Oil Crops in the Context of Global Biodiesel Production

Decio Luiz Gazzoni and Amélio Dall'Agnol

Abstract There are hundreds of plants with potential to produce oil for biodiesel industry but only a few are largely cultivated, being the same that have been used for other purposes, especially for nutrition. Along the last 10 years, palm, soybean, canola, and sunflower accounted for 80 % of the world vegetable oil production, or 90 % if peanut, cotton, coconut, and olive are also included. Similarly, almost all countries are potential producers of oil but USA, China, Brazil, India, Argentina, and Indonesia account for about 70 % of the 180 Mton produced worldwide, and for almost all of the vegetable oil traded in the international market. In order to consider an oil crop as a trusty supplier of raw material for the biodiesel industry, it must fulfill the following criteria: (a) must be produced on a large scale; (b) should belong to a well-organized supply chain; (c) be considered a commodity in the international market and its oil be competitive in price with not only other vegetable oils but also with petrol; (d) its by-products obtained besides the oil should also have a steady demand on the domestic and international market. The world biodiesel production strongly accelerated within 2000–2009, reducing the rates of expansion after 2009 because of the world financial crisis (2008–2010). Currently (2016), biodiesel global production is estimated to be slightly over 35 Mton, awaiting new stimuli to reaccelerate considering the well-known environmental and social benefits of biodiesel, which can overcome the disadvantage of the higher cost as compared to mineral diesel.

Keywords Vegetable oils · Oilseeds · Palm oil · Soybean · Sustainability · Public policies

D.L. Gazzoni (✉) · A. Dall'Agnol
Embrapa Soybeans, Brazilian Agricultural Research Corporation (Embrapa), Londrina, PR, Brazil
e-mail: decio.gazzoni@embrapa.br

C.R. Soccol et al. (eds.), *Green Fuels Technology*,
Green Energy and Technology, DOI 10.1007/978-3-319-30205-8_3

1 Introduction

Oilseeds are among the most important crops in international trade. Annually, world consumption of vegetable oils and animal fats exceeds 300 Mton (USDA 2015d). According to the FAO database (FAOSTAT 2015), world production of vegetable oils has grown dramatically in recent decades, increasing more than 600 % in roughly 40 years, jumping from 23.6 Mton in 1972/1973 crop season to 180 Mton in the 2014/2015 crop season. More than 70 % of the world production of vegetable oil is concentrated in just six countries: United States (USA), China, Brazil, India, Argentina, and Indonesia. Nutrition is by far the major market, but general industry application, fine chemistry, and energy are also demanding increasing amounts of vegetable oils in recent years.

There are hundreds of species with potential to provide oil for domestic use or as a raw material for oil chemistry or biodiesel industry. However, few of them have characteristics that justify their large-scale farming, chiefly: high-oil content, well-structured supply chain, and production technology at the cutting edge. Many oilseeds are only economically viable because their coproducts after oil extraction (ex., soybean meal and cotton fiber) are highly demanded in the market, sometimes even higher than the oil itself.

Currently, about 80 % of vegetable oil produced worldwide comes from only four oil crops: palm (pulp + almond), soybean, rapeseed (canola), and sunflower. Four other crops account for the next 11 % share: peanut, cotton, coconut, and olive. Then, dozens of other oil producing plants share less than 10 % of the world oil production. Among which it is worth mentioning some with different potential degrees for future expansion, depending on the availability of adequate production technology and a well-structured production chain: castor, flaxseed, sesame, safflower, forage turnip, crambe, tucuman, rubs, buriti, macaúba, indaiá, açaí, gerivá, patauá, cotieira, oiticica, nhandiroba, tung, pequi, jatropha, jojoba, tingui, among others.

As for biodiesel production, which demands annually over 20 Mton of vegetable oil and animal fat, four aspects are crucial for a given crop to be considered as a feedstock, according to Gazzoni et al. (2012): (a) large production; (b) well-organized value chain; (c) insertion as a commodity in the international market; and (d) competitive price, as compared to other oils, but specially against petrol, the fossil energy paradigm.

Figure 1 shows the evolution of market prices of the internationally traded vegetable oils, compared to international petrol prices. Usually, vegetable oils do not compete with petrol prices, but other advantages should be taken into account, like being more environmentally friendly, the creation of additional jobs evenly distributed, and more business opportunities, among others.

In some oilseeds, the protein fraction is more important to the market than the oil, as for soybeans. Others, such as cotton, are grown primarily for the production of fiber, being oil clearer a byproduct; peanuts, sesame, coconut, and açaí are

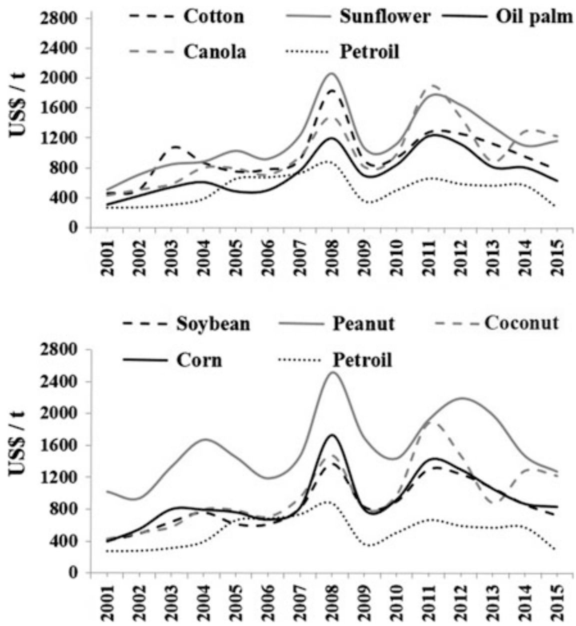


Fig. 1 Vegetable oil and crude oil prices in the international market, adjusted to Oct, 2015

cultivated to meet demands for direct human consumption, and only marginally for oil extraction.

The global biodiesel production is about 35 billion liters (GL), according to 2015 statistics (REN 21 2015). The major feedstocks for its production are palm, soybeans, and rapeseed (canola), with some participation of animal fat and sunflower. As a rule, each country uses its more abundant raw material to produce biodiesel, so that USA, Brazil, and Argentina largely relies on soybean oil; Indonesia and Malaysia use palm oil; and the European Union counts on rapeseed (canola). Animal fat also constitutes an important source of raw material for biodiesel production, being the main raw material in China (pork fat). In Brazil, about 20 % of the biodiesel is obtained from animal fat (mainly tallow), usually blended with biodiesel obtained from vegetable oil, to meet legal and technical specifications.

Biodiesel global production increased dramatically in the first decade of the present century, when oil prices hovered around US$100.00/barrel, with a peak of US$142.00/barrel in 2008,[1] surfing the wave of the pursuing of a more sustainable energy matrix. As an average for all locations and raw materials, biodiesel yields 93 % more energy than invested on its production (Hill 2006), not accounting for solar radiation energy captured by plants through photosynthesis.

During the first decade of the twenty-first century, the Land Use Change/Indirect Land Use Change theory(LUC/ILUC) was very popular, blaming biofuels as

[1] www.commoditycharts.com/commodities/Energies.

responsible for carbon debt and for competition with food production (Fargione et al. 2008; Searchinger et al. 2008), leading to higher food prices. A review by Gazzoni (2014a) concluded that the model described by the LUC/ILUC theory did not fit to actual agricultural production data, according to the most recent studies and FAO statistics.

A case study of the Brazilian biofuels production and use demonstrated that from 2007 to 2011 the use of biodiesel in Brazil accounted for avoided emissions up to 16 Mton of CO_2 (Gazzoni 2014b). Due to the uncertainty in the scientific literature regarding the ecological benefits of biofuels, Davis et al. (2009) proposed that providing new information on biogeochemistry and plant physiology, ecologists, and plant scientists could increase the accuracy of Life Cycle Analysis for biofuel production systems.

As for the moment, the vegetable oil for biodiesel production cost exceeds that of mineral diesel (see Fig. 1). Following the financial crisis of the end of last decade, and the recent reduction on petrol prices, biodiesel production has stabilized, waiting for new stimuli to resume former production increase rates, which includes public policies supporting its production and use. Nevertheless, besides environmental benefits, it should be considered that social gains partially help offsetting its higher costs, as biodiesel production generates much more jobs than the petrol chain. Each 1 % biodiesel added to mineral diesel results in the creation of approximately 45,000 jobs, according to estimates of the Ministry of Agrarian Development of Brazil (Abreu et al. 2012).

2 Feedstock for Biodiesel Production

Even though several plants can produce oil, stored on grains or fruits, only a few of them are actually commercially important, traded in the international market and constituting important feedstock for industrial purposes. Table 1 presents the global area cultivated with oil crops while Table 2 details the area cultivated with the most important oil crops worldwide, including ones that are not used for biodiesel production due to unsuitable oil characteristics.

The competitiveness of any crop, including the oil crops, largely relies on its yield. Table 3 shows the evolution of the average global yield of several oil crops, including the ones not suited for the biodiesel industry, whereas the Table 4 presents the grain production of those oil crops. It is important to consider the different

Table 1 Worldwide cultivated area and grain production of the major oil crops

	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2014
Area (Mha)	98	108	116	127	145	155	164	185	198	224	239	265
Production (Mton)	106	126	145	174	201	253	282	328	373	468	536	634

Source FAOSTAT database

Table 2 Global area cultivated with selected oil crops worldwide, in million hectares (Mha)

Crop	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2014
Castor	1.2	1.5	1.5	1.4	1.5	1.7	1.7	1.2	1.8	1.6	1.5	1.5
Coconuts	5.3	6.0	6.7	7.4	8.8	9.4	10.0	10.7	10.8	11.2	11.8	12.1
Cottonseed	31.9	33.7	34.1	32.5	34.3	33.4	33.1	35.5	31.8	35.0	31.8	36.9
Peanuts	16.6	19.8	19.5	20.0	18.4	18.5	19.8	22.0	23.2	24.0	25.5	25.9
Hempseed	0.3	0.4	0.3	0.3	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0
Rapeseed (Canola)	6.3	7.1	8.2	9.9	11.0	14.8	17.6	23.8	25.8	27.7	32.2	38.4
Safflower	0.8	0.8	1.0	1.3	1.3	1.4	1.2	1.2	0.8	0.8	0.8	0.8
Sesame seed	5.0	5.6	5.9	5.8	6.3	6.9	6.1	6.7	7.2	7.5	8.3	9.5
Soybeans	23.8	25.8	29.5	38.8	50.6	53.1	57.2	62.5	74.4	92.6	102.8	113.3
Sunflower	6.7	7.5	8.7	9.2	12.4	14.8	17.0	20.9	21.2	23.2	23.1	26.0
Tallowtree	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.4	0.4	0.4	0.4
Tung	0.1	0.1	0.1	0.1	0.1	0.3	0.2	0.2	0.2	0.2	0.2	0.2

Source FAOSTAT database

Table 3 Average global yield for selected oil crops, in kilograms per hectare (kg/ha)

Crop	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2014
Castor	470	547	563	571	504	707	818	876	777	943	1136	1235
Coconuts	4532	4247	3922	4149	3681	3825	4353	4649	4759	5126	5094	5103
Cottonseed	862	1063	1042	1113	1206	1523	1639	1599	1668	2005	2153	1979
Peanuts	849	801	922	956	920	1134	1169	1298	1494	1602	1677	1777
Hempseed	241	265	270	308	281	347	559	1187	1612	3973	3128	3114
Jojoba	0	0	0	0	0	337	340	1000	800	300	380	417
Rapeseed (Canola)	573	741	816	887	979	1304	1387	1435	1529	1806	1864	2000
Safflower	432	627	688	782	703	643	690	712	757	700	810	827
Sesame seed	286	279	340	297	277	336	388	381	385	466	529	506
Soybeans	1129	1228	1480	1657	1600	1906	1896	2031	2169	2318	2578	2684
Sunflower	1023	1059	1149	1068	1099	1270	1333	1255	1250	1323	1363	1800
Tallowtree						2590	2299	2309	2343	2342	2398	2457
Tung	7967	3898	10,536	10,797	8033	2059	2227	2943	3236	2696	2873	2745

Source FAOSTAT database

Table 4 Grain production for selected oil crops worldwide, in million ton

Crop	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2014
Castor	0.6	0.8	0.8	0.8	0.8	1.2	1.4	1.1	1.4	1.5	1.7	1.9
Coconuts	23.8	25.5	26.3	30.8	32.2	35.9	43.5	49.7	51.2	57.4	60.3	62.0
Cottonseed	27.5	35.8	35.6	36.2	41.4	50.9	54.2	56.7	53.1	70.1	68.6	73.0
Peanuts	14.1	15.8	18.0	19.1	16.9	20.9	23.1	28.6	34.7	38.5	42.7	45.2
Hempseed	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1
Jojoba	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rapeseed (Canola)	3.6	5.2	6.7	8.8	10.8	19.2	24.4	34.2	39.5	50.0	60.1	72.5
Safflower	0.3	0.5	0.7	1.0	0.9	0.9	0.8	0.8	0.6	0.6	0.6	0.6
Sunflower	6.8	8.0	10.0	9.9	13.7	18.9	22.7	26.3	26.6	30.8	31.5	4.6.6
Sesame	1.4	1.6	2.0	1.7	1.7	2.3	2.4	2.5	2.8	3.5	4.4	4.8
Soybeans	26.9	31.7	43.7	64.2	81.0	101.2	108.5	127.0	161.3	214.6	265.0	276.4
Tallowtree	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	1.0
Tung	0.5	0.3	0.6	0.7	0.5	0.5	0.5	0.5	0.5	0.4	0.5	0.5

Source FAOSTAT database

uses of the vegetable oil, which include the most important one—gastronomy and nutrition industry—but also other industrial (not food), lubricants, fine chemistry, cosmetics and hygiene, besides the energy industry.

