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OILSEEDS, OVERVIEW

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Introduction

Oilseed crops are generally grown for the oil in their seeds and vary considerably in oil content, quality, and composition – factors that rely heavily on the crop species or cultivar and upon the environmental conditions in which the crop is grown. The seed meal left after the oil has been extracted can provide a high-protein product for use in either animal or human food. In other crops, the seed meal or some other factor is more important than the oil and the oil is a by-product. For example, soybean is primarily grown for its high-protein meal and cotton for its fiber. Consequently, in oil-producing crops, plant-breeding programs are aimed both at increasing oil production and quality with the additional aim of increasing meal quality. In some oil crops, antinutritional components are present (such as gossypol in cottonseed and glucosinolates in rapeseed) that also need to be considered that may limit the use of the meal.

Oilseeds and Their Uses

The major use of oilseed crops is the oil, which, in many cases accounts for up to 80% of the crop value. The oil-free meal provides additional value along with various by-products such as lecithin, and a range of extracts from both meal and oil.

Vegetable oils contain 95–98% triacylglycerols (or triglycerides). The remaining fraction consists of phospholipids, mono and diacylglycerols, and unsaponifiable components including sterols and tocopherols. The oils consist of long-chain fatty acids from C14 to C24 in length and the proportion of these fatty acids in the oil has a significant contribution to its nutritional value. In recent years, there has been a trend in human diets towards reduction of saturated fats such as palmitic acid (C16:0) and an increase in polyunsaturated (C18:2 and C18:3), and monounsaturated (C18:1) fats. Plant breeders have successfully developed more nutritionally favorable products from traditional oilseed crops by altering their fatty acid profiles and other constituents.

World consumption of oils is forecast by FAO to exceed 122 million tons (Mt) in 2005. Although demand is slowing down in developed countries as they reach saturation levels, consumption in developing countries is steadily increasing. Nonfood uses of vegetable oils in developed countries are estimated to account for ~22% by 2005 due to developments in the oleochemical industries with a shift away from petroleum-based products to environmentally friendly oleochemicals. In addition, there is an increase in technological developments, particularly with the genetic modification of oilseeds to create a new range of products. For cooking oils and salad dressings, plant breeders have selected cultivars with lower levels of polyunsaturated and saturated fats and an increase in monounsaturates for increased oxidative stability. New developments include oils with increased stearic acid to provide margarine type fats without the need for hydrogenation and the subsequent production of trans-fatty acids. The uses of vegetable oils in paints, lubricants, cosmetics, and pharmaceuticals have been well documented.

World consumption of oilseed meal is expected to reach 28 Mt by 2005. Soybean meal dominates the market, forecast to account for ~63% of the global meal production by 2005. It is expected, however, that future meal production from sunflower and rapeseed will increase relative to soybean. Much of the meal is utilized as stock feed and the production of livestock products, in particular pork and poultry and more recently, aquaculture. Meal products, such as protein extracts, are used for edible purposes and consumption of whole seed, including roasted soybeans, peanuts, and sesame seed is common. The meal also has industrial applications in cosmetics, paints, and adhesives.

Oil Analysis

The traditional methods of oilseed analysis made plant breeding and selection a slow and tedious process. The Goldfische or Soxhlet methods of oil extraction required several hours to complete and involved the use of hazardous flammable solvents. In addition, only a few samples could be processed at a time reducing the capacity of the laboratories to service the needs of plant-breeding programs. Kjeldahl nitrogen analysis to determine the nitrogen content of the meal also required the use of dangerous chemicals and strong acids. More recent advances in oil content determination include nondestructive seed analysis, such as the use of nuclear magnetic resonance (NMR) spectroscopy. The rapid and accurate nondestructive testing of seed for oil content allows the breeder to retain the seed of potentially suitable lines. The introduction of near-infra-red reflectance (NIR) spectroscopy has further enhanced the ability of laboratories to determine a wider range of seed components including oil, protein, moisture, fiber, and numerous others on relatively small samples in a short time. Consequently, hundreds of seed samples can now be analyzed each day and the intact seed returned to the breeder for further growth and evaluation.

New Variations on Old Crops

The major oilseed crops of the world include soybean, cottonseed, rapeseed, sunflower, groundnut (or peanut), sesame seed, linseed (from which the name linolenic acid is derived), safflower, and mustard seed. Many other crops can be used for oilseed production including castor beans, grape seed, tobacco seed, flax, corn oil, tung beans, and okra. The oil and protein content of the major oilseed crops is shown in Table 1.

