in wider rows by a spike-tooth or coil-spring harrow. Harrowing may control some weeds, but damage to the emerging safflower seedlings can occur if the soil is ridged and some plants are buried too deeply.Considering the chemical weeding a Dual (metolachlor) and Treflan (trifluralin) are labeled for use on safflower. Dual is applied as either a preplant or preemergence herbicide. Treflan is used as either a fall or spring preplant incorporated treatment. Treflan is primarily used to control grasses, but will control some broadleaf weeds. If there are large numbers of broadleaf weeds, consider not growing safflower in that field. Wild mustard, kochia, and Russian thistle are difficult weeds to control in safflower. The herbicide rate applied will vary with the soil type and organic matter content, and the species of weeds that need to be controlled.

11.5 Production-Yields

The main producer of safflower seed remains United States and China, while in India even if the area harvested is important, the yield obtained are relative. In the European Union this crop is only exploited in Spain and Hungary, like all the remaining production of Europe is made in southern Russia (FAOStat, 2010).

Table 11-2 Production of safflower seeds (FAOStat, 2010).

Country	Yield (Hg/Ha)	Area Harvested (Ha)	Production (tonnes)
Spain	8333	60	50
Hungary	2740	73	20
India	6319	270600	171000
China	14690	22600	33200
United States of America	14793	67870	100400
European Union + (Total)	5263	133	70
Oceania + (Total)	11098	7800	4900
Africa + (Total)	7007	19553	13700
Americas + (Total)	8213	220418	244628
Asia + (Total)	7075	524401	371036
Europe + (Total)	6379	533	340
World + (Total)	6282	772705	634404

Two types of safflower oil with corresponding types of safflower varieties exist: those high in monounsaturated fatty acid (oleic) and those high in polyunsaturated fatty acid (linoleic). The safflower varieties that are high in oleic oil are used as a heat stable cooking oil to fry food, chips and other snack items and are also used in cosmetics, food coatings, and infant food formulations. The oil in linoleic safflower contains nearly 75% linoleic acid and is used primarily for edible oil products such as salad oils and soft margarines, but is even used in painting in the place of linseed oil, particularly with white, as it does not have the yellow tint which linseed oil possesses.

Table 11-3 Chemical oil composition of safflower seeds.

	oleic safflower oil	linoleic safflower oil
compounds		
palmitic acid	5–6%	5–8%
stearic acid	1.5–2%	2–3%
oleic acid	74–80%	8–30%
linoleic acid	13–18%	67–89%
linolenic acid	traces	traces
long cfa	traces	traces

Safflower flowers are occasionally used in cooking as a cheaper substitute for saffron, and are thus sometimes referred to as "cheap saffron."

In textile dyeing, the dried flowers of safflower are used as a natural textile dye. The pigment in safflower is the benzoquinone-based Carthamin, which is a direct dye (CI Natural Red 26) and soluble. Safflower was particularly important as an oil and pigment in southern Asia (Iran, Afghanistan, and India), and early carpets from these regions used safflower dye. All hydrophilic fibres may be dyed with this plant since it may be classified as a direct dye. Safflower flowers are used in Traditional Chinese medicine to alleviate pain, increase circulation, and reduce bruising. They are included in herbal remedies for menstrual pain and minor physical trauma.

11.6 Applications: current/potential

Safflower was originally grown for the flowers that were used in making red and yellow dyes for clothing and food preparation. Today this crop supplies oil, meal, birdseed, and foots (residue from oil processing) for the food and industrial products markets, although this crop is now primarily grown for the oil. Safflower oil is a drying oil that is used in white and light-colored oil-based paints instead of linseed oil, because it does not yellow with age like similar oils rich in linoleic or oleic acid (depending on cultivar). Safflower was used as a substitute for more precious oils. Safflower arrived in China relatively late (200-300 A.D. according to current records), and the dyes became important there. In China safflower oil was considered inferior to sesame oil but nonetheless is mixed with sesame and cottonseed oil in the preparation of Japanese tempura. The Japanese cosmetic beni is also made from safflower, and French chalk was mixed with safflower to make a cosmetic. In India and Afghanistan, saffron rice is made with safflower, which gives it an interesting orange colour. Moreover, over the centuries safflower has been used commonly in potions and folk medicines throughout the Old World. [3]

The meal, which is about 24 percent protein and high in fiber, is used as a protein supplement for livestock and poultry feed. Safflower seed also is marketed as birdseed. This industry prefers the white hull or normal hull type of safflower even though striped and partial hull types usually are higher in oil and protein content. The birdseed market does not have a preference for a fatty acid type. Safflower also makes an acceptable livestock forage if cut at or just after bloom stage.

