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OILSEED CULTIVARS DEVELOPED FROM INDUCED MUTATIONS AND MUTATIONS ALTERING FATTY ACID COMPOSITION

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ABSTRACT

One hundred and sixty-three cultivars of annual oilseed crops, developed using induced mutations, have been officially approved and released for cultivation in 26 countries. The maximum number of cultivars have been released in soybean (58), followed by groundnut (44), sesame (16), linseed (15), rapeseed (14), Indian mustard (8), castorbean (4), white mustard (3) and sunflower (1). The majority (118 of 163) of the cultivars have been developed as direct mutants and 45 of 163 by using the induced mutants in a crossing programme. While in soybean 53 out of 58 cultivars were selected as direct mutants, in groundnut 22 from 44 were developed after hybridization. Eighty-three cultivars were developed directly by exposing seeds to gamma or X-rays. Attempts have been made to infer the successful dose range, defined as the range which led to the development, registration and release of the maximum number of mutant cultivars for gamma and X-rays. The successful dose ranges in Gy for the main oilseed crops are: soybean 100-200, groundnut 150-250, rapeseed 600-800, Indian mustard 700 and sesame 100-200. The main characteristics of the new cultivars, besides higher yield, are altered plant type, early flowering and maturity and oil content. Mutants altering fatty acid composition have been isolated in soybean, rapeseed, sunflower, linseed and minor oil crops. New cultivars having altered fatty acid composition have been released in rapeseed, sunflower and linseed. The latter, previously grown for non-edible oil, has been converted to a new edible oil crop.

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INTRODUCTION

Oilseed crops, grown all over the world, are an important source of edible and non-edible oils and fatty acids [61]. Edible oils constitute an important component of the human diet. They provide a concentrated source of energy and serve as substrate for the biosynthesis of other molecules. The addition of vegetable oils, or their use as a cooking medium, makes other foods more palatable and tasty. There are strong regional preferences for the use of vegetable oils in food. Non-edible oils have been traditionally used to light lamps and as lubricants. In industry they are used for manufacturing soaps, cosmetics, paints, varnishes and coatings [30]. The use of vegetable oils for lighting and as lubricants declined with the availability of cheaper petroleum products. However, after the "oil crisis" of the seventies, there was considerable interest to develop vegetable oils as a renewable source of hydrocarbons and as "Biofuels" [42; 1]. The use of vegetable oils, as a renewable resource of starting material for industrial production, is being explored for agricultural diversification in food surplus regions. Soybean, cotton seed, sunflower, rapeseed and sesame are the major annual crops providing edible oils, while castorbean and linseed oil are the source of non-edible oils. Cotton is mainly grown for its fibre and is not included under oilseed crops. Coconut, oilpalm and olive are the perennial sources of edible oils. Polyploidy and mutations have played a significant role in the evolution of oilseed crops. In recent years, induced mutations have been extensively used for genetic enhancement of the annual oilseed crops, and specially to modify the fatty acid composition of *Brassica* species, sunflower, linseed and soybean [35]. The role of mutation breeding for quality improvement of oilseed crops was reviewed by [60]. Current information, on oilseed crop cultivars developed by using induced mutations, as well as mutants with significant changes in the fatty acid composition, is summarised in this review.

METHODOLOGY

The methodology followed is essentially similar to that developed by Kamra (personal communication,1997) for the cereals data base. The data included is based on the information appearing in the Mutation Breeding Newsletter Vol. 1 (May 1972) to Vol. 43 (October 1997) and in the records of the Plant Breeding and Genetics Section of the Joint FAO/IAEA Division.

Successful dose can be defined as the dose which led to the selection of mutants which will be directly released as mutant varieties. However, considering all the variables, it is advantageous to present a dose range which led to successful development of a maximum number of new cultivars. The potential sources of error are:

- Insufficient or incorrect information provided by the breeders responsible for developing the new cultivars
- Incorrect measurement of the radiation dose.

The dose in chemical mutagen treatments is much more complex. It is expressed as mutagen concentration x time (duration of soaking). Temperature, pH, post-treatment washing and soaking alter the actual mutagen concentration. Most breeders just mention the mutagen concentration without stating the duration of treatment. Hence, with the available information it is not possible to draw any conclusions regarding the successful dose.