Depending on the oil content of the seeds, the resulting oil volumes obtained from each hectare is variable according to the crop, but also depends on the total grain harvest of a given crop.

The world vegetable oil production since 1960 with a projection to 2020 is given in Fig. 2, while the percent share of each one of the major feedstocks of the world vegetable oil production, in 5-year time scale between 1960 and 2015, is shown in Fig. 3.

Table 5 illustrates the evolution of world oil production of different oil crops and Table 6 states the characteristics of the major vegetable oils.

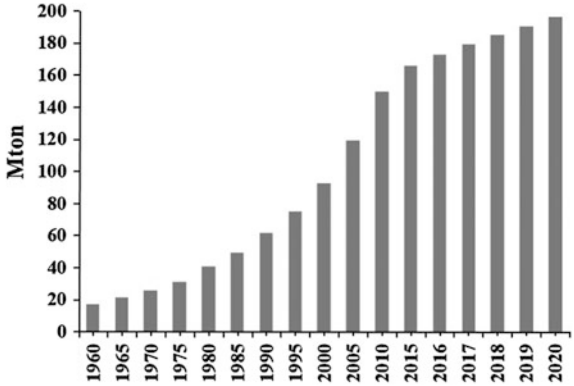


Fig. 2 World vegetable oil production

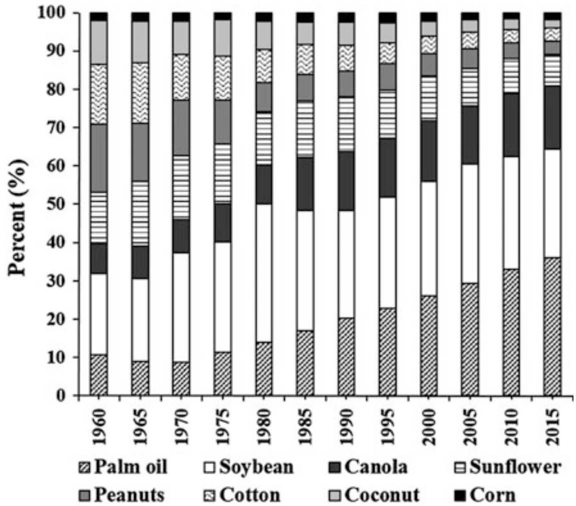


Fig. 3 Share of the major vegetable oils

Table 5 Vegetable oil production from selected oil crops, in million ton

Source	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2014
Corn	0.3	0.4	0.5	0.5	0.8	1.1	1.4	1.8	1.9	2.1	2.3	2.9
Soybean	3.0	3.8	6.3	7.8	13.2	14.1	15.9	20.1	25.6	34.2	40.7	42.7
Peanut	2.5	2.7	3.2	3.1	2.7	3.1	3.8	4.7	5.1	5.6	5.6	5.2
Coconut	1.6	1.9	1.9	2.6	2.7	2.6	3.4	3.7	3.4	3.4	3.9	3.2
Palm	1.5	1.6	1.9	3.1	5.1	7.6	11.4	15.9	22.2	32.3	45.8	54.4
Palm kernel	0.5	0.5	0.5	0.6	0.7	1.2	1.7	2.1	2.8	4.4	5.6	6.7
Olive	1.4	1.2	1.4	1.8	2.0	1.7	1.5	1.7	2.5	2.6	3.3	2.8
Sunflower	1.9	3.0	3.7	4.2	5.1	6.6	8.1	8.8	9.8	10.7	12.6	12.6
Safflower	0.1	0.1	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1
Rapeseed (Canola)	1.1	1.5	1.9	2.7	3.7	6.2	8.6	10.7	13.5	16.8	22.8	24.7
Sesame	0.4	0.5	0.6	0.5	0.5	0.7	0.7	0.7	0.7	0.9	1.1	1.1
Cotton	2.2	2.8	2.6	3.1	3.2	3.5	3.8	3.8	3.8	4.9	4.8	5.1
Linseed	0.9	1.0	1.0	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.5	0.6

Source FAOSTAT database

Table 6 Characteristics of the major vegetable oils

Feedstock	Saturated	Monounsaturated		Polyunsaturated			Smoke point (°C)
		Total	Oleic	Total	Linolenic (ω-3)	Linoleic (ω-6)	
Canola (rapeseed)	7	64		29	10	10	204
Coconut	91	6	6	3		2	177
Corn	15	30	28	55	1	58	232
Cottonseed	28	19	19	53	1	54	216
Flaxseed/linseed	8	13	11	79	64	15	107
Olive	14	72		14	2	15	193
Palm	49	42	40	9		10	235
Peanut	18	50	48	32		32	225
Safflower (>70 % linoleic	8	17		75			210
Safflower (high oleic)	8	77		15			210
Soybean	16	26	24	58	7	50	238
Sunflower (<60 % linoleic)	10	45	45	40		40	227
Sunflower (>70 % oleic)	9	84		4			227
Cottonseed hydrogenated	94	2	1				
Palm hydrogenated	48	41	8				
Soybean hydrogenated	21	74	1	1			

Sources USDA Rel 27 (http://www.ars.usda.gov/Services/docs.htm?docid=24912); Ivanov et al. (2010), Katragadda et al. (2010)

By far, gastronomic and nutritional uses (salad dress, industrial food, cooking, etc.) is the largest market for vegetable oil, followed by other industrial uses, including fine chemistry. In spite of being used as fuel since the beginning of the twentieth century, only during last decade the energy market expanded its share, specially based on public policies incentivizing its production and use.

It is noteworthy to observe that soybeans led the global vegetable oil production up to the beginning of the twenty-first century, when it was surpassed by palm oil production. The high oil yield by unit of area obtained from palm oil plantations is the major drive for the expansion of this crop, especially in Southeastern Asia.

Oils have different characteristics, according to the crop. Depending on the range of its use, oils can be considered as multipurpose or have a narrow market, with quite specific purpose (nutrition, oil chemistry, bioenergy, etc.).

The major oil crops, in the sense of being the most cultivated and traded in the international market, and representing over 90 % of the global biodiesel feedstock, are analyzed below.

*2.1 Soybean (*Glycine max *(L.) Merrill)*

2.1.1 Soybean History

Soybean has been cultivated in China since 5000 years BC, considered the most important legume in ancient Chinese culture (Merril 1931). By the first century BC to the Age of Discovery (fifteen and sixteenth centuries), soy was introduced in several Asian countries (Japan, Indonesia, Philippines, Vietnam, Thailand, Malaysia, Burma, Nepal, and northern India). These regions are considered today as the secondary center of soybean dispersion (Hymowitz 1983). Although considered a sacred grain and extensively used in the diet of the East for thousands of years, its introduction in the West happened only during the eighteenth century (Bretschneider 1882).

The first report on soybean crops in the United States dates from 1765, having first been tested for use as silage and green manure (Piper and Morse 1910). Until 1941, the area cultivated as a forage crop or green manure was greater than the one dedicated to grain production. At the peak of its use as forage, more than 2 million hectares were grown in the USA for that purpose. However, since the 1950s, the main use toggled from fodder to grains, and by the early 1960s the “soy fodder” had disappeared from the USA fields (USDA 2015e).

During the first three decades of the twentieth century, soybean production on a large scale, was still confined to the East (China, Indonesia, Japan, and Korea), in latitudes near or above 35°N. China continued to be the major global producer until the mid-50s, when it was surpassed by the USA. Since the 1960s, the area and soy production increased dramatically, not only in the USA but also in Brazil and Argentina (Myasaka and Medina 1981; Dall’Agnol et al. 2007).

China, once the largest world producer (up to mid-1950s), nowadays is the largest soybean importer, absorbing in excess of 60 % of the soybeans internationally traded in 2015. Brazil is the largest nonprocessed grain exporter and Argentina leads the sales of meal and oil, as well as biodiesel (Gazzoni 2013).

2.1.2 Soybean Expansion in Latin America

The exceptional high price of soybeans in the world market in the mid-70s—when soybeans reached the highest value of all time (US$1249/ton of grains in 1973, adjusted price to 2015[2]) was the main driver of the rapid expansion of its cultivation in the Mercosur (regional common market) region. Since 2010, countries of this economic block are leading the world soy production, with a market share of 53 %, and a total production of 168 Mton. These countries are Brazil (95.5 Mton), Argentina (60.5 Mton), Paraguay (8.5 Mton), and Uruguay (3.5 Mton) (FAOSTAT 2015).

Soybean production started showing socioeconomic importance in Brazil from the mid-50s, in Argentina and Paraguay from the 1970s and Uruguay only recently gained importance as a soybean producer. Even though, it is already the main item on the export basket of this country, as also happens in Brazil, Argentina, and Paraguay.

While the crop was confined to temperate and subtropical regions, Brazilian pioneer growers depended on soybean cultivation technology imported from the USA, especially, the varieties. However, when the cultivation of soybean shifted to Brazilian tropical regions, the imported varieties did not grow properly. It was necessary a comprehensive program for developing local technology, mainly varieties adapted to low latitude conditions, as well as other techniques like soil management and fertilization or pest management (Myasaka and Medina 1981; Câmara 2000; Dall'Agnol et al. 2007). Nowadays, soybean is grown with similar efficiency from the south to the extreme north of the South America, with consistently higher yields in the tropics than those obtained in the subtropics, even higher than the ones obtained in the traditional cropping area of the USA (Congresso Brasileiro de Soja 2006). Such facts brought economic development and social well-being to a previously poor and under habited regions, largely because land was undervalued, as there was no adequate technology for extensive cropping, according to Gazzoni (2013).

Soybean is a milestone in the agro-industrial development of Mercosur countries. Its influence is so deep that two phases of regional agriculture are clearly differentiated, before and after 1970. Until that date, the prevailing cropping system in the region was the subsistence agriculture, for own or local consumption. When growers started cropping soybeans, they were obliged to face modern agriculture

[2] http://archives.chicagotribune.com/1973/02/15/page/58/article/soybean-prices-surge-to-peaks.

strategies and to be connected to the international market, which led to a chain of unprecedented changes in regional agriculture.

Extensive soybean fields were largely responsible for accelerating mechanization of the farms; the transport system had to quickly modernize; the growing demand forced agriculture to open a new agricultural frontier; growers had to professionalize their farm management; private organizations had to enhance their international trade skills; an overall and accelerated process of development covered all soybean regions. Due to soybean influence, other crops, like corn, wheat, and cotton, also experienced a quick revolution on their cultivation and management, as well as created solid new big business on animal production, like the modern poultry and pork value chains (Dall'Agnol et al. 2007; Gazzoni 2013).