From these crops, breeders have developed specialty oil types within the different species. Sunflower oil, for example, is traditionally high in linoleic (polyunsaturated) acid and is promoted as such for its health benefits. With further plant breeding, there are now several grades of sunflower oil, from high linoleic acid to high oleic (monounsaturated) as well as intermediate types. Oleic acid, being monounsaturated, has higher oxidative stability. In addition, the reduction in linoleic acid means that the need for hydrogenation to reduce polyunsaturated oils and the formation of trans-fatty acids is reduced. Trans-fatty acids are nutritionally undesirable and similar to saturated fats in their effects. Examples of plant species, which have been bred with increased oleic acid, include sunflowers (high oleic and Nusun^{TM}), linseed (solin, Linola^{TM}), cottonseed, soybean, rapeseed (canola, Monola^{TM}), safflower, and mustard.

Table 1 Approximate oil content of seed and protein content of oil-free meal and the main uses of selected oilseed crops

Oilseed	*Oil (%)*	*Protein (%)*	*Main use*
Soybeans	20	46	Food
Cottonseed	16	37	Fiber
Peanut	41	46	Food
Rapeseed	41	34	Oil
Sunflower seed	40	28	Oil
Sesame seed	40–60	42	Food
Linseed	40	32–34	Oil
Safflower seed	34	23	Oil
Mustard seed	20–50	35	Condiment

Adapted from Australian Oilseed Federation Technical and Quality Standards – 2002 and other literature values.

Other changes of significance to oilseed crops have been the development of genetically modified plants with specific applications other than for edible oils. The most obvious example of these is soybean in which large numbers of products are in development including those containing antibodies, altered amino acid profiles, zero lipoxygenase and others. Rapeseed is also in the process of undergoing numerous transformations to produce products for polymers and detergents, inks, cosmetics, pharmaceuticals, lubricants, plasticizers, and resins.

The Crops

Soybean Seed

The seeds are rich in protein, mainly globulins, which make up 90% of the total proteins and 36% of the seed weight. Ten percent of the seed weight is carbohydrate, mainly sugars, and 3% is starch. The seed is relatively low in oil compared to other oilseed crops at ~20%. Following oil extraction, heat treatment is used to inactivate enzymes in the high-protein meal that otherwise reduce the digestibility of the stock feed. Traditional soybean oil is polyunsaturated with 48–59% linoleic acid (C18:2) and 4–11% linolenic acid (C18:3) (Table 2). Breeding has produced cultivars with various fatty acid profiles; in particular, high oleic soybean oil, which contains up to 84% oleic, has less saturated (palmitic) acid, and is more stable for cooking purposes. The meal may also be

Table 2 The fatty acid components and quantities in the major oilseed crops (amounts in rounded percentages)

Fatty acid	*Name*	*Palmitic*	*Palmitoleic*	*Stearic*	*Oleic*	*Linoleic*	*Linolenic*	*Arachidic*	*Gadoleic*	*Behenic*	*Erucic*
	Symbol	*C16:0*	*C16:1*	*C18:0*	*C18:1*	*C18:2*	*C18:3*	*C20:0*	*C20:1*	*C22:0*	*C22:1*
Oilseed	*Type*										
Soybean	Normal	8–14	<0.2	2–6	17–30	48–59	4–11	<0.6	<0.5	<0.7	<0.3
Soybean	High oleic	6		3	84	2	4				
Cottonseed	Normal	21–26	<1.2	2–3	15–22	47–58	<0.5	0.2–0.5	<0.1	<0.6	<0.3
Peanuts	Normal	8.3		3.1	56	26		2			
Rapeseed	Low erucic	2–7	<0.6	1–3	51–70	15–30	5–14	0.2–1.5	0.1–5	<0.6	<2.0
	High erucic	1.5–6	<3	0.5–3	8–60	11–23	5–13	<3	3–15	<2	2–60
	High oleic	3–4		2–3	63–76	13–25	2–3		1–2	<0.6	<0.2
Sunflower	Linoleic	5–8	<0.3	2–7	14–40	48–74	<0.3	0.1–0.5	<0.3	0.3–1.5	<0.3
	Mid-oleic	4–5		3–4	50–75	20–30	<1				
	Oleic	2–5	<0.1	3–7	75–91	2–17	<0.3	0.2–0.5	0.1–0.5	0.5–1.5	<0.3
Sesame seed	Normal	8–12	<0.2	5–6	36–42	42–48	0.3–0.4	0.3–0.6	<0.3	<0.3	
Linseed	Normal	5–7	<0.3	3–4	19–20	14–17	52–61	<0.5	<0.6		
	Low linolenic	6		3–4	15	73	2–3				
Safflower	Linoleic	5–8	<0.2	2–3	8–22	68–33	<0.1	0.2–0.4	<0.3	<1.0	<1.8
	Oleic	3–6	<0.2	1–3	70–84	9–20	<1	0.3–0.6	<0.5	<0.4	<0.3
Mustard seed	*B. carinata*	4–10		<2	8–23	15–22	18–27		<2		20–50
	B. nigra	2–7		<2	10–27	15–22	11–27				33–45
	B. juncea	3–10		1–3	15–64	14–28	9–24		1–3		<40