Safflower oil consists of two types with corresponding types of safflower varieties: those high in monounsaturated fatty acid (oleic) and those high in polyunsaturated fatty acid (linoleic). As an industrial oil, it is considered a drying or semidrying oil that is used in manufacturing paints and other surface coatings. The oil is light in colour and will not yellow with aging, hence it is used in white and light-colour paints. This oil can also be used as a diesel fuel substitute, but like most vegetable oils, is currently too expensive for this use. The meal that remains after oil extraction is used as a protein supplement for livestock. The meal usually contains about 24% protein and much fiber. Decorticated meal (most of hulls removed) has about 40% protein with a reduced fiber content. Foots are used to manufacture soap. The birdseed industry buys a small portion of the seed production. Sheep and cattle can graze succulent safflower and stubble fields after harvest .[3]

11.7 Restricting factors

Weeds can be a major problem for safflower crops by reducing potential crop yields. Protection from weed competition during the early portion of the growing season is very important. A dense canopy of vegetation forms as the plants grow, which allows safflower to compete successfully with late-emerging weeds. Safflower with a combination of tillage and herbicides inappropriate for use on cereal grains, can be used to reduce numbers of grassy weeds in a small grain rotation. Diseases have caused economic losses in years with above normal rainfall and prolonged periods of high humidity. Alternaria (Alternaria carthanti) leaf spot and bacterial blight (Pseudomonas syringae) are the most serious disease problems under these conditions. Alternaria leaf spot has symptoms of large, brown irregular spots on leaves and flower bracts. Varieties vary in the degree of resistance they have to leaf spot, and severe losses may occur. Bacterial blight has symptoms similar to those of Alternaria leaf spot that usually appear during periods of heavy rainfall. These leaf lesions have yellow-green margins. Using disease-free seed of a variety with some resistance, and the proper seed treatment before planting, should reduce these disease problems. Rust (Puccinia carthand) is usually not a problem in safflower since it is easily controlled by seed treatment. There are other diseases that can cause economic losses: flower head rots caused by Sclerotinia and Botrytis, root rots produced by Phytophthora and Pythium fungi, and wilts from Verticillium or Fusarium are included in this list of potential disease problems. A four-year crop rotation should separate safflower from safflower, sunflower, canola, mustard, dry bean, soybean, or lentils so that common disease problems are reduced. [3]

11.8 References

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12. SUNFLOWER (Helianthus annus L.)

12.1 Plant anatomy

Sunflower belongs to Compositae family and to genus Helianthus that included 67 annual and perennial species. The crop originated in subtropical and temperate zones, but though selective breeding has been made highly adaptable, especially to warm temperate regions.

Figure 12-1 Sunflower at several stages of growth (vegetative phase, flowering phase and maturity phase) (Source: CRES)

It is an annual spring crop with a plant height from 1.5 to 2.5 m at the flowering and has strong taproots, from which deeply-penetrating lateral roots develop. In each stem a total number of leaves between 20 and 30 developed. The flower is a typical head that develops in the top of each stem with a diameter 15-30 cm. The flowers tend to cross pollinating and the best temperature range for the production of seed is 20-25^0C. Seed and oil yields are reduced under conditions of stress. Oilseed producing varieties have a 1000 seed weight of 40 to 60 g and non-oilseed varieties have a 1000 seed weight of sometimes over 100 g (www.ienica.net).