2.1.3 Soybean Grain and Oil Production

Soybean is one of the most important crops in the world, ranked among the four top producing and traded grains, which also include corn, wheat, and rice. While the other grains are important due to its carbohydrate content (especially starch), the demand of soybean is driven by the high quality of its protein meal, consisting a key raw material for meat production. In this sense, the soybean oil can be considered a byproduct of the soybean processing.

Oil content (18–20 %) in the seed is lower than protein (36–40 %), but given the large amount of soybean meal demanded to feed meat producing animals, the resulting oil volume is significant (EMBRAPA 1994). Soy scientists, especially breeders, refer the difficulties to increase the oil content on soybeans, as a result of inappropriate cross links with protein content as well as with the crop yield. Considering present average soybean yield and oil content, ca. 600 kg of oil can be obtained out of each hectare of cultivated with soybean.

Oil represents 18–20 % of the soybean seed weight. Triacylglycerols represent over 94 % of the lipid fraction, followed by phospholipids (3.7 %), unsaponifable matter (1.5 %), sterols (0.24 %), tocopherols (0.12) and free fatty acids (0.5 %), referred by Hammond (2005) as a typical soybean oil composition.

In order to extract the oil, the soybean is crashed, adjusted for moisture content, heated to between 60 and 88 °C, rolled into flakes, and solvent-extracted with hexanes. The oil is then refined, blended for different applications and, sometimes, hydrogenated. Soybean oils, both liquid and partially hydrogenated, are traded as vegetable oil or are constituents for a wide variety of processed foods.

The residue remaining from oil extraction (soybean meal) is used in the nutrition industry for animal feed. Soybean is one of the most important protein sources (36–40 %). According to Hammond et al. (2005), lysine (2.6 %), threonine (1.5 %), cysteine (0.7 %), and methionine (0.6 %) are the most common amino acids found on soybean meal.

As an average, soybean oil has 17 % of saturated fat, 24 % of monounsaturated fat, and 59 % of polyunsaturated fat (Poth 2001). According to Ivanov et al. (2010), the major unsaturated fatty acids in soybean oil triglycerides are the polyunsaturated alpha-linolenic acid (C-18:3), with 7–10 %, and linoleic acid (C-18:2), with 51 %. The monounsaturated oleic acid (C-18:1) represents 23 %. Soybean oil also contains saturated fatty acids like 10 % palmitic (C-16:0) and 4 % stearic (C-18:0). Hammond et al. (2005) mention lineolate (54.5 %), oleate (22.9 %), linolenate (23 %), palmitate (10.6 %), and stearate (4.1 %) as being the most common methyl esters found on typical soybean oils, while myristate, palmitoleate, arachidate, gondoate, behenate, and lignocerate are also present, but at lower concentrations. According to the same authors, the average values for saponification and iodine are 190.4 and 132.7, respectively. Other components of soybean seeds are carbohydrates and ashes, with 29.4 and 4.6 %, respectively, expressed on dry weight basis.

Gazzoni et al. (2005), using Life Cycle Analysis methodology, determined that the relationship between input and output energy, considering the whole soybean grain (oil for biodiesel plus meal for other uses) was 1:3.38. Considering only the oil fraction for biodiesel production the relation was 1:1.12.

Global soybean area and production for the last 53 years are shown on Fig. 4. In 2014, about 45 Mton of soybean oil was produced worldwide, being second only to palm oil. In fact, soybean oil led the vegetable oil production until last decade, and might be the leader again, in the near future. In 1960, the world production was roughly 25.5 Mton, 92 % concentrated in the USA (59 %) and China (33 %).

Currently, the USA remains at the forefront of soy production, with 108 Mton (34.3 %), but Latin America, led by Brazil (98.6 Mton) and Argentina (60.5 Mton) overcome with great advantage (49.3 vs. 34.3 %) the USA production, turning the region the main center of global soybean production. These three countries account for about 84 % of the global harvest of 2014/15 season, meaning 264 Mton out of the world total of 315 Mton. Detailed statistics regarding soybean area, yield, and production for the major producing countries, are shown in Table 7.

Fig. 4 Global soybean area and production

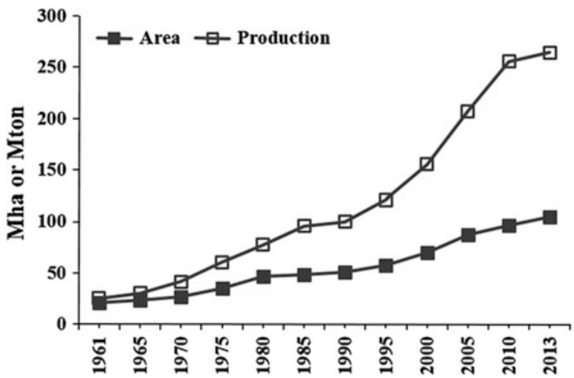


Table 7 Soybean area, yield and production for the most important countries

Year	Argentina			Bolivia			Brazil			Canada			India		
	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)
1961							0.24	1127	0.27	0.09	2103	0.18	0.01	455	0.01
1965	0.02	1035	0.02				0.43	1212	0.52	0.11	2038	0.22	0.02	435	0.01
1970	0.03	1032	0.03				1.32	1144	1.51	0.14	2085	0.28	0.03	438	0.01
1975	0.36	1363	0.49	0.01	1262	0.01	5.82	1699	9.89	0.16	2324	0.37	0.09	979	0.09
1980	2.03	1724	3.50	0.04	1267	0.05	8.77	1727	15.16	0.28	2489	0.69	0.61	727	0.44
1985	3.27	1988	6.50	0.06	1376	0.08	10.15	1800	18.28	0.41	2499	1.01	1.34	764	1.02
1990	4.96	2157	10.70	0.14	1623	0.23	11.49	1732	19.90	0.48	2610	1.26	2.56	1015	2.6
1995	5.93	2045	12.13	0.43	2031	0.87	11.68	2200	25.68	0.82	2783	2.29	5.04	1012	5.1
2000	8.64	2331	20.14	0.62	1941	1.20	13.64	2400	32.73	1.06	2548	2.70	6.42	822	5.28
2005	14.03	2729	38.29	0.94	1799	1.69	22.95	2230	51.18	1.17	2708	3.16	7.71	1073	8.27
2010	18.13	2905	52.68	1.09	1558	1.69	23.33	2948	68.76	1.48	2942	4.35	9.55	1333	12.74
2013	19.42	2539	49.31	1.24	1896	2.35	27.91	2929	81.72	1.82	2857	5.20	12.2	979	11.95

Year	China			Paraguay			USA			Uruguay		
	Area (Mha)	Yield (Kg/ha)	Production (Mton)	Area (Mha)	Yield (Kg/ha)	Production (Mton)	Area (Mha)	Yield (Kg/ha)	Production (Mton)	Area (Mha)	Yield (Kg/ha)	Production (Mton)
1961	10.01	626	6.26	0.01	1.615	0.01	10.93	1.690	18.47			
1965	8.64	719	6.21	0.01	1.925	0.02	13.94	1.651	23.01			
1970	8.02	1.094	8.78	0.03	1.459	0.04	17.1	1.794	30.68			
1975	7.03	1.038	7.30	0.15	1.465	0.22	21.7	1.942	42.14	0.01	1.719	0.02
1980	7.23	1.101	7.97	0.48	1.130	0.54	27.44	1.783	48.92	0.04	1.216	0.05
1985	7.73	1.361	10.51	0.72	1.631	1.17	24.92	2.292	57.13	0.01	1.449	0.02

(continued)

Table 7 (continued)

Year	China			Paraguay			USA			Uruguay		
	Area (Mha)	Yield (Kg/ha)	Production (Mton)	Area (Mha)	Yield (Kg/ha)	Production (Mton)	Area (Mha)	Yield (Kg/ha)	Production (Mton)	Area (Mha)	Yield (Kg/ha)	Production (Mton)
1990	7.56	1.455	11.01	0.9	1.994	1.79	22.87	2.292	52.42	0.03	1.298	0.04
1995	8.13	1.662	13.51	0.74	3.008	2.21	24.91	2.376	59.17	0.01	1.824	0.02
2000	9.31	1.656	15.41	1.18	2.533	2.98	29.3	2.561	75.05	0.01	764	0.01
2005	9.59	1.704	16.35	1.97	2.024	3.99	28.83	2.896	83.5	0.28	1.838	0.51
2010	8.52	1.771	15.08	2.67	2.793	7.46	31.01	2.922	90.61	0.86	2.317	2
2013	6.79	1.760	11.95	3.08	2.950	9.09	30.7	2.915	89.48	1.21	2.667	3.2

Source FAOSTAT database

2.1.4 Soybean in the Near Future

Demand for soybean remains strong chiefly because of the continuous growing need for protein meal, both for human consumption and animal feed. Nowadays, in addition to the food market for both commercial animal production, humans, and pet's nutrition, new markets like bioenergy and oil chemistry, extend the horizons of soybean demand, leveraging breakneck annual growing rates since 1990, when global production (108 Mton) was just one third of the current (315 Mton) production. The mean annual growth during the last 20 years surpassed 8 Mton (FAOSTAT 2015).

A close look into the future make it clear that a growing world population, as well as the increasing in longevity and income per capita of this population, with consequent changes in food habits and consumption patterns, will keep the demand growing at a steady pace, similar to the process of the last 50 years (Dall'Agnol et al. 2007). This forecasted continuous growing for soybean meal demand result in increasing soybean oil production, helping to assure the supply of vegetable oil for the biodiesel industry.

Prospective scenarios for soybean in the medium term (Fig. 5) show that Brazil and Argentina will capture most of the incremental market for the next two decades, given the depletion of the North American, Chinese, and Indian agricultural frontier. Among current competitors, Brazil is the one with the best comparative advantages, like abundant land, favorable climate to produce throughout the year, technology in state of the art, modern businesspersons, and entrepreneurs, but needs satisfactorily solve the issues encompassed in the so-called "Brazil cost" to ensure market leadership. Among the Brazil cost restrictions, ones linked to storage, transportation, and ports are the most challenging ones.

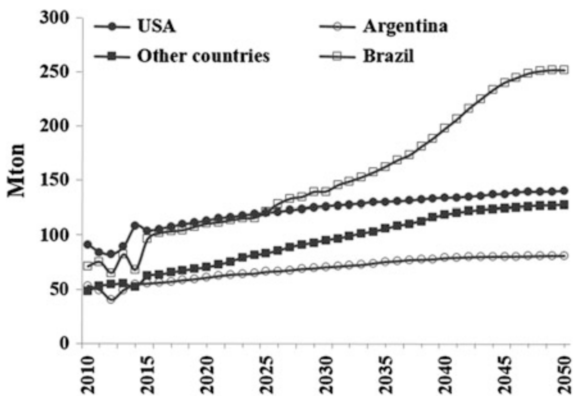


Fig. 5 Forecast of the major soybean producing countries

2.2 *Oil Palm (***Elaeis guineensis***)*

2.2.1 Origin and Highlights

Originally from the Gulf of Guinea, west central Africa, it is also known as African palm and dendê (only in Brazil). Although known and exploited for millennia in Africa, its commercial cultivation is relatively new, starting on the first decade of the twentieth century, in Malaysia. Palm is recognized as the oil crop that produces the largest amount of oil per hectare, which supports its leadership on the world vegetable oil production (Corley and Tinker 2003).

Palm oil is responsible for 57 Mt of the global production of 180 Mt of vegetable oils. Along with soybean oil, it accounts for over 50 % of the world vegetable oil production but, considering the 2015 average oil yield of each crop, one hectare of palm oil yields approximately the same amount of oil as 10 ha of soybean.

The high oil yield allows palm oil to occupy only 8 % of the world area cultivated with oil crops, while providing almost a third of vegetable oil produced globally (FAOSTAT 2015).

According to Cornet (2001), due to its tropical origin, palm oil is quite suitable for cultivation in the humid tropics of the original region, as well as southeastern Asia, northwestern South America and part of Central America. Presently, Asian countries account for nearly 90 % of its cultivated area, being Indonesia, Malaysia, and Thailand the major producers, according to the FAO database (FAOSTAT 2015). As well as the major producers, the largest importers are also located in Asia (China and India).