Adapted from Codex Alimentarius Commission, Alinorm 03/17, 2003 and other literature values.

used for industrial purposes such as cosmetics, paints, and adhesives as well as various edible purposes.

Cottonseed

Cotton is basically grown for its fiber but the seed has several important components consisting of oil (16%), protein (37%), hull (37%), and linters (10%). Also, within the kernel is a phenolic compound called gossypol, ~1% of the seed weight: toxic to humans and monogastric animals. Cottonseed oil, prior to refining, is red due to the residual gossypol and associated products. Increased seed oil content has been a secondary objective to fiber production although the value of the oil is significant. Cottonseed oil contains ~47–58% linoleic acid. To make the oil more stable for cooking and to reduce the need for hydrogenation, the Commonwealth Scientific and Industrial Organization (CSIRO) in Australia have developed an alternative cottonseed oil. By "switching off" genes that convert oleic acid to linoleic they have been able to produce high oleic (73%), low linoleic (5%) oil with increased oxidative stability. Additionally, they have found it possible to alter the proportions of saturated fatty acids, palmitic and stearic, which provide the solid properties necessary for making margarine.

Groundnut or Peanut

Peanuts are a valuable source of oil and also produce a high-protein meal for stock feed. Increased yields are an important breeding priority, particularly in developing countries where yield is poor. Increased oil content is also desirable as peanuts have a wide range from 40% to greater than 60% in wild types. Reduction in linoleic acid produces oil with a better oxidative stability. Meal protein is high at ~46% but the amino acid profile is lacking in sulfur-containing amino acids particularly methionine. The components of whole peanuts are protein (26%), oil (41%), and carbohydrates (24%). The main product is the oil that has ~80% unsaturated fatty acids making it a nutritionally favorable oil. Additionally, the level of oleic acid and palmitic acid makes it stable with good keeping qualities for cooking and in food mixtures. Plant selection has seen the development of new cultivars with high oleic acid levels of up to 60% and a subsequent reduction in linoleic acid content. Fatty acid profiles are influenced significantly by environmental conditions with high temperatures favoring high oleic acid contents.

Rapeseed

Traditional rapeseed oil characteristically contains high levels of erucic acid, found to have detrimental effects on the myocardial muscle of rats fed the oil. The value of the meal was also low due to the presence of sulfur-containing compounds called glucosinolates, found to have deleterious effects on the thyroid gland of mono-gastric animals. Through plant breeding, major changes have been achieved to traditional rapeseed by increasing yield, oil, and simultaneously increasing meal protein content. The development of cultivars with very low levels of glucosinolate in the meal has also been achieved. With the dramatic change in rapeseed from traditional types to those grown today, new terms have been used to discriminate between the types. Canola is recognized under ISO 5725, Codex Alimentarius and ISTA as cultivars of rapeseed with less than 2% erucic acid in the oil and less than 30 μmol of aliphatic glucosinolates in the meal. European nomenclature to describe cultivars of rapeseed include low erucic acid rapeseed (LEAR) and Colza which is the French name for *B. napus* rapeseed in general. The seed oil is the main value of the crop yielding 42% oil, while the meal contains 35% protein. Current canola cultivars have very low erucic acid and saturated fatty acids levels and a good proportion of oleic (C18:1), linoleic (C18:2), and ω-3 linolenic (C18:3) fatty acids. The balanced fatty acid profile makes rapeseed ideal for mayonnaise and salad dressings as well as a wide range of applications in the bakery and confectionary industry. New high oleic/low linolenic types have improved oxidative stability for cooking and longer shelf life. Alternatively, high erucic oil is utilized for industrial purposes such as cutting oils. Erucic acid is extracted from high erucic rapeseed and converted to erucamide for plastic manufacture.