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12.2 Domestication and area of origin

Sunflower is one of the most widely cultivated oil crops in the world. It is native to the Americas and widely grown in EU as cooking ingredient

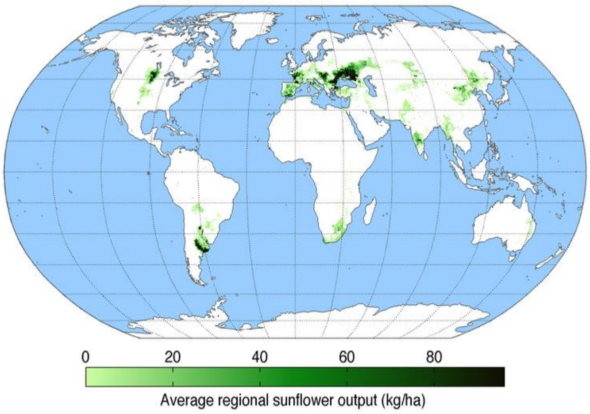

Figure 12-2 Sunflower distribution (Source Wikipedia)

12.3 Growing conditions

Sunflower is adapted to a wide range of soil conditions, but grows best on well-drained, high water-holding capacity soils with near neutral pH (6.5-7.5). Production on high-stress soils such as those affected by drought, salinity or wetness is not exceptional but compares favorably with other commonly grown commercial crops. Having a well-developed root system is considered as one of the most drought resistant crops suitable for the southern semi-arid EU countries. However, oil yields are sustainable reduced if plants are allowed to become stressed during the main growth period and at flowering. Under moisture stress conditions the number and the size of the leaves are reduced. One of mechanisms employed by sunflower to resist moisture stress is by willing, since it has been shown in controlled experiments that in limp leaves water loss was reduced to a greater extend than photosynthesis. A satisfactory crop can be produced, without irrigation, even in winter rainfall regions of approximately 300mm.

Native sunflower and the early varieties were self incompatible and required insect pollination for economic seed set and yields. However, because the number of pollinators was often too low current hybrid varieties have been selected for and possess high levels of self compatibility. Modern hybrids still benefit from insect pollination.

The crop is highly productive throughout Europe with modest water and fertilisation needs. It is grown from March to June or in rotation as a double crop.

12.4 Production-Yields

One of the main characteristics that determine the quality of the produced biodiesel is the fatty acid composition of the sunflower oil. It is varied according to the cultivation site, the sowing dates and the years. This is because the oleic/linoleic ratio depends on the temperature during the early stages of oil synthesis in the seeds (Izquierdo et al. 2002). Moreover, the effect of temperature can be different according to the genotype (Izquierdo and Aguirrezaba, 2008).

Several quality parameters of biodiesel (e.g. density, kinematic viscosity, heating value, cetane number and iodine value) are highly dependent on fatty acid composition.

Table 12-1 Area harvested (ha), yields (kg/ha), production quantity (tones) and seed yields (t) in the EU-27 countries for sunflower.

Country	Area harvested (ha)	Yields (kg/ha)	Production quantity (tones)	Seed yields (tones)
Austria	26446	2251	59527	267
Bulgaria	602398	937	564447	21650
Croatia	20615	2634	54303	247
Czech Republic	24426	2129	52000	293
France	534000	2577	1376000	5340
Germany	19161	2655	50862	0
Greece	12100	1593	19273	363
Hungary	504900	2045	1032300	5000
Italy	127329	2129	271090	1500
Poland	3243	1746	5662	
Portugal	9000	1833	16500	100
Romania	748545	731	546922	5661
Slovakia	64746	2049	132656	2248
Slovenia	200	2000	400	2
Spain	601000	1170	703000	3000
EU-27	**3298109**	**1899**	**4884942**	**45671**

The harvested area of sunflower in EU27 is presented in Table above. The total harvested area in EU-27 in 2007 was 3.298 million ha. The top five EU countries in terms of harvested area are: Romania 0.749 million ha, Bulgaria 0.602 ha, Spain 0.601 million ha, France 0.534 million ha and Hungary 0.504 million ha. The yields varied from 731 kg/ha (Romania) to 2655 kg/ha (Germany), while the mean seed yields in the cultivated countries of the EU-27 is 1899 kg seeds/ha.