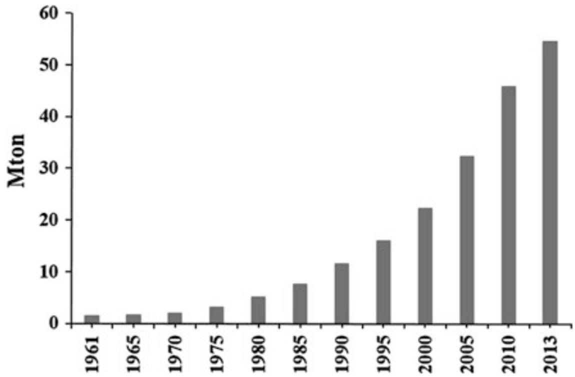
Indonesia, given its monumental production, is using part of its oil to produce biodiesel, with mandates for adding 5 % palm oil biodiesel in petrodiesel in 2006, 10 % in 2010, and 25 % in 2025 (REN 21 2015). The energy balance (input/output) of biodiesel from palm oil is very favorable, sometimes reaching up to 1:8, according to Gazzoni et al. (2008). The palm oil is used for bioenergy production, but the largest use is found in the nutrition segment (industrial frying, chocolates, pasta, margarine, vegetable creams, cookies, ice cream), and in cosmetics industry (beauty products, shampoos, detergents, and soaps).

2.2.2 Palm Oil Production

Figure 6 illustrates the evolution of the palm oil production worldwide, and the major palm oil producing countries are shown in Table 8.

Besides the leading Southern Asia countries (Indonesia, 26.9 Mton; Malaysia, 19.2 Mton; and Thailand, 1.97 Mton), Nigeria (0.96 Mton), and Colombia (0.95 Mton), plus over 40 other countries produce palm oil (Fig. 6). Up to the 1970s, Malaysia was the major producer of palm oil, with more than half of world production. In the last 40 years, Indonesia's production has skyrocketed from 0.7 Mton, in 1980, to 31 Mton, in 2014.

Fig. 6 Global palm oil fruit production



A significant proportion of the area presently used for palm oil cultivation in Southeastern Asia countries was formerly occupied by native forest, causing intense deforestation. Environmentalists advert that if deforestation proceeds at this pace, there will be no rainforests in countries like Indonesia within a decade, which would jeopardize the survival of Sumatra tiger, Asian rhino and orangutan. According to the environmentalist NGO Greenpeace, every year Indonesia loses 620,000 ha of rainforest, making it one of the largest emitters of greenhouse gases on the planet. This fact, associated with the loss of biodiversity could undermine the future of millions of Indonesians who depend on the forests for their food, shelter and livelihoods (Greenpeace 2015).

In contrast, Brazil has the world largest reserve of suitable land for palm cultivation, estimated to be around 50 Mha (Müller 1980), but cultivates only 0.16 Mha (FAOSTAT 2015). Largely, this is due to the restrictions imposed by the Brazilian environmental legislation for Amazonian lands, which restricts to 20 % the amount of area of a given farm that can undergo any kind of economic exploitation, imposing that more than 80 % of the biome should be preserved (Müller and Furlan Junior 2001). As a consequence, in spite of having the largest potential area for oil palm cultivation, Brazil is 9th among palm oil producers (0.37 Mt) and such a small production does not meet the country's needs, resulting in continuous import of palm oil, reason why the amount dedicated to biodiesel production is very small.

As for the future palm oil production, it should be taken into account that vast areas of the Brazilian tropical rainforests were cleared in the 1960s and 1970s, for the establishment of national integration highways. These areas are currently occupied by degraded pastures with low nutrition levels, and might be reinserted on profitable and sustainable business through the palm cultivation (Müller and Furlan Junior 2001). This land use change could provide new opportunities for employment and income to thousands of poor small farmers established on the banks of these highways, given adequate market and government incentives are put in place.

Table 8 Palm oil fruit production of the major countries, in Mton

Country	1961	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2013
Indonesia	0.15	0.16	0.22	0.40	0.72	1.24	2.41	4.48	7.00	11.86	21.96	26.90
Malaysia	0.09	0.15	0.43	1.26	2.57	4.13	6.09	7.81	10.84	14.96	16.99	19.22
Thailand	0.00	0.00	0.00	0.00	0.02	0.09	0.23	0.37	0.58	0.78	1.29	1.97
Nigeria	0.67	0.69	0.49	0.50	0.65	0.62	0.73	0.86	0.90	1.17	0.97	0.96
Colombia	0.00	0.00	0.03	0.04	0.07	0.13	0.25	0.39	0.52	0.67	0.75	0.95

Source FAOSTAT database

Table 9 Oil of palm and oil of kernel produced by the major countries, in Mton

Year	Colombia		Indonesia		Malaysia		Nigeria		Thailand	
	Palm	Kernel	Palm	Kernel	Palm	Kernel	Palm	Kernel	Palm	Kernel
1961			0.15		0.09		0.67			
1965			0.16		0.15	0.01	0.69	0.02		
1970	0.03		0.22		0.43	0.03	0.49	0.05		
1975	0.04		0.40	0.02	1.26	0.11	0.50	0.06		
1980	0.07	0.01	0.72	0.04	2.57	0.22	0.65	0.08	0.02	0.00
1985	0.13	0.01	1.24	0.12	4.13	0.51	0.62	0.15	0.09	0.01
1990	0.25	0.02	2.41	0.31	6.09	0.83	0.73	0.16	0.23	0.02
1995	0.39	0.03	4.48	0.43	7.81	1.04	0.86	0.24	0.37	0.04
2000	0.52	0.05	7.00	0.72	10.84	1.39	0.90	0.20	0.58	0.05
2005	0.67	0.07	11.86	1.46	14.96	1.84	1.17	0.57	0.78	0.07
2010	0.75	0.07	21.96	2.36	16.99	2.01	0.97	0.51	1.29	0.13
2013	0.95	0.08	26.90	3.06	19.22	2.27	0.96	0.51	1.97	0.18

Source FAOSTAT database

Palm oil is a huge oil producing plant and Table 9 shows the evolution of the palm oil and kernel oil from major producing countries. However, unlike most of the major oil crops, its residues after oil extraction have only marginal or no commercial value. The main uses for palm oil residues are organic fertilizer or electricity generation by burning the waste. Two types of oils are obtained from the palm oil fruits: the palm oil itself, extracted from the pulp; and palm kernel oil, extracted from the fruit kernel. The oil fraction constitutes about 22 % of the weight of the palm bunch, and only 3 % is palm kernel oil. Lauric acid is almost absent in palm oil, being the predominant component of palm kernel oil (Ramos et al. 2009).

Palm oil is composed almost by 50:50 saturated:unsaturated fatty acids. Major saturated are palmitic (44 %), followed by stearic (4 %), while oleic (monounsaturated, 37 %), and linoleic (polyunsaturated, 9 %) are the major unsaturated fatty acids found on palm oil (Ramos et al. 2009).

2.2.3 Special Requirements

Müller and Furlan Junior (2001) point out that the establishment of a palm plantation is expensive, being an investment of long maturity and late paying back, taking 4–6 years for the first harvest. During this period, the crop does not generate income, unless it is consortiated with other food or fiber crops, in between palm lines, like cassava, pineapple, papaya, banana, or even pastures. This is important not only to ensure food for self-consumption, but also to allow an extra income from the sale of the remaining production.

For this reason, small growers need official or private support to withstand the heavy crop establishment costs and to survive during the initial period of the project (Müller and Furlan Junior 2001). Moreover, it is paramount the existence of a processing industry in the surroundings of the crop plantation, because the fruit demands rapid processing after harvest, and the low value of the fruit does not allow transport over long distances (Müller 1980).

*2.3 Canola (Rapeseed) (*Brassica napus *L.)*

2.3.1 History and Highlights

Rapeseed belongs to the Brassicaceae family (formerly Cruciferae), the same family as mustard, broccoli, or cauliflower. *Brassica napus* is the result of an interspecific cross between *Brassica campestris* and *Brassica oleracea*. The canola name results from a contraction of "**CAN**adian **O**il **L**ow **A**cid," a variety of rapeseed modified in the early 1970s by traditional breeding, through which Canadian scientists from the

University of Manitoba selected varieties, which oil has low erucic acid (toxic for humans and animals). Its bran has very low glucosinolates content (antinutritional components), making both excellent alternatives for humans (oil) and animals (cake) consumption (Downey and Harvey 1963). The rapeseed, in turn, differs from canola because high levels of erucic acid and glucosinolates are present in the grains (Cultura da colza 1980).

Brassica oilseed varieties are among the oldest plants cultivated by humanity, with documentation of its use in India 4000 years ago, and in China and Japan 2000 years ago, but *B. napus* use is more recent, and first records are restricted to the Mediterranean region (Prakash and Hinata 1980). Its use in northern Europe for oil lamps dates to the thirteenth century (Snowdon 2007), but a larger use was limited until the development of steam power, when machinists found rapeseed oil clung to water- and steam-washed metal surfaces better than other lubricants. Because of its lubricant properties, there was a high demand for rapeseed oil during World War I to supply the increasing number of steam engines in naval and merchant ships. The war demand used all the European and Asian rapeseed oil available, creating a critical shortage, giving the opportunity for Canada to expand its rapeseed production. After the war, the lubricant demand declined sharply, and other uses for the oil were developed (USDA 2015a).

Presently, canola is the leading group of varieties grown worldwide as rapeseed. The oil is the main product of canola, although its meal is also highly valued for the formulation of animal feed, because of the high-protein content. According to De Mori et al. (2014), the oil content of canola seeds is high (38–45 %) and the volume of oil produced worldwide is surpassed only by palm and soybean oil, and the meal is second only to soybeans.

Low amounts of unsaturated fatty acids are found in canola oil, being palmitic (16:0) the one with higher content, normally 4 %. The major fatty acid found in canola is the mono unsaturated oleic (18:1) with 63 %, followed by polyunsaturated linoleic (18:2) with 20 %, and linolenic (18:3) with 9 % (Ramos et al. 2009). Due to its favorable fatty acid profile, doctors and nutritionists indicate canola and sunflower oils as the best composition of fatty acids for people interested in healthy diets.

In canola oil are found high amount of omega-3, vitamin E, monounsaturated fats, and the lowest saturated fat content of all vegetable oils. Perhaps this is the reason why the demand exceeds supply and the market value exceeds the price of soybean oil. High prices of canola oil make biodiesel from this source rather costly for the market and for supporting public policies. As for the total energy balance of biodiesel from canola oil, considering the utilization of its meal, it was concluded that for each energy unit input along the life cycle (from feedstock production to biodiesel consumption), 2.9 energy units are obtained; when considering only oil production (not computing energy on the meal), this relationship decreases to 1:1.4 (Gazzoni et al. 2009).

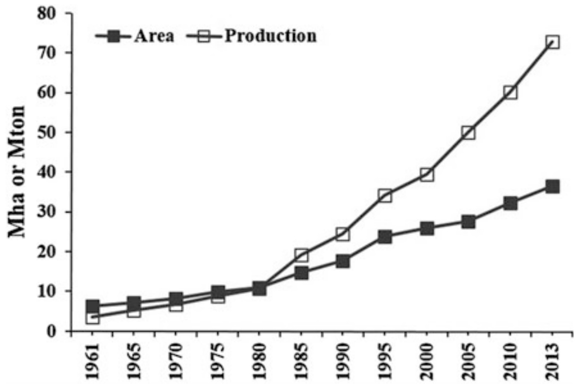


Fig. 7 World area and production of canola

2.3.2 Canola Production

World area production of canola is shown on Fig. 7, and Table 10 details the canola production parameters for the leading producing regions or countries

In 2014/15, world production of canola was 72 Mton of grains, allowing the extraction of 26 Mton of oil, representing 16 % of global vegetable oil production (FAOSTAT 2015). The leading production region is the European Union (24.0 Mton), followed by China (14.7 Mton), Canada (14.45 Mton), India (7.5 Mton), and Japan (2.0 Mton).