OILSEED CULTIVARS DEVELOPED WITH THE HELP OF INDUCED MUTATIONS

Oilseed cultivars developed with the help of induced mutations are listed in Table 1. Crops and countries are in alphabetical order, while within a country the listing is based on the year of approval in an ascending order. A total of 163 cultivars have been released in 26 countries listed in Table 2. Data on the number of cultivars in each crop is summarised in Table 3. Maximum number of cultivars have been released in soybean (58), followed by groundnut (43), sesame (16), and linseed (15), rapeseed (14), Indian mustard (8), castorbean (4), white mustard (3) and sunflower (1). A number of medium and high oleic acid content hybrids have been developed by the seed companies in sunflower, however, the source of the trait could not be ascertained in the available information.

MUTAGENS USED TO PRODUCE NEW CULTIVARS

Mutagens used for the development of new cultivars are given in Table 3. Ninety-five cultivars have been developed using radiations, 45 using mutants in hybridization and 20 with chemical mutagen treatments. Considerable variation with respect to the use of induced mutations in the development of new cultivars is seen. In soybean 91% (53/58) of the cultivars have been developed as direct mutants and only five by using the mutants in crossing. In groundnut 50% (22/44) of the cultivars have been developed as direct mutants and the other half after using the mutants in crossing. In sesame, rapeseed and Indian mustard a majority of the new cultivars have originated as direct mutants. In linseed ten cultivars have been released utilizing two mutants that increase the linoleic acid content by decreasing the linolenic content of the oil. Gamma and x-ray treatment of seeds led to the development of 83/163 cultivars.

SUCCESSFUL DOSE RANGE OF GAMMA/X-RAYS

Successful dose can be defined as the dose which led to the selection of mutant which will be directly released as a new mutant cultivar. Successful doses for gamma and X-rays are listed in Table 4. The number of cultivars resulting from the dose in Gy are given in brackets. The successful dose range shows a wide variation for all crops. Successful dose ranges which can be used in future mutation experiments aiming at the development of new cultivars, are given. In soybean where 38 cultivars have been developed as direct mutants, following gamma or x-ray treatments, exposures between 100 - 200 Gy resulted in 18 cultivars. In groundnut exposure between 150 - 250 Gy resulted in 11 cultivars Both rapeseed and Indian mustard require higher doses close to 700 Gy.

CHARACTERS MODIFIED IN MUTANT CULTIVARS

The most frequent and other characters of the new cultivars are listed in Table 5. The most common improved traits of the new cvs, after higher yield, are altered plant type, early flowering/maturity and oil content. Mutations affecting fatty acid composition have been utilised for the development of new cultivars in rapeseed, linseed and sunflower. A number of other traits have also been altered in the mutant cultivars. These include increased resistance/tolerance to diseases and insect pests, pod shattering and seed coat colour. Low glucosinolates, low erucic acid and low linolenic acid have contributed to the development of "Canola" type rapeseed [60]. In linseed, fatty acid mutants have been utilised to develop "Linola" cultivars that yield edible oil suitable for human consumption with 65 to 76% of linoleic acid. The fatty acid composition of "Linola" oil is reported to be similar to the premium polyunsaturated oils such as sunflower, safflower and maize [8; 9]

MUTATIONS ALTERING FATTY ACID COMPOSITION

The first induced mutants altering fatty acid composition were reported by Rakow [53]. Mutants with reduced or increased levels of linolenic acid were isolated in rapeseed. This and subsequent research on induction of mutations for fatty acid composition were discussed by Röbbelen [60]. The role of induced mutagenesis in modification of the fatty acid composition has been reviewed recently by Velasco *et al*. [76]**.** A large number of mutants with altered fatty acid composition have been isolated in soybean (Table 6), sunflower (Table 7), *Brassica* species (Table 8), linseed/flax (Table 9), and in minor oil crops (Table 10). Several such mutant lines have been registered as germplasm. Induced mutants altering the fatty acid composition have been extensively used in the breeding programmes to develop new cultivars. However, it was not always possible to ascertain the source of the altered fatty acid character in the new cultivars or hybrids, especially those developed by the seed industry, and trace it back to the original mutant.