Sunflower

Sunflower is grown for the seed oil, which is ~80% of the seed value. The de-hulled meal has 28–42% protein. The oil is highly considered due to its low linolenic acid value and therefore oxidative stability for cooking, salad oil, and margarines. Heritability of high oil is reliable and it has been possible to increase oil contents from 30% in early types to over 50% in recent years. Sunflower cultivars with a range of fatty acid profiles have been developed including high oleic acid (75–91%) with reduced levels of linoleic acid (2–17%) and high levels of alpha tocopherol (vitamin E), providing the market with very stable monounsaturated oil for cooking purposes. Mid-oleic cultivars are also available, such as NuSun™, with saturated fatty acid levels of 8% and only 20–30% linoleic acid. The meal has high protein content and is used in animal feed for livestock and poultry. A small percentage of the crop is used for nonoilseed production for confectionary purposes.

Sesame Seed

Sesame seeds are used intact or as oil and meal. The seeds generally have high oil content of ~50% and ~25% protein, although the oil content can vary between 40–60%. The fatty acid composition also shows a large range (Table 2). A high oleic (40%) and linoleic acid (45%) content makes the oil nutritionally beneficial. The unsaponifiable fraction of the oil contains sesamine and sesamoline that during the refining process form sesamol and sesaminol. These are strong antioxidants that give the oil exceptional resistance to oxidation and rancidity. The oil-free meal is high in protein (34–50%), depending on the variety, and has a favorable amino acid profile with high methionine and low lysine content. Today the seed is used for human consumption on bread rolls, health food and confectionary.

Linseed

Due to its high iodine value, linseed oil has been used primarily for industrial purposes, such as linoleum floor covering, with a high level of unsaturated fatty acids making the oil very reactive and resulting in a short shelf life. Low linolenic acid cultivars have introduced linseed to the edible food market. In 1994, the Flax Council of Canada developed the term “Solin” to describe linseed with less than 5% linolenic acid. The original hybridization work was carried out by the CSIRO in Australia with the release of two Linola cultivars in 1992 under the Plant Varieties Rights Scheme. Linola 947 was the first Solin cultivar registered in Canada. Solin cv. Linola™ 989 has been reported as 46% oil (dry basis) and 34% protein. Linseed meal has a high crude protein value but low lysine levels. It also has a high level of soluble fiber, called mucilage that is indigestible to nonruminants and reduces the energy value of the meal. Linseed is traded at 40% oil although the oil can range significantly depending on growing conditions.

Safflower

Safflower was originally domesticated for its flowers: red carthamin dye was extracted for coloring food and cloth. Early cultivars were unsuitable for commercial development due to low oil content of ~30%. Breeding programs have since increased oil contents and altered the fatty acid profiles to take it from an industrial product to the edible oil market with modern cultivars containing 34% or more oil. Traditional high linoleic types contain ~68–83% linoleic acid and 8–22% oleic acid (Table 2). Through plant breeding, high oleic levels (70–84%) have been achieved. Due to the wide range of environmental conditions from countries as diverse as Australia, India, and China, fatty acids may vary considerably. The meal from safflower seed is also valued as a stock feed. The protein content of the meal remains relatively low in relation to other oilseeds at only 23%.

Mustard Seed

Typically mustard oil is high in erucic acid (20–50%) and the meal is high in glucosinolate compounds (50–150 μM g^{-1}), providing pungency to mustard for condiments but reducing the palatability of the meal for stock feed. With plant breeding, very low levels of erucic acid have been achieved and current aims are to develop cultivars that are more closely related to low erucic rapeseed cultivars, with increased oleic acid content.

Production and Trade

For the purpose of this article, fruit oils will not be discussed although it is significant. Palm oil fruit (from which comes the name palmitic acid) production in 2002 exceeded 136 Mt, second only to soybean. Oilseed yields from 1982 to 2002 are shown in Figure 1 and the area grown and yields of the various crops in 2001 and 2002 in Table 2.

Soybean

The global oilseed market is dominated by soybean with a total of ~180 Mt produced in 2002, making up almost 50% of the total oilseed production (Table 3). The United States of America produced 40%, with Brazil (23%), Argentina (17%), and China (9%) also producing significant amounts. Not unexpectedly, the United States is the largest exporter followed by Brazil and Argentina.