Canola is more adapted to mild temperature regions, distant from the Equator. In these locations, the cropping window is very narrow, not favoring crops such as soybean or corn. In regions of more severe climates, canola is seeded previously to the formation of snow and remains dormant until the spring when germinates after soils thawing, completing the cycle with approximately 85 days (USDA 2015a). This system is more profitable (20–30 % higher yields) than the canola seeded in the spring, after the melting of the snow.

Canola grain are rich in oil content (around 40 %; USDA 2015a), leading to large amounts of oil produced worldwide, as demonstrated on Fig. 8, being the aggregated data detailed by each producing region or countries on Table 11.

In regions where canola is cultivated during the spring either corn, soybeans, or cotton may result more profitable. Canola would be an excellent crop rotation alternative for soybeans and corn, but as it is very susceptible to the attack of a disease known as *sclerotinia*, the rotation is not recommended because the pest inoculum is build up during canola cycle and negatively affect soybean yield (De Mori et al. 2014). Furthermore, producing canola requires appropriated machines, especially harvesters and seed machines, due to the very small size of its grains, in order to provide adequate sowing and avoid harvesting losses.

Table 10 Canola area, yield and production for the most important countries

Year	Europe			Canada			China			India			Japan		
	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)
1961	0.61	1546	0.95	0.29	885	0.25	1.47	263	0.39	2.88	467	1.35	0.19	159	0.27
1965	0.84	1898	1.59	0.58	883	0.51	1.84	604	1.11	2.91	507	1.47	0.09	1403	0.13
1970	1.05	1869	1.97	1.64	999	1.64	1.45	666	0.97	3.17	493	1.56	0.02	1470	0.03
1975	1.29	2057	2.65	1.83	1006	1.84	2.31	665	1.54	3.68	612	2.25	0.01	1568	0.01
1980	1.66	2265	3.77	2.08	1194	2.48	2.84	839	2.39	3.47	412	1.43	0.01	1649	0.01
1985	2.57	2462	6.32	2.78	1257	3.50	4.49	1248	5.61	3.99	771	3.07	0.01	1711	0.01
1990	3.62	2553	9.23	2.53	1291	3.27	5.50	1264	6.96	4.97	831	4.13	0.01	1739	0.01
1995	4.27	2534	10.81	5.27	1221	6.44	6.91	1416	9.78	6.06	950	5.76	0.01	1795	0.01
2000	4.62	2542	11.74	4.86	1483	7.21	7.49	1519	11.38	6.03	960	5.79	0.01	2123	0.01
2005	5.46	3023	16.51	5.18	1832	9.48	7.28	1793	13.05	7.32	1038	7.59	0.01	2038	0.01
2010	8.94	2598	23.24	6.85	1865	12.77	7.37	1775	13.08	5.58	1184	6.61	0.01	1276	0.01
2013	9.31	2749	25.58	8.01	2240	17.94	7.52	1923	14.46	6.34	1233	7.82	0.01	1208	0.01

Source FAOSTAT database

Fig. 8 World production of canola oil from 1961 to 2013

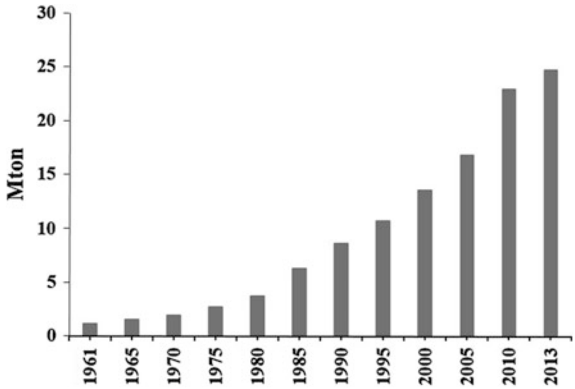


Table 11 Oil of canola produced by the major countries or regions, in Mton

Year	Europe	Canada	India	Japan	China
1961	0.34	0.01	0.40	0.12	0.11
1965	0.53	0.02	0.44	0.10	0.30
1970	0.68	0.07	0.48	0.14	0.29
1975	0.91	0.14	0.69	0.29	0.42
1980	1.38	0.42	0.42	0.41	0.80
1985	2.37	0.50	0.94	0.59	1.58
1990	3.37	0.58	1.37	0.75	2.14
1995	3.61	1.15	1.76	0.79	2.73
2000	4.51	1.30	1.79	0.91	3.64
2005	5.79	1.29	2.35	0.93	4.65
2010	9.37	2.50	2.05	0.99	5.39
2013	9.91	2.83	2.31	1.04	5.60

Source FAOSTAT database

*2.4 Sunflower (*Helianthus annuus *L.)*

2.4.1 History and Highlights

The center of origin of sunflower is the region comprising southwest USA and northern Mexico, from where it disseminated to the rest of the continent. Its most likely domestication occurred in that region, based on evidences of its cultivation by North American Indians over 3000 years ago (Lentz et al. 2001).

Upon the discovery of America, the Spaniards introduced sunflower in Spain as an ornamental plant, from where it spread to the rest of Europe. In the eighteenth century, the sunflower reached Eastern Europe, presently the main world producing region, led by Ukraine (10.0 Mton) and Russia (9.0 Mton), followed by the European Union (8.8 Mton), Argentina (2.5 Mton), and Turkey (1.2 Mton) (FAOSTAT 2015).

Russia was largely responsible for the spread of sunflower as a worldwide economically important crop. By 1880, after being improved by Russian agronomists, the sunflower was reintroduced into the USA, where it was initially used as fodder. The importance of sunflower as an edible oil source only emerged by the 1920s. However, it was after World War II that sunflower aroused to the front line of the international oil crop production worldwide (USDA 2015b).

2.4.2 Production and Use

The global sunflower cultivated area in 2014 was, approximately, 18 Mha, with an overall production of 40 Mton of grain, being 16 Mton of oil, and 17 Mton of meal (FAOSTAT 2015), ranking fourth among the most important oils and meal production, globally. Sunflower accounts for about 7.5 % of world production of vegetable oil, behind palm (34 %), soybeans (30 %), and canola (16 %).[3] The oil content of the grains is about 45 %, consumed almost completely as edible oil for its excellent quality, while grain protein content range from 28 to 32 % (de Leite et al. 2005; USDA 2015b).

Figure 9 displays the evolution of sunflower area and production worldwide, while Table 12 details the history of sunflower area, yield, and production, for the major producing countries. In this Table, data for Russia and Ukraine are absent until 1995, as they were aggregated under the common name of Soviet Union on the FAO database.

According to Ungaro (2000), sunflower requires soil with good content of potassium and phosphorus, being more tolerant to drought than other major grains, because of its deeper root system. It is insensitive to photoperiod and can be cultivated from the vicinity of the equator to latitudes above 40°. Temperatures around 27 °C are considered optimum for proper plant growth, but it develops quite satisfactorily from 8 to 34 °C, reason why can be grown as a second summer crop (off-season). The crop is also an agronomic important option for rotation with soybeans, corn, and wheat.

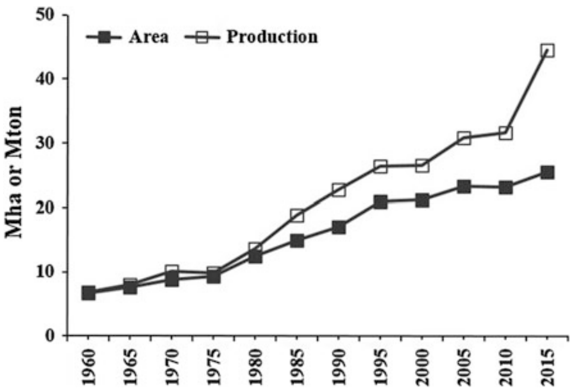


Fig. 9 Global sunflower area and production

[3] www.statista.com.

Table 12 Sunflower area, yield and production for the most important countries

Year	Argentina			Russia			Turkey			Ukraine			USSR		
	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)
1961	0.90	651	0.59				0.12	822	0.10				4.22	1127	4.75
1965	1.02	746	0.76				0.16	1002	0.16				4.87	1119	5.45
1970	1.35	846	1.14				0.36	1042	0.38				4.78	1286	6.14
1975	1.01	728	0.73				0.42	1168	0.49				4.05	1234	4.99
1980	1.86	890	1.65				0.58	1304	0.75				4.34	1065	4.62
1985	2.36	1441	3.40				0.64	1245	0.80				4.05	1298	5.26
1990	2.69	1451	3.90				0.71	1204	0.86				4.65	1376	6.40
1995	2.95	1963	5.80	4.13	1018	4.20	0.59	1539	0.90	2.01	1425	2.86			
2000	3.48	1746	6.07	4.37	896	3.91	0.54	1476	0.80	2.84	1217	3.46			
2005	1.92	1905	3.66	5.41	1190	6.44	0.57	1723	0.98	3.69	1276	4.71			
2010	1.50	1493	2.23	5.58	959	5.34	0.64	2058	1.32	4.53	1496	6.77			
2013	1.62	1916	3.10	6.80	1550	10.53	0.61	2498	1.52	5.09	2170	11.05			

Source FAOSTAT database

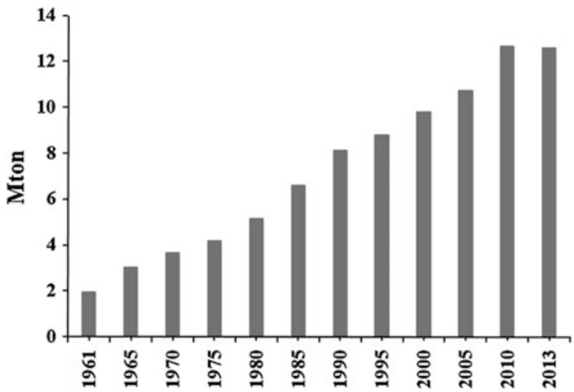


Fig. 10 World sunflower oil production

From sunflower grains, it is extracted high-quality oil and the remaining meal is excellent for animal nutrition. The oil is rich in unsaturated fatty acids, like the monounsaturated oleic (18:1), with 16 % and the polyunsaturated linoleic, with 72 %; major saturated fatty acids are palmitic (16:0), with 6 % and stearic (18:0), with 4 % (Ramos et al. 2009).

The sunflower meal contains about 50 % protein and is rich in sulfur amino acids, allowing a perfect integration with soybean meal, which is rich in lysine and low in sulfur amino acids. A mixture of both would provide ideal balanced food for animal nutrition (de Leite et al. 2005). According to these authors, besides oil and meal production, sunflower is an important feeding source for domestic and native bees (honey production), as well as an ornamental plant and for silage (animal fodder). Sunflower seeds are great for feeding birds and for edible oil production, and used as a lubricant. The nutritional quality of sunflower oil is similar to the canola oil, being highly suitable for biodiesel production. Figure 10 displays the historical series of the world sunflower oil production.

Regarding energy efficiency of biodiesel production from sunflower oil, Gazzoni et al. (2005), using Life Cycle Analysis techniques, determined that when the whole grain destination was considered (meal for nutrition, oil for biodiesel), 2.69 energy units were obtained from each energy unit input to the system. This relation was reduced when meal was not considered, and then each unit of input energy generated 1.61 units released by biodiesel combustion.

2.5 *Cotton (*Gossypium hirsutum *L.)*

2.5.1 History and Uses

Iqbal et al. (2001) refers cotton as one of the oldest plants domesticated by man, known for more than 8000 years, with records of its use to about 4000 years ago. The most likely center of origin of cotton is India, although some kind of cotton is found on all continents (Iqbal 1997), including 40 native species found in subtropical and tropical regions, some of which are used for commercial production of textile fibers. The most common species used for fiber production are *Gossypium hirsutum* (USA and Australia), *Gossypium arboreum* and *Gossypium herbaceum* (Asia), and *Gossypium barbadense* (Egypt) (USDA 2015c).

Cotton is a tropical crop, but has broad adaptation and can be grown on latitudes ranging from 0° to 40° (Cia et al. 1999), growing well in various soil types, but the plant root needs a well-oxygenated environment, for what the cropped area cannot be compacted. It is considered quite tolerant to median water deficit, requiring good soil moisture during the growing season and relatively dry weather during ripening and harvesting (Beltrão 1999).