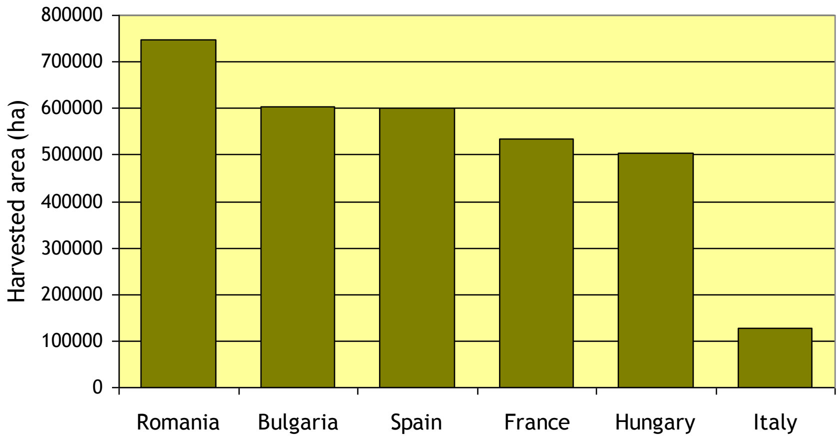

Figure 12-3 Harvested area (ha) in six most important EU countries for sunflower cultivation

12.5 Applications: current/potential

The sunflower oil is considered as high quality oil since it has low percentage of saturated fatty acids and high percentage of unsaturated fatty acids.

According to the results of the Probiodiesel (www.probiodiesel.com) project the oils of rapeseed, soybean, sunflower and palm are suitable for the production of biodiesel in the process of ACCIONA production plant (Spain). The only raw material that can be used neat and is in accordance EN14214 specification parameters is rapeseed. When biodiesel is produced from sunflower, soybean and palm it is necessary to blend them or use additives to comply with the iodine index specification (for sunflower and soybean) and to improve the cold flow properties (for palm).

The results on oils of rapeseed and sunflower (and the biodiesel that were produced from them) carried out by ACCIONA in the framework of the probiodiesel project are presented in the Table below:

Table 12-2 Results from two oils (rapeseed, sunflower) –source Probiodiesel (D2.1, www.probiodiesel.com)

	Rapeseed	Sunflower
Non-soluble in ether	Oil:<0.01%	Oil:<0.01%
Iodine number	Oil/biodiesel: 111 g/100 g fat	Oil/biodiesel: 131 g/100 g fat
Unsaponifiable content	Oil: 1.02%	Oil: 0.75%
Acidity	Oil: 0.08% Biodiesel: 0.38 mgKOH/g sample	Oil: 0.05% Biodiesel: 0.41 mgKOH/g sample
Stability to oxidation	Oil:10.1 hours Biodiesel: 8.3 hours	Oil:5.1 hours Biodiesel: 2 hours
Ester content	Biodiesel: 99.9%	Biodiesel: 98.8%
Density at 15^0 C	Biodiesel: 883 kg/m^3	Biodiesel: 881 kg/m^3
Viscosity at 40^0 C	Biodiesel: 4.44 mm^2/s	Biodiesel: 4.13 mm^2/s
Ignition index	Biodiesel: 183 ^{0} C	Biodiesel: 165 ^{0} C
Sulphur content	Biodiesel: 0.5 mg/kg	Biodiesel: 0.5 mg/kg
Carbon residue-Micro Method (in 10% of distillation residue)	Biodiesel: 0.07% (m/m)	Biodiesel:<0.30% (m/m)
Content in sulphated ashes	Biodiesel: <0.01%	Biodiesel: 0.01%
Water content	Oil: 0.04% Biodiesel: 64 mg/kg	Oil: 0.1% Biodiesel: 334 mg/kg
Total contamination	Biodiesel: 14 mg/kg	Biodiesel: 5 mg/kg
Corrosion in copper sheet	Biodiesel: class 1A	Biodiesel: class 1A
Methyl ester of linoleic acid	Biodiesel: 9.1% (m/m)	Biodiesel: 0.1 % (m/m)
Methyl esters of poliinasaturated acids	Biodiesel: <0.01% (m/m)	Biodiesel: <0.01% (m/m)
Content in methanol	Biodiesel:<0.01% (m/m)	Biodiesel:0.10 % (m/m)
Content in mono-, di- and triglycerids, free glycerine and total glycerol	Biodiesel: Cont. monoglycerids: 0.43 % Cont. diglycerids: 0.08%	Biodiesel: Cont.monoglycerids: 0.62 % Cont. diglycerids: 0.05%