Cotton

Production of cotton in the last 20 years has gradually increased (Figure 1) with the result that cottonseed is the second largest oilseed crop despite its major purpose for textile use. China is the largest producer, with ~15 Mt per annum, together with the United States, India, and Pakistan. Australia is the leading exporter of cottonseed while Mexico, Spain, Japan, Italy, Korea, and United States are large importers.

Peanuts

A global peanut production of 35 Mt is led by China (14 Mt) with India (19%), Nigeria (8%), the United States (5%), and Indonesia (3%) also being significant producers.

Rapeseed

Rapeseed is currently rated in fifth position in world production of oilseeds with 33 Mt produced in 2002. There has been a continual decline from 1999 to 2002 (Figure 1) due partly to environmental conditions in leading producer countries. China is the largest producer of rapeseed with nearly one-third of the world

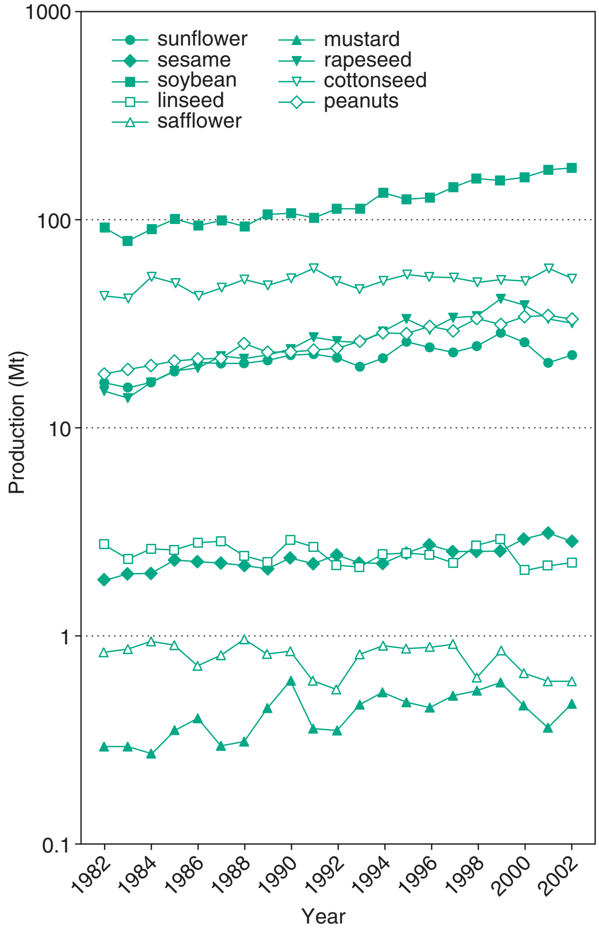

Figure 1 Global production of major oilseed crops ($\log_{10}$) from 1982 to 2002 in million tons (Mt). (Adapted from Food and Agricultural Organization of the United Nations Statistics.)

Table 3 World production of the major oilseed crops for 2001 and 2002

	Area harvested (Mha)		*Production (Mt)*	
	2001	*2002*	*2001*	*2002*
Soybeans	76	79	177	180
Cottonseed	34	32	61	54
Groundnuts	25	26	36	35
Rapeseed	22	23	34	33
Sunflower seed	18	20	21	23
Sesame seed	8	7	3	3
Linseed	3	3	2	2
Safflower seed	0.9	0.8	0.6	0.6
Mustard seed	0.5	0.6	0.4	0.5

Adapted from Food and Agricultural Organization of the United Nations Statistics.

production with India, Germany, France, and Canada also being major producers. Canada is the major exporter of rapeseed (canola) with exports of nearly 4 Mt in 2001, while France and Australia exported nearly 1.5 Mt each. Japan is the biggest importer of rapeseed (canola) importing over 2 Mt in 2001, with China (1.7 Mt), and Mexico (0.9 Mt) also being major importers.

Sunflower

Sunflower production has increased dramatically in the period between 1982 and 2002, from 16 Mt toward 25 Mt (Figure 1). Argentina has been the major producer of sunflower seed in recent years with 17% of the total global production. Ukraine was the major exporter in 2002 with 584 000 T. Other exporters included France, Russia, Hungary, USA, and Romania. Major importers include Netherlands, Spain, Germany, Turkey, Italy, and Portugal.