The cottonseed contains medium levels of oil (15–18 %), used both for industrial purposes (hygiene/cosmetic industry and bioenergy) and for domestic consumption (fried foods and margarine) (USDA 2015c). Cotton oil contains both saturated fatty acids like palmitic (20 %) and stearic (2 %), and unsaturated ones as oleic (35 %) and linoleic (42 %) (Ramos et al. 2009). The meal resulting after cottonseed processing contains from 20 to 25 % protein and is directed to animal feed, preferably mixed with other proteinaceous cakes, because of the presence of gossypol, a toxic substance found in cottonseed meal (Cia et al. 1999).

2.5.2 Cotton Production

Cotton is a crop favored by a well-structured production chain, with extensive technological expertise and comprehensive coverage of research institutions and networks, readily available to solve any technological problem (Cia et al. 1999). Cotton varieties differ in the size of fiber (short, medium, and long), plant height (tall and short), and the cycle length (early: 120/150 days or late: 150/180 days). The perennial cotton—which is a tree—depends on manual harvest, being restricted to small farms. Approximately, 90 % of world production corresponds to annual cotton with early cycle (Beltrão 1999).

The cotton production cost is high because the plant is a suitable host for several pests, demanding a large number of pesticide applications, turning its production cost one of the most expensive among the major crops.

Cotton is widely grown, being present in over 80 countries, occupying an area in excess of 30 Mha (2014/15 season), producing 45 Mt of cottonseed (Fig. 11) and 26.3 Mt of cotton lint (total of 71.3 Mt).

The major driver for cotton production in the world is the fiber, used mainly for textile applications, besides other minor industrial uses. It should be taken into consideration that cotton market is quite unstable and competitive, partially because of the limited demand of its fiber, which competes with other natural, but chiefly with synthetic fibers.

The large number of producing countries contributes for an unstable market, making it easy to replenish low global stocks as a reaction to the stimulus of good market prices. This is one of the reasons why, despite the large number of

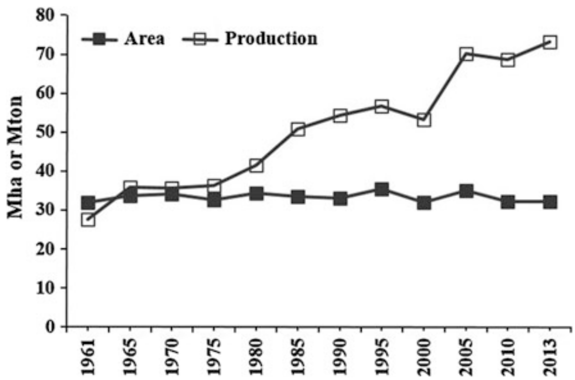


Fig. 11 Global cotton area and production

producing countries, not all of them are present on the market every other year, due to production problems, mainly climatic and phytosanitary constraints, increasing production costs. So, the competition status of the countries changes, depending on the production amount and its costs and on the market price.

Table 13 details the cotton area, yield, and production for the most important producing countries, while Fig. 12 presents the recent history of cotton oil production. According to the FAO database (FAOSTAT 2015), the major producers of cotton lint are India (6.51 Mton), China (6.48 Mton), USA (3.55 Mton), Pakistan (2.31 Mton), and Brazil (1.51 Mton). The plume international trade, amounting 7.67 Mton, are led by the USA (2.33 Mton) and followed by India (0.98 Mton), Brazil (0.87 Mton), Australia (0.63 Mton), and Uzbekistan (0.61 Mton). China, despite being the second largest producer, is also the number one cotton fiber importer, followed by the East Asian countries, Europe, Bangladesh, and Pakistan.

*2.6 Peanut (***Arachis hypogea** *L.)*

2.6.1 History and Highlights

Wild peanuts are common plants along South America (mainly Brazil, Paraguay, Bolivia, and northern Argentina), between latitudes 10 and 30°S, with its most probable center of origin located in the Chaco region (Kochert et al. 1996). It belongs to the botanic family Fabaceae, the same as beans, peas, and soybean. Peanut plants are classified into four groups, according to differential characteristics: Runner, Spanish, Valencia, and Virginia, being the first three upright and early types; the latter is creeping and have a longer cycle (Beasley and Baldwin 2015).

According to archaeological documentation referred by Jones (2007), there is evidence of its consumption since 3800 BC. The cultivation and dispersion of peanut began with the Indians, spreading it to various regions of Latin America. In

Table 13 Cotton area, yield and production for the most important countries

Year	Brazil			India			Pakistan			USA			China		
	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)
1961	2.02	631	1.28	7.72	358	2.76	1.40	697	0.97	6.33	1349	8.53	3.87	621	2.40
1965	2.33	583	1.36	7.94	392	3.12	1.56	801	1.25	5.51	1593	8.78	5.00	1259	6.30
1970	4.30	455	1.95	7.61	392	2.98	1.75	932	1.63	4.51	1309	5.91	4.99	1368	6.83
1975	3.88	451	1.75	7.46	486	3.63	1.85	833	1.54	3.56	1328	4.73	4.95	1443	7.14
1980	3.70	453	1.68	7.82	516	4.04	2.11	1017	2.14	5.35	1211	6.48	4.92	1652	8.12
1985	3.59	796	2.86	7.53	615	4.64	2.36	1544	3.65	4.14	1863	7.71	5.14	2420	12.44
1990	1.90	1009	1.92	7.44	703	5.23	2.66	1845	4.91	4.75	1851	8.79	5.59	2420	13.52
1995	1.19	1218	1.45	9.04	756	6.83	3.00	1804	5.41	6.48	1561	10.11	5.42	2638	14.30
2000	0.80	2508	2.01	8.58	598	5.13	2.93	1871	5.48	5.28	1814	9.58	4.04	3279	13.25
2005	1.26	2904	3.67	8.68	1133	9.83	3.10	2141	6.64	5.59	2305	12.88	5.06	3387	17.14
2010	0.83	3555	2.95	11.14	1594	17.76	2.69	2088	5.61	4.33	2188	9.47	4.85	3694	17.91
2013	0.94	3621	3.42	11.70	1617	18.91	2.81	2225	6.24	3.05	2498	7.63	4.35	4356	18.93

Source FAOSTAT database

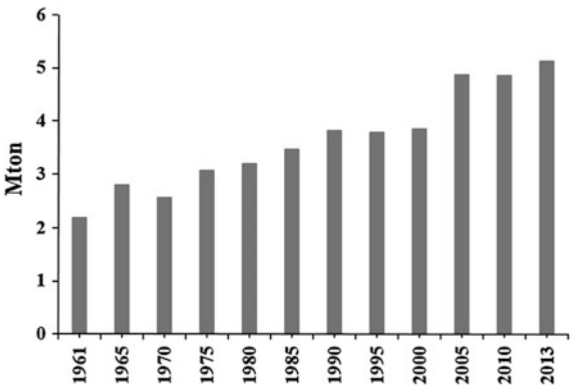


Fig. 12 World cotton oil production

the eighteenth century, it was introduced in Europe. In the nineteenth century, it was introduced to Africa, from Brazil, and to Asia, from Peru.

Peanut is one of the oil crops with highest oil fraction, ranging from 45 to 50 % (Mercer et al. 1990). It is highly prized in the market and appreciated for human consumption, and can be used in the pharmaceutical, cosmetics, and in the production of biodiesel. The meal quality is comparable to soybean meal making it highly valued for animal feed (dos Santos et al. 2013).

2.6.2 Production

The peanut plant grows well at temperatures between 20 and 30 °C, throughout the cycle. The plant prefers loamy sandy soil, well fertilized. Like all legumes, peanut does not tolerate high soil acidity, requiring liming when appropriate. It requires good availability of calcium for the formation of pods, as well as phosphorus, for grain formation. Nitrogen can be made available by the inoculation of grains with N-fixing bacteria of the *Bradhyrizobium* genus prior to sowing. There are limitations of appropriate machinery for the harvest process, normally carried out manually (dos Santos et al. 2013).

Peanut is highly susceptible to the attack of microorganisms-producing mycotoxins, particularly aflatoxin, depreciating its commercial value (Pitt and Hocking 2006). The inadequate management of humidity and temperature during peanut harvest, transport, and storage favors this attack. These microorganisms can survive in plant debris and infect subsequent crops. For this reason, it is recommended to avoid continuous peanut cultivation in the same area. Rotation with other crops is highly desirable. In addition to providing a good meal to feed pigs and poultry from the beans, its shoots can provide hay or quality silage for feeding cattle.

Peanut world area has been stable around 30 Mha for the last 55 years, while the production jumped from less than 30 Mt to over 70 Mt (Fig. 13). The largest producers are China, India, Nigeria, USA, and Brazil (Table 14). Major uses of

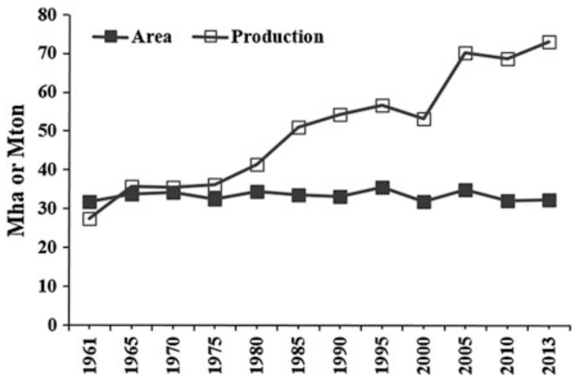


Fig. 13 Global peanut area and production

peanut are for oil production, human food, and animal feed (dos Santos et al. 2013). World peanut oil production is displayed on Fig. 14.

2.7 *Minor Oil Crops*

A series of species are used locally, even regionally, for oil production in small scale. Some are directed for self-consumption, either for human or animal nutrition, for elaborating soaps or producing energy. Those minor crops represent less than 5 % of the world oil production, and are restricted to commercial or purposes niches. Two species of minor oil crops are described below.

2.7.1 Castor (*Ricinus communis* L.)

The center of origin of the castor bean is undefined, as both India and Ethiopia are mentioned as its center of origin (Anjami 2012). It belongs to the family Euphorbiaceae, the same of cassava, rubber, and jatropha. The plant shows broad adaptation, being cultivated or naturally occurring on latitudes from 0° to 40°, with prevailing temperatures between 20 and 30 °C, requiring annual rainfall between 500 and 1500 mm (Abreu et al. 2012). It is recognized as a suitable crop for semi-arid regions, because of its relative tolerance to drought (Carvalho 2005).

According to Azevedo and Beltrão (2007), under dry conditions, castor yields are very low, but there are situations where castor is the only cash crop for peasants living on semi-arid regions, even though the plant is more productive on well-drained, deep, non-compacted and fertile soils, with pH on the range 6.0–7.0 (Rodrigues Filho 2000).