	Cont. triglycerids: 0.01% Free glycerin: 0.01% Total glycerin: 0.13 %	Cont. triglycerids: < 0.01% Free glycerin: <0.01% Total glycerin: 0.18 %
Content in Na, K, Ca and Mn	Biodiesel: Metals of group I (Na+K): 3.9 mg/kg Metals of group II (Ca+Mg): Ca:< 1 mg/kg Mg: < 1 mg/kg	Biodiesel: Metals of group I (Na+K): Na <0.1 mg/kg, K: 0.4 Metals of group II (Ca+Mg): Ca: 0.3 mg/kg Mg: 0.1 mg/kg
Phosphorus content	Biodiesel: <1 mg/kg	Biodiesel: 0.8 mg/kg
Cold Filter Plugging Point (CFPP)	Biodiesel: -12 ^{0}C	Biodiesel: -5^{0}C

12.6 Restricting factors

The crop is highly productive throughout Europe with modest water and fertilisation needs, but Nitrogen fertilisation is a limiting factor for achieving high yields.

12.7 References

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13. CONCLUSIONS

While European oilseed production is dominated by rapeseed **(Brassica napus)** and **sunflower (Helianthus annus)** accounting for the 59% and 20% of the total vegetable oil production respectively, a number of other oilseed crops are produced, and this range has increased with the accession of the new European states. Oilseed rape dominates in most northern countries and sunflower in most central and southern countries. Although the largest proportion of the produced oil was used for food purposes, a significant proportion was used for non-food. **Soya bean (Glycine max)** cultivation was shown to be increasing in southern Europe, accounting for the 16% of the total vegetable oil production in 2009; the area of **linseed (Linum usitatissimum)** was shown to fluctuate, it was largely subsidy driven, and considerable quantities of, primarily tropical, oilseeds were imported to supplement European production. About 15,000ha are grown with linseed in Europe. **Safflower (Carthamus tinctorius)** production is commercialized with 0.10% of the total vegetable oils production. The main producers are India (54,000 tons), USA (39,256 tons) and Argentina (27,460 tons).

For certain crops like **castor seed and safflower** there is already an established market and considerable research going on in the Mediterranean area, thus it is highly likely that these crops could be candidate for larger-scale development in Europe. Castor requires irrigation while safflower is vulnerable to weeds. In both crops, seed and oil yield improvement is required with the use of biotechnology, among others. **Castor seed, jatropha and safflower** are commercialized for a number of industrial uses; castor oil is used mainly in industry for technical polymer (polyamide-11), fragrances, coating fabrics, high-grade lubricants, inks, textile dyeing, leather preservation, etc as well as in medicine. Jatropha recently gained a lot of attention for biodiesel production, while safflower has been known since ancient times as a source of orange and yellow dyes and food colourings, and more recently has been grown for oil, meal, birdseed for the food and industrial product markets, such as paints and varnishes as well as for the oil food market. Researchers are trying to genetically modify the castor plant to prevent the synthesis of ricin but this would not solve the issue with the allergenic compound.

Crambe is closely related to rapeseed and mustard and thus can be cultivated with existing agricultural methods and machinery. Crambe production would not compete directly with domestic seed oils since it would provide a substitute for erucic acid extracted from imported rapeseed. However, there is no broad commercial outlet for crambe seed, therefore its commercial deployment depends on the market needs. In the cold climate of Central Europe only crambe seems to have a potential to grow as it shows similar performances to rapeseed.

Calendula, caper/wild spurge, cuphea and lunaria still need experimentation on agronomic methods and plant breeding to improve crop characteristics in order to allow their industrial exploitation.

Calendula is a good competitor to tung oil, which is currently imported in the EU, due to the calendic fatty acid content. Its indeterminate flowering and seed crushing difficulties hinders its development in large scale. Thus, there is need to improve cultivars, production systems and seed dehulling for oil extraction and that is to be achieved through breeding, ecophysiology studies, and seed cleaning and processing investigations.