Sesame

World production of sesame seed is increasing, from 2–3 Mt between 1982 to 3.17 Mt in 2001. All but a small part of total world production is from developing countries including India, Sudan, Myanmar, and China. India and Sudan are the largest exporters of sesame. In 2001, Japan imported 148 000 t. Other major importers were Korea, Egypt, USA, and China.

Linseed

World production of linseed has shown a gradual decline since the 1980s despite a peak in 1999 of almost 3 Mt (Figure 1). The total production of 2.21 Mt in 2001 was the lowest level of production in the previous forty years. The major producers of linseed are Canada, China, USA, and India. Canada is the major exporter with over 600 000 T exported in 2001.

Safflower

Production of safflower has also fallen in the 1980s from ~900 000 t in 1985 to 600 000 t in 2002 (Figure 1). This may reflect the increased demand for monounsaturated oil in place of polyunsaturated oils. The major safflower producing countries are India, USA, and Mexico. The USA (21 812 t) and Australia (13 660 t) accounted for 72% of the world exports. Japan is a major importer.

Mustard

There has been a gradual increase in world production of mustard since the 1980s (Figure 1) from ~360 000 t in 2001 to 500 000 t in 2002. Major producers include Nepal, Canada, and Russia. In 2001, Canada exported 152 000 t of mustard while the Czech Republic, Germany, Russia, and Hungary were also significant exporters. Bangladesh was the major importer in 2001.

Future Developments

Oilseeds play an increasingly important role in society, both as an edible food product and for industrial uses. The benefits include the valuable oil component and the secondary but also useful meal, which provides a high energy and nutritionally important food. Breeders have been able to optimize the characteristics of many of these crops to achieve higher levels of production and to alter the products to suit specific requirements. These changes include improvements in nutritional value, particularly with changes in fatty acid profiles and the reduction in antinutritional components. Undoubtedly the biggest changes will come in the future from genetic modification in which long term breeding programs can be dramatically reduced to relatively short periods of time. Traditional, breeding techniques rely on natural variability in plant populations to achieve change. Genetic engineering can create new products previously out of the reach of established breeding techniques. Engineering plants for specific aims or more suitable to environmental conditions can increase production. Nutritionally, fatty acid profiles can be dramatically altered to reduce saturated and trans fatty acids and simultaneously improve oxidative stability. Vegetable oils are already being substituted, in many instances, for less environmentally friendly petroleum products. The major competition to oilseed crops in the future will only be from the ever-growing range of additional oilseed types.

See also: **Canola**: Agronomy. **Cottonseed**. **Peanuts**. **Soybean**: Agronomy. **Sunflower**.

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ORGANIC GROWING OF GRAINS

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Introduction

Organically grown foods are also called ecologically or biologically grown foods. Organic agriculture has become more popular over the years, being practiced in ~1–5% of farmed land of most countries. Organic agriculture is an alternative to the striking increase of synthetic fertilizers and pesticide, which has become necessary to maintain high-productivity crops even if it leads to environment impacts (i.e., water degradation). This alternative agricultural method represents a viable solution especially well suited for constrained and low-input conditions (i.e., climate, regulation). Nonetheless, it cannot be assured that organically grown foods are safer, healthier, or more nutritive than conventionally grown produce. However, organically grown cereal crops might contribute to human health, for example, because it does not spread toxic pesticides in the environment. This article describes organic growing of grains and its regulations. Potential advantages and limits of organic growing of grains are also presented.

Definition

Contrary to conventional agricultural practice, the concept of organically grown foods is an ethical or holistic concept based on naturalness, which involves:

1. the absence of synthetic inorganic chemicals (laboratory-made) for growing and processing crops, like fertilizers, pesticides or insecticides;
2. an agro-ecological, broad, and long-term approach throughout the food chain, including care for soil fertility, recycling of agricultural materials from in-site or community, energy preservation, stimulating the self-regulating capacity of the agro-ecosystem and care for water, soil, and air quality preservation; concepts such as genetically-modified organisms (for seeds and others) and irradiation are not acceptable, and
3. the integrity of living nature as a whole, not strictly focused on crop production but also on animal welfare, environment, and social impact; for example, avoidance of any process or practice that might endanger the health of agricultural workers and consumers, including minimal food processing.

A key issue in the overall sustainability of the organic farming systems, compared to nonorganic, is the financial viability. On arable systems, the financial situation is critical during conversion while specific