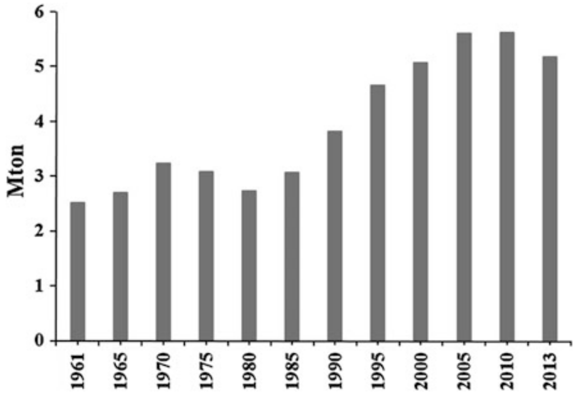
The area and the world production of castor beans is approximately 1.5 Mha/Mt, being India responsible for over 50 % of this production, followed by China and Brazil, and the castor oil production is around 0.5 Mt (FAOSTAT 2015). Its market

Table 14 Peanut area, yield and production for the most important countries

Year	Brazil			China			India			Nigeria			USA		
	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)	Area (Mha)	Yield (kg/ha)	Production (Mton)
1961	0.44	1339	0.58	1.30	889	1.15	6.89	725	4.99	1.49	1052	1.57	0.57	1329	0.75
1965	0.54	1374	0.74	1.95	1054	2.05	7.70	554	4.26	2.23	887	1.98	0.58	1862	1.08
1970	0.67	1386	0.93	1.80	1264	2.27	7.33	834	6.11	1.87	846	1.58	0.59	2276	1.35
1975	0.35	1281	0.44	1.94	1218	2.36	7.22	935	6.75	1.42	323	0.46	0.61	2874	1.74
1980	0.31	1543	0.48	2.39	1542	3.69	6.80	736	5.01	0.56	837	0.47	0.57	1844	1.04
1985	0.19	1756	0.34	3.37	2003	6.75	7.12	719	5.12	0.59	1046	0.62	0.59	3148	1.87
1990	0.08	1655	0.14	2.94	2187	6.43	8.31	904	7.51	0.71	1649	1.17	0.74	2223	1.63
1995	0.09	1796	0.17	3.85	2684	10.33	7.52	1007	7.58	1.77	894	1.58	0.61	2558	1.57
2000	0.10	1793	0.18	4.88	2972	14.52	6.56	988	6.48	1.93	1500	2.90	0.54	2740	1.48
2005	0.14	2317	0.32	4.68	3073	14.40	6.74	1187	7.99	2.19	1590	3.48	0.66	3351	2.21
2010	0.09	2772	0.26	4.55	3454	15.71	5.86	1410	8.27	2.79	1362	3.80	0.51	3712	1.89
2013	0.12	3222	0.39	4.65	3659	17.02	5.25	1804	9.47	2.36	1271	3.00	0.42	4496	1.89

Source FAOSTAT database

Fig. 14 World peanut oil production



is narrow and limited, reason why a production much higher than this amount can lead to exaggerated stocks and low market prices.

Severino et al. (2006) mention that castor yields are low when compared to major oil crops, but the seeds are rich in oil (45–52 %). Although there are cultivars of annual cycle, the most commonly cultivars grown worldwide are late ripening (180–240 days), requiring manual harvest, which is one of the limitations for the crop expansion. Ogunniyi (2006) mention that ricinoleic, a monounsaturated (18:1) omega-9 fatty acid, represents up to 90 % of the seed oil obtained from mature castor beans. It differs from oleic acid due to the presence of a hydroxyl radical linked to the 12th carbon of the chain. Ricinoleic is not an edible fatty acid, but has multiple uses in the industry (manufacturing of paints, varnishes, soaps, detergents, insecticides, fungicides, bactericides, candles, synthetics, plastics, pharmaceuticals, specialty greases, etc.), according to Ogunniyi (2006).

The high proportion of ricinoleic acid on the castor oil is largely responsible for its low viscosity and for the formation of polymers on the combustion chambers of engines, limiting its use for biodiesel production, unless blended with biodiesel obtained from feedstocks with oils of higher viscosity. It is a much sued oil to lubricate high-speed engines (aircraft, rockets, ships), not changing its characteristics whether used in high or low temperatures. Castor meal has no commercial value because it is toxic to animal feed, being generally used as organic fertilizer, due to its effectiveness in controlling soil nematodes.

2.7.2 Oil Radish (*Raphanus sativus* L. var. *oleiferus* Metzg)

Originally from Asia, it is one of the oldest species exploited for oil production (Wang et al. 2015). Although the oil radish is a plant whose seeds are rich in oil, its major use is as a winter cover plant, for crop rotation and for feed. The plant belongs to the family Brassicaceae (formerly Cruciferae), the same as crambe, canola and mustard.

According to Hernani and Henn (1995), this species shows large adaptability to different climates and soils, being a very vigorous plant, with pivoting and aggressive root system, able to break through extremely dense soil layers and/or compacted, at depths greater than 2.50 m. It grows fast, exerting high suppressive effect on weeds. Sixty days after sowing, the oil radish covers about 70 % of the land surface; its biomass has easy and rapid decomposition due to the low carbon/nitrogen ratio (C/N), providing, instantly nutrients to subsequent crops (CATI 2001). Produces between 20 and 35 t/ha of biomass, 3–8 t/ha of dry matter, and 500–1500 kg/ha of seeds, resulting in 150–500 kg/ha of oil.

Oliveira et al. (2011) stated that the oil radish is a rustic plant that grows well in poor soils, either in cold or hot places, indifferent to low (0 m) or high (1000 m) altitudes. The plant requires the presence of moisture in the soil during implantation and early development, but during the rest of the cycle shows median tolerance to drought and frost, being adequately cropped during fall and winter. It is quite resistant to pests and diseases and does not demand soil preparation. Despite its tolerance to soils with aluminum saturation and high acidity, the plant increases the green mass and grain production when cultivated on fertile soils.

The oil content of the seeds is relatively high (32–42 %) but, due to its low grain yield, the oil production is small and is not edible (Wang et al. 2015). The oil market is restricted to industrial uses and its production chain is deficient.

2.8 Potential Oil Crops

There are innumerous plant species with median to high oil content, with a theoretical potential for oil production. Some are source of oil on extractive systems, based on native formation. Its commercial development depends on (a) possibility of production of over 500 kg/ha of oil, in order to compete with major oil crops; (b) domestication of the species; (c) establishment of sound production systems; (d) organization of the productive chain connecting growers, suppliers, processors, industry and consumers (Gazzoni et al. 2012). Among others, potential oil crops include flaxseed, sesame, safflower, crambe, tucuman, rubs, buriti, macaúba, indaiá, açaí, gerivá, patauá, cotieira, oiticica, nhandiroba, tung, pequi, jatropha, jojoba, and tingui. Two examples of potential oil crops are described below.

2.8.1 Crambe (*Crambe abyssinica*)

This species is native from the Mediterranean region and has been cultivated on several regions as central and west Asia, Europe, USA, and South America (Weiss 2000). The plant belongs to the family Brassicaceae (formerly Cruciferae), the same as turnip, mustard, and canola. Until recently, it was only used as fodder. However, given its rusticity, precocity (90–120 days) and high potential to produce oil

(26–38 % content in seeds) (Meier and Lessman 1971), it has been investigated as a potential oil crop, aiming biodiesel production, in spite of its low productivity.

Weiss (2000) describes crambe as an annual, herbaceous plant, about one meter high. The oil is inedible because of the presence of erucic acid (60 %), being useful as a raw material for the manufacture of plastic films, nylon, adhesives, anticorrosive, and lubricating products, which are traditionally dependent on rapeseed oil.

According to Dalchiavon et al. (2012), crambe shows lower production costs when compared to soybean, sunflower or canola, and potential for winter cultivation as it can withstand temperatures as low as 4 °C below zero, being relatively tolerant to drought. Crambe grows better on well-drained soil with a pH between 6 and 7 (White and Higgins 1966).

The oil extracted from crambe seeds is used as an industrial lubricant, a corrosion inhibitor, and as an ingredient in the manufacture of synthetic rubber. The oil contains 50–60 % erucic acid, a long chain fatty acid, which is used in the manufacture of plastic films, plasticizers, nylon, adhesives, and electrical insulation (Oplinger et al. 2015). The authors refer that crambe is being promoted in the USA as a new domestic source of erucic acid, primarily obtained from imported rapeseed oil. Supplies of industrial rapeseed are less-plentiful since the development of varieties (canola) that have no erucic acid content, in contrast with crambe oil that contains 8–9 % more erucic acid than industrial rapeseed oil.

Crambe meal contains 25–35 % protein when the pod is included and 46–58 % protein when the pod is removed, with a well-balanced amino acids content (Hesketh et al. 1963). Defatted crambe meal is a protein supplement for livestock feeds (Oplinger et al. 2015) and its use has been approved by the FDA for beef cattle rations for up to 5 % of the daily intake. Nevertheless, the meal has not been approved for nonruminant feeds due to the presence of glucosinolates, broken down during digestion to harmful products that depress the appetite and can cause liver and kidney damage.

Untreated oil-free crambe meal may contain up to 10 % thioglucosides (McGhee et al. 1965), which is toxic to nonruminant animals, such as hogs and chickens (Van Etten et al. 1965, 1969). However, subjecting whole seed to moist heat before processing can deactivate the enzyme, and the glucosinolates remain intact through the oil extraction process, according to Oplinger et al. (2015).

2.8.2 Jatropha (*Jatropha curcas*)

This plant belongs to the family Euphorbiaceae, the same as the castor bean and cassava, and its center of origin is located in Mexico (Dias et al. 2012). It is a tree of rapid growth, whose average height is two to three meters, but can reach up to five meters, under special conditions of climate and soil. It takes 3–4 years for commercial harvesting and production may extend from 40 to 100 years.

The plant has been traditionally used as a living fence, from where fruits are harvested for oil extraction (Carvalho et al. 2009). Jatropha seeds contains 25–40 % oil (average of 37.5 %) and its use has been restricted to self-consumption on production sites (farms), for energy purposes or for soap production. As it happens with castor, the meal resulting from oil extraction is highly toxic to animals, and cannot be used as feed, unless it is detoxified (Dias et al. 2007).

During the 1990s and up to the first decade of the twenty-first century, there was a global wave of incentives for using jatropha seeds as feedstock for biodiesel production, with several private and public initiatives aiming to establish large commercial jatropha plantations in Asia (mainly China, India, Indonesia, Malaysia, and others), Africa and Latin America. All these initiatives failed, due to the absence of feasible production systems (commercial varieties, recommendations for plant nutrition and for controlling several pests hosted by the plant), low productivity, large period until first commercial harvest, and the high demand for labor force, especially for harvesting.

The fruit ripening of jatropha does not occur at the same time, but extends for 3–4 months, exacerbating the requirement of manpower. In addition, the high toxicity of the jatropha meal prevents its use as animal feed and even its use as organic fertilizer may pose environmental hazards. In this case, only the jatropha oil would have commercial value, making it impossible to compete with major oil crops, like soybean, canola or sunflower, whose meal is highly demanded in the market, or cotton oil, supported by the commercialization of the lint.

References

Abreu YV, Oliveira HR, Leal JE. C (2012) Biodiesel no Brasil em Três Hiatos: Selo Combustível Social, Empresas e Leilões. Eumed, Univ. Malaga (Esp), 213 p

Anjami K (2012) Castor genetic resources: a primary gene pool for exploitation. Ind Crop Prod 35 (1):1–14

Beasley J, Baldwin J (2015) Peanuts cultivars and description. The University of Georgia College of Agricultural & Environmental Sciences. Available at http://www.caes.uga.edu/commodities/fieldcrops/peanuts/production/cultivardescription.html. Retrieved on 27 Sept 2015

Bretschneider W (1882) Botanicum Sinicum. Notes on Chinese botany from native and western sources. J Roy Astron Soc N China Br NS 16–17:18–23

Camara GMS (ed) (2000) Soja: tecnologia da produção II. Piracicaba, ESALQ/LPV 450p

Carvalho BCL (2005) Manual do cultivo da mamona. EBDA, Salvador, 65 p (il.)