Indeterminate flowering and seed shattering is also occurring in **caper/wild spurge** and **cuphea**, which makes harvesting difficult and less economic. The major constraint to the development of **Cuphea** for industrial uses, apart from its frost sensitiveness, sequential maturation and release of seeds from seed pots, is the seed shattering, stickiness and dormancy, which is at present being studied by plant breeders. In the case of **caper/wild spurge,** the presence of poisonous latef in the foliage makes the crop highly toxic and also blocks the threshing drums during harvest. Thus the highest priority to assure maximum seed yields is genetic and plant breeding research to obtain determinate flowering and non-shattering cultivars.

Lunaria is also at the development stage. Its mechanical harvesting and cleaning of the seeds is a problem but the major limitation to progress is the biennial nature of the plant and its high vernalisation requirement. The production potential and agronomy of the crop requires further investigation as the crop often does not thrive in large open fields. Thus, at present commercial production of lunaria is limited to seed multiplication for ornamentals.

Linseed is widely grown also as a fiber crop in Europe. Harvesting can be a major problem with linseed, particularly if the crop is late, incompletely desiccated or lodged.Several studies are carried out on the biological process leading to the filling of seeds in order to improve the quality of seed flax (oil content, improved fatty acid profile).

In contrast to all oil crops studied in this work, **cardoon** is a perennial crop grown only in the Southern European climates. It is the best crop for arid conditions because it matures naturally on the field in summer time when crops usually need irrigation. Mechanical harvesting still needs improvement to efficiently separate seeds from the whole plant.

14. Summary table

Oil Crops	Origin	Area of EU cultivation	Plant nature	Yields	Products/ Markets	Pros (+)	Cons (-)	Needs (Research, policy, etc	Perspectives
Calendula (*Calendula officinalis* L.)	Native in Mediterra-nean W.Asia	EU 10000 ha Trials in Morocco	Annual spring crop Sown in April Hardy	Seeds: 1-2.5 t/ha of seeds 14-22% oil content 55-60% calendic fatty acid 300 kg/ha of oil	Paints, alkyd resins, non fogging polyurethan e foam, varnish additives, cosmetics	Mechanical sowing with grain drills Mechanical harvesting with grain combining machines but no swathing. Several uses of the plant parts: essential oils and pigments from flowers, oils from seeds which contain calendic acid.	Potential problems with seed drilling because seeds are small and irregularly shaped. Optimum harvest date difficult to determine because of indeterminate flowering. Seed crushing difficulties (hook). Crude oil of bad quality and difficult to refine due to its very high oxidative sensitivity.	Need to improve cultivars, production systems and seed dehulling for oil extraction. This to be achieved through breeding, ecophysiology studies, and seed cleaning and processing investigations.	Good competitor of tung oil, which is currently imported in the EU, due to the calendic fatty acid content.

Cardoon (*Cynara cardunculus* L.)	Native in Mediterra-nean, America (California, Mexico, Argentina) Australia	1000 ha in Spain	Perennial crop Sown in March or October Drought tolerant	Seeds: 3.4 -25 t/ha of dry matter 8% seeds 1.1 t/ha of seeds (mean) 25% oil content 60% linoleic fatty acid	Aerial biomass is used for heat and power, seeds for biodiesel production	Mechanical sowing with grain drills Mechanical harvesting in two steps in order to separate seeds from the aerial biomass	High variability of yields when grown in marginal lands	Mechanical harvesting still needs improvement to efficiently separate seeds from the whole plant	Best grown crop for arid conditions because it grows during winter and benefits of rainfalls and is harvested in August when it is naturally matured
Caper/Wild spurge (*Euphorbia lagascae* SPRENG)	Native in Mediterra-nean (Spain, Italy). Spread in N.America & N.Europe Adapted to cool temperate zones	Grown in arid SE Spain, Sardinia. Trials in the Netherlands and Germany	Annual spring crop Sown in April-May Drought tolerant	Seeds: 0.4-1.6 t/ha (experimental) 46-52% oil content 60-75% vernolic fatty acid	Seeds for biofuels, adhesives, varnishes, paints, industrial coatings Leaves, latex for pharma, medicinal nutrition	Mechanical sowing with grain drills Mechanical harvesting with pea harvesters equipped with a special cutter-bar table to avoid blockage. Low nutrient inputs and plant protection Oil rich in vernolic acid	Optimum harvest date difficult to determine due to indeterminate flowering (Scalar maturity) Foliage rich in latex that blocks the threshing drums during harvest. Seed shattering Highly toxic due to poisonous latex Vesicant for operators skin	Breeding programmes should limit seed shattering, improve resistance against herbicides, increase yields and eliminate the toxic traits	Oil composition close to diesel oil thus suitable for biofuels. Niche crop Many potential market applications but little industrial use so far.

Castor seed (*Ricinus communis* L.)	Ethiopia Well diffused in India, Australia, USA, South America Naturalized in tropical and warm temperate regions throughout the world	Eu27: 0 Brasil: 149803 ha China: 210000 ha India: 910000 ha Russia: 400 ha World: 1537773 ha	Annual spring crop Sown in March-April	EU : 0t World: 9985 t Seeds: 0.5 -4 t/ha 40-55% oil content Oil yields: 0.6-2 t/ha Rich in ricinoleic fatty acid: 85-95%	Biodiesel, Technical oil, Pharmaceutical Cosmetics Food Additive Inks and Paints Electronics Polymers	Good Rotation crop Dryland crop Traditional Mechanical Harvest Low nutrient inputs and plant protection	It is a tropical season crop and cannot tolerate temperatures as low as 15°C Irrigation is necessary It contains ricin that is a toxic protein	Yield Improvement Limitation of ricin content	Oil for technical products polymers (Nylon11) Researchers are trying to genetically modify the castor plant to prevent the synthesis of ricin but this would not solve the issue with the allergenic compound.
Crambe (*Crambe abyssinica* Hochst.ex. R.E. Fries)	Medditerranean, Euro-Siberia and Turko-Iranian Tropical, subtropical Africa, Near East, C & W Asia USA and S. America, Canada	EU (Poland, Denmark, Germany, Lithouania , Sweden)	Annual spring crop Cool season but not frost tolerant	Seeds: 1.5-2 (up to 2.5) t/ha in EU, USSR. 35-60% oil content 35-65% erucuc fatty acid 550kg oil/ha	Lubricants, plastics (via erucamide), chemicals	Mechanical sowing with grain drills Can grow on a variety of climate and soil types Tolerant to lodging Drought tolerant Mechanical harvesting with grain combining machines but no swathing.	Monitoring of harvest onset Susceptible to seed shatter if harvesting delays Low genetic variability Very low investments in research - some industrial production in USA Low seed germination Competition with	Selection programs for improving seed and oil yields	Industry is looking for erucic acid Crambe appears to be a better potential domestic crop than rapeseed. Many potential uses for pharma, cosmetics, detergents, ceramids,

							high erucic rapeseed but lower oil yields		perfumes
Cuphea (*Cuphea spp* L.)	Central America and South America (adapted to North America and Europe)	0	Annual spring crop Sown in late April	Seeds: 0.5-1.5 t/ha (experimental USA) Oil content: 27 - 35% Oil yields: 240 - 300 kg/ha.	Lauric acid Chemicals Pharma Technical oil Inks and Paints	Commercial hybrid line PSR23 Mechanical Harvest Low nutrientinputs and plant protection	Seed shatter Undeterminate flowering making harvest diffcult and less economic Long term maturation and high moisture content (>50%) at harvest Sticky petals can clog mechanical harvester	Yield Improvement Elimination of seed shatter trait Domestication in Europe	Need to be re-introduced and exploited in Europe
Ethiopean mustard (*Brassica carinata* L)	Originated from Ethiopia, but also grown in East and South Africa. Well adapted in the Mediterran	Europe: 0 ha Some trials in Greece.	Annual spring crop Vegetable and oil crop Sown in autumn in Mediterranean areas,	Seeds: 1.4 - 3 t/ha of seeds 14-22% oil content 55-60% calendic fatty acid 300 kg/ha of oil	At present oil from Brassica carinata is regarded as low quality; High erucic acid Brassica carinata types may be suitable for biodiesel	Heat and drought tolerant but not very resistant to frost Similar to rapeseed growing methods Much more vigorous and branched than rapeseed;	Production likely to be limited to southern Mediterranean regions.	Seed breeding programmes must select cultivars to improve oil content, lower erucic acid and lower glucosinolate content.	Potential crop for biofuels, principally as a new crop for Southern EU countries but with potential also for use in Northern Europe.