CATI (2001) Nabo forrageiro: adubação verde para inverno. CATI, Campinas. 1 folder (CATI. Responde, 25)

Cia E, Freire EC, dos Santos WJ (eds) (1999) Cultura do algodoeiro. Piracicaba: POTAFOS, 286 p

Congresso Brasileiro de Soja 4 (2006) Londrina. Resumos. Londrina: Embrapa Soja, 202 p. Organizado por Odilon Ferreira Saraiva, Simone Ery Grosskopf

Corley RHV, Tinker PB (2003) The oil palm, 5th edn. Blackwell Science Ltd., Oxford, 627 p

Cornet D (2001) Oil Palm—*Elaeis guineensis* Jacq. In: Raemaekers RH (ed) Crop production in Tropical Africa. Directorate General for International Cooperaction, Brussels, pp 769–797

Cultura da colza (1980) Fert Informa 3(28):4–5

Dalchiavon MP, Santos RF, de Souza SNM, Bassegio D, Rossetto C, Bauerman HB (2012) Growth analysis of *Crambe abyssinica* according to the variation in planting density. Acta Iguazu 1(3):33–43

Dall'Agnoll A, Roessing AC, Lazzarotto JJ, Hirakuri MH, Oliveira AB (2007) O complexo agroindustrial da soja brasileira. Circular Técnica, 43, Embrapa Soja, Londrina, PR, Brasil, 11 p

Davis SC, Anderson-Teixeira KJ, Delucia EH (2009) Life-cycle analysis and the ecology of biofuels. Trends Plant Sci 14(3):140–146

de Azevedo DMP, de Beltrão NEM (eds) (2007) O Agronegócio da mamona no Brasil. 2 ed. rev. amp. Campina Grande: Embrapa Algodão; Brasília, DF: Embrapa Informação Tecnológica. 506 p

de Beltrão NEM (Org.) (1999) O agronegócio do algodão no Brasil. Brasília, DF: Embrapa Comunicação para a Transferência de Tecnologia; Campina Grande: Embrapa Algodão, 2:1–2, 491p

de Carvalho BCL, Oliveira EAS, Leite VM, Dourado VV (2009) Informações técnicas para o cultivo do pinhão-manso no estado da Bahia. EBDA, Salvador, p 79

de Leite RMVBC, Brighenti AM, de Castro C (eds) (2005) Girassol no Brasil. Embrapa Soja, Londrina, 613 p

De Mori C, Tomm GO, Ferreira PEP (2014) Aspectos econômicos e conjunturais da cultura da canola no mundo e no Brasil. Embrapa Trigo, Passo Fundo, 36 p (html) (Embrapa Trigo. Documentos online, 149)

Dias LA, Leme LP, Laviola BG, Pallini A, Pereira OL, Dias DCFS, Carvalho M, Manfio CE, AS, de Sousa LCA, de Oliveira TS, Pretti LA (2007) Cultivo de pinhão manso (*Jatropha curcas* L.) para produção de óleo combustível. L. A. S. Dias, Viçosa, MG, 40 p

Dias LA, Missio RF, Dias DC (2012) Antiquity, botany, origin and domestication of *Jatropha curcas* (Euphorbiaceae), a plant species with potential for biodiesel production. Genet Mol Res 11(3):2719–2728

dos Santos RC, Freire RMM, de Lima LM (eds) (2013) O agronegócio do amendoim no Brasil. 2. ed. rev. e ampl. Brasília, DF: Embrapa, 585 p. il. color. Autores: Alessandra Pereira Fávero, Ana Cristina Miranda Brasileiro, Ana Heloneida de Araújo Morais, Ana Maria Rauen de Olvieira Miguel, Bill Jorge Costa, David John Bertioli, Denizart Bolonhezi, Francisco José Alves Fernandes Távora

Downey RK, Harvey BL (1963) Methods of breeding for oil quality in rape. Can J Plant Sci 43(3):271–275

Embrapa (1994) Tropical soybean improvement and production. Food and Agriculture Organization of the United Nations (FAO), Rome 253 p

FAOSTAT (2015) FAOSTAT database. Available at www.faostat.fao.org

Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P (2008) Land clearing and the biofuel carbon debt. Science 319(5867):1235–1238

Gazzoni DL (2013) A sustentabilidade da soja no contexto do agronegócio brasileiro e mundial. Embrapa Soja Série Documentos 344, 50 p

Gazzoni DL (2014a) O impacto do uso da terra na sustentabilidade dos biocombustíveis. Embrapa Soja Série Documentos 347, 82 p

Gazzoni DL (2014b) Balanço de emissões de CO_2 por biocombustíveis no Brasil: histórico e perspectivas. Embrapa Soja Série Documentos 334, 107 p

Gazzoni DL, Felici PHN, Coronato RMS, Ralisch R (2005) Balanço energético das culturas de girassol e soja pra produção de biodiesel. Biomassa e Energia 2(4):259–265

Gazzoni DL, Avila MT, Felici PHN, Ralisch R (2008) Balanço energético do biodiesel de dendê. In: CONGRESSO BRASILEIRO DE AGROENERGIA, 1., SIMPÓSIO INTERNACIONAL DE BIOCOMBSTÍVEL, 1., Uberlândia. Anais. UFU, Uberlândia

Gazzoni DL, Borges JLB, Avila MT, Felici PHN (2009) Balanço energético da cultura da canola para a produção de biodiesel. Espaço Energia 11:24–28

Gazzoni DL, Azurdia I, Blanco G, Estrada C, Macedo IC (2012) Sustainable energy in Latin America and the Caribbean: potential for the future. Available at http://www.icsu.org/latin-america-caribbean/publications/reports-and-reviews/sustainable-energy/energy_english.pdf. Retrieved on 15 Sept 2015

Greenpeace (2015) Indonesia forest threats. Available at http://www.greenpeace.org/international/en/campaigns/forests/asia-pacific/threats/. Retrieved on 26 Sept 2015

Hammond EG, Johnson LA, Su C, Wang T, White PJ (2005) Soybean oil. In: Bailey's industrial oil and fat products. Available at https://pharosproject.net/uploads/files/cml/1360080729.pdf. Retrieved on 12 Sept 2015

Hernani LC, Henn R (1995) Nabo forrageiro. Dourados: EMBRAPA-CPAO (1 folder)

Hesketh HR, Creger CR, Crouch JR (1963) *Crambe abyssinica* meal as a protein source for broilers. Poultry Sci 42:1276

Hill J, Nelson E, Tilman D, Polasky S, Tiffany D (2006) Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. PNAS 103(30):11206–11210

Hymowitz T (1983) History of soy—soybeans: the success story. Available at http://www.nsrl.uiuc.edu/aboutsoy/history3.html. Retrieved on 11 July 2015

Iqbal MJ, Aziz N, Saeed NA, Zafar Y, Malik KA (1997) Genetic diversity evaluation of some elite cotton varieties by RAPD analysis. Theor Appl Genet 94(1):139–144

Iqbal MJ, Reddy OUK, El-Zik KM, Pepper AE (2001) A genetic bottleneck in the evolution under domestication of upland cotton *Gossypium hirsutum* L. examined using DNA fingerprinting. Theor Appl Genet 103(4):547–554

Ivanov DS, Jovanka D, Sredanović A (2010) Fatty acid composition of various soybean products. J Inst Food Tech Novi Sad 37(2):65–70

Jones J (2007) Earliest-known evidence of peanut, cotton and squash farming found. Anthropoly.net. Available at http://anthropology.net/2007/06/28/earliest-known-evidence-of-peanut-cotton-and-squash-farming-found/. Retrieved on 27 Sept 2015

Katragadda HR, Fullana AS, Sidhu S, Carbonell-Barrachina ÁA (2010) Emissions of volatile aldehydes from heated cooking oils. Food Chem 120:59–65

Kochert G, Stalker HT, Gimenes M, Galgaro L, Lopes CR, Moore K (1996) RFLP and cytogenetic evidence on the origin and evolution of allotetraploid domesticated peanut, *Arachis hypogaea* (Leguminosae). Am J Bot 83(10):1282–1291

Lentz DL, Pohl ED, Pope KO, Wyatt AR (2001) Prehistoric sunflower (*Helianthus annuus* L.) domestication in Mexico. Econ Bot 55(3):370–376

McGhee JE, Kirk CD, Mustakas GC (1965) Methods for determining thioglucosides in *Crambe abyssinica*. J Am Oil Chem Soc 42:889–891

Meier VD, Lessman KJ (1971) Estimation of optimum field plot shape and size for testing yield in *Crambe abyssinica* Hochst. Crop Sci 11(5):648–650

Mercer LC, Wynne JC, Young CT (1990) Inheritance of fatty acid content in peanut oil. Peanut Sci 17(1):17–21

Merrill ED (1931) The phytogeography of cultivated plants in relation to the assumed pre-Columbian-Eurasian-American contacts. Am Anthropologist 33:375–382

Miyasaka S, Medina JC (eds) (1981) A soja no Brasil. ITAL, Campinas, 1062 p

Müller AA (1980) A cultura do dendê. Belém. EMBRAPA-CPATU, PA, 24 p (il.) (EMBRAPA-CPATU. Miscelânea, 5)

Muller AA, Furlan Junior J (eds) (2001) Agronegócio do dendê: uma alternativa social, econômica e ambiental para o desenvolvimento sustentável da Amazônia. Embrapa Amazônia Oriental, Belém, 288 p (il.)

Ogunniyi DS (2006) Castor oil: a vital industrial raw material. Biores Tech 97(9):1086–1091

Oliveira AdS, de Carvalho MLM, Nery MC, Oliveira JA, Guimaraes RM (2011) Seed quality and optimal spatial arrangement of fodder radish. Sci Agricola 68(4):417–423

Oplinger ES, Oelke EA, Kaminski AR, Putnam DH, Teynor TM, Doll1 JD, Kelling KA, Durgan BR, Noetzel DM (2015) Crambe. In: Altenative crops manual. Available at https://www.hort.purdue.edu/newcrop/afcm/crambe.html. Retrieved on 17 Oct 2015

Piper CV, Morse WJ (1910) The soybean: history, varieties and field studies. USDA Bur Pl Ind Bull 197:1–84

Pitt JI, Hocking AD (2006) Mycotoxins in Australia: biocontrol of aflatoxin in peanuts. Mycopathologia 162:233–243

Poth U (2001) Drying oils and related products. Ullmann's encyclopedia of industrial chemistry. Wiley-VCH Verlag GmbH & Co. KGaA

Prakash S, Hinata K (1980) Taxonomy, cytogenetics and origin of crop Brassicas, a review. Opera Bot 55:1–57

Ramos MJ, Fernández CM, Casas A, Rodríguez L, Pérez A (2009) Influence of fatty acid composition of raw materials on biodiesel properties. Bioresour Tech 100(1):262–268

REN 21 (2015) Global status report. Available at www.ren21.net. Retrieved on 7 Oct 2015

Rodrigues Filho A (2000) Cultura da mamona. Belo Horizonte, EMATER, MG, 18 p (il.) (Agricultura: culturas)

Searchinger T, Heimlich R, Houghton RA et al (2008) Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 319:1238–1240

Severino LS, Nóbrega MB de, Gonçalves NP, Eguia MTJ (2006) Viagem à Índia para prospecção de tecnologias sobre mamona e pinhão manso. Campina Grande, Embrapa Algodão, 56 p (Embrapa Algodão. Documentos, 153)

Snowdon R, Lühs N, Friedt W (2007) Oilseed rape. In: Kole C (ed) Genome mapping and molecular breeding in plans, vol 2. Springer, Berlin, pp 55–114

Ungaro MRG (2000) Cultura do girassol. IAC, Campinas, 36 p (IAC. Boletim Técnico, 188)

USDA (2015a) Canola. Available at http://www.ers.usda.gov/topics/crops/soybeans-oil-crops/canola.aspx. Retrieved on 26 Sept 2015

USDA (2015b) Sunflowerseed. Available at http://www.ers.usda.gov/topics/crops/soybeans-oil-crops/sunflowerseed.aspx. Retrieved on 26 Sept 2015

USDA (2015c) Cotton. Available at http://www.ers.usda.gov/topics/crops/cotton-wool/background.aspx. Retrieved on 26 Sept 2015

USDA (2015d) Oilseeds. Available at http://www.fas.usda.gov/data/oilseeds-world-markets-and-trade. Retrieved on 11 Oct 2015

USDA (2015e) Soybeans & Oil crops. Available at http://www.ers.usda.gov/topics/crops/soybeans-oil-crops/background.aspx. Retrieved on 13 Oct 2015

Van Etten CH, Daxenbichler ME, Peters JE, Wolff IA, Booth AN (1965) Seed meal from *Crambe abyssinica*. J Agric Food Chem 13:24–27

Van Etten CH, Daxenbichler ME, Wolff IA (1969) Natural glucosinolates (thioglucosides) in foods and feeds. J Agric Food Chem 17:483–491

Wang Q, Zhang L, Zheng P (2015) Genetic diversity and evolutionary relationship analyses within and among Raphanus species using EST-SSR markers. Mol Breeding 62:35–62

Weiss, EA (2000) Oil seed crops. World Agriculture Series, Cab Direct, 373 p

White GA, Higgins JJ (1966) Culture of crambe: a new industrial oilseed crop. Agricultural Research Service, USDA. ARS Production Research Report. 95