	ean climate		whereas in cooler areas (N. Europe) it is best sown from spring onwards		and for the production of plastics additives	therefore required plant densities are lower			
Honesty (*Lunaria annua* L.)	Southern Europe and West Asia	0	Biennial crop Sown in May-June	Seeds: 1-3 t/ha (experimental) 36% oil content 38-48% in erucic fatty acid 20-25% in nervonic fatty acid	Nervonic acid: Pharma, Medical nutrition, Neurological disorders Chemicals Technical oil Richest source in LCT	Low nutrient inputs and plant protection Non-food crop Resistant to seed shattering Oil that contains nervonic acid and erucic acid Natural source of lunarine for pharmaceuticals	Seed Indehiscence Limited domestication Uncertain yields Does not trive in large open fields Poorly suitable to mechanical harvest Difficulty in seed cleaning	Yield Improvement Cultivation improvement Hybrid rapeseed containing genetic elements from the nervonic pathway Need for vernalisation	Oil for food and medical nutrition Nervonic acid exploitation
Jatropha (*Jatropha curcas* L.)	Peru, Mexico and Central America	Widely distributed in cultivated sytands in Central and South America, Africa,Indiaand South East Asia.		Seeds: 0.1- 5 t/ha More realistic seeds yields: 1-2,5 t/ha Max oil content: 30-35 %	Biodiesel and other traditional uses : soaps	wild nature of the plant seeds are toxic for humans and animals : non food uses	It likes high temperatures like in the tropics and subtropics		Rlesults from european research programs : JATROPT, ECODIESEL and EUROBIOREF) expected uncertain interest in EU

		Trials in Greece and Italy							
Linseed (*Linum usitatissimum* L.)	N. USA Adapted to cool temperate zones	15,000 ha		1.2-2 t/ha	Food Chemicals Pharma Research towards new green products	Traditional Many varieties, Mechanical cultivation Low N inputs and plant protection Good in crop rotations Breeding efforts in France towrds better yields and oil quality (>% in linolenic fatty acid)	Sensitive to seed bed conditions Timely harvest Oil content, fatty acid distribution affected by envir. Canadian GMO	Several studies are carried out on the biological process leading to the filling of seeds in order to improve the quality of seed flax (oil content, improved fatty acid profile)	The seed industry is working to develop new uses for flaxseed in animal feed and human food, improve plant properties and select new breeds capable of producing high quality oil with an optimal nutritional content
Rape-seed (+High erucic rape seed HEAR)	Asia, S EU, Med, Adapted to cool temperate zones	6,500 Mha (HEAR: 40,000 ha)		Seeds: 2.5 t/ha (EU mean)	Biodiesel Food	Traditional Many varieties (2-3 HEAR varieties available) Mechanical sowing with	Prone to shattering at harvest Small market for HEAR Narrow genetic variability - Only	Crop development studies involving the development of new types as well as visual markers for	Despite the fact that this crop is the most important oil crop for biodiesel production in

						grain drills	few HEAR varieties exist	each crop type would contribute to achieve higher yields at lower production costs	Europe better adapted varieties should be developed for the Mediterranean region
Safflower (*Carthamus tinctorius* L.)	Asia (Turkey-Afghanistan)	EU27 133 Spain 60 Hungary 73 India 270600 China 22600 USA 67870	Annual spring crop	EU27 5263 Spain 8333 Hungary 2740 India 6319 China 14690 USA 14793 (Yield Hg/Ha) Seed: 2600-4000 21-22% oil content 0.5 -1 t/ha oils	Food Dye Textile Dye Technical oil Inks and Paints	Traditional Many varieties Mechanical Harvest Modest water needs Oleic and linoleic varieties	Weed Poor seed yield	Improvement of diserbant and weed resistance	Oil for food and medical nutrition. Dye more important product

Sunflower	USA, Med Adapted in wide range of soil and climate conditions)	3,300 Mha		Seeds: 1.9t/ha	Food Biodiesel	Traditional Many varieties, Mechanical sowing with grain drills Drought resistant Modest water needs BUT N is crucial factor	Self-incompa-tible varieties BUT hybrids are developed Oleic/linoleic varies depending on site, date, year	Crop development studies involving the development of new types (i.e high oleic) would contribute to achieve higher yields at lower production costs	