TABLE 1. Cultivars developed with the help of induced mutations in different oilseed crops

Name of new variety	Country and year of release	Mutagenic treatment or cross with mutant	Main improved attributes of the variety	Reference MBNL
***Arachis hypogaea* L. (groundnut)**				
Virginia No. 3	Argentina 1979	Gamma rays	Large pods; higher oil yield	30:20
Colorado Irradiado	Argentina 1972	X-rays, 200 Gy	Higher yield; higher oil content; better resistance to disease	7:13
Virginia No.5	Argentina 1980	Selected from segregating material from Florida	na	15: 9
Yueyou No. 22	China 1968	Cross: (Fushi x Fuhuasheng) Fushi is Beta ray induced mutant	Dwarf plant type; higher pod number and yield	19: 2
Yueyou No. 33	China 1971	Selection from Yueyou 22	Higher yield	37:20
Changua No. 4	China 1972	Gamma rays, 150 Gy recurrent irradiation	Early flowering; cold and drought tolerant; 'dense' pods	27:19
Yueyou 551	China 1972	Cross: Yueyou 22 x Yueyou 431	Dwarf type; larger number of pods, higher yield	25: 9
Yueyou 551-38	China 1975	Selection from Yueyou 551	Higher yield	37:21
Yueyou 551-116	China 1975	Selection from Yueyou 551	Higher yield; 6.6 to 12.8 % over Yueyou 551	37:21
Yueyou 551-6	China 1975	Selection from Yueyou 551	Higher yield; large pods;	37:21
Yangxuan 1	China 1978	Cross: Yueyou 1 x Yueyou 551	na	37:20
Yuexuan 58	China 1978	Selection from Yueyou 551	Higher yield, 8.5% over Yueyou 551	37:21
Yueyou 169	China 1980	Cross: Yueyou 551-6 x 76/30	Luxurious growth; large and thick dark leaves,large pods; 5.6% higher yield over Yueyou	37:21
Yueyou 187	China 1981	Cross: (Yueyou 1 x Yangxuan 1) x Yueyou 551	Relatively tall; more flowers; large pods; 9-10% higher yield over Yueyou 551	37:21

Yueyou 187-93	China 1982	Cross: (Yueyou 1 x Yangxuan 1) x Yueyou 551	Relatively tall; more flowers and large pods; 9-10%, higher yield over Yueyou 551	37:21
Lainong	China 1984	Laser, seed	Early maturity, higher yield	37:19
Shanyou 27	China 1985	Cross: Yuexuan 58 x Yueyou 320-14	Uniform emergence, many branches; thin shell, rust resistance; 10% higher yield over Yueyou 551-116	37:20
Xianghua No. 1	China 1985	Cross: Yueyou 551 x Furong	Early maturity, yield	41:24
Fu 22	China 1985	Gamma rays	Resistance to *Aspergillus flavus* causing aflatoxin development	37:19
Fu 21	China 1985	Gamma rays, 200 Gy	Short stem; more branches; higher yield; better resistance to bacterial wilt	29:20*
P-12	China 1986	Cross: (Changda 6 x ma 143) x Baisa 1016	Higher yield, reduced plant height, greater peg strength	37:20
Luhua 6	China 1986	Gamma rays, 240 Gy	13.6% higher yield; and 10 days earlier than parent variety	34:26
Luhua No. 7	China 1986	Gamma rays	Improved lodging, water logging and vertical plant type; large pods shattering resistance; medium maturity;	32:19
78961	China 1988	Cross: ma143 x RH77-4-2	Early maturity; reduced plant height	37:19
Ganhua No. 1	China 1990	Gamma rays, 200 Gy	Early; higher yield	41:23
8130	China, 1993	Gamma rays 250 Gy, Cross: (Luhua 4 RP1) x RP1	High yield; good flavour; export quality	44:
Luhua 13	China 1994	Cross: involving Luhua 6	High yield; seed shape; leaf colour.	44:
Luhhua 15	China 1997	Gamma rays; 250 Gy Cross (7896 x Runner) x irradiated Runner M1	High yield; maturity, improved seed quality	44:
Huaya 16	China, 1999	Gamma rays, 250 Gy	Higher yield and shelling percent, wider adaptability	44:
MH-2	India 1973	na	Higher yield; semi-dwarf; resistant to *Cercospora personata*	37:20
TG 3	India 1973	X-rays, 150 Gy	Higher yield; more pods per plant	3:11
TG 1 (Vikram)	India 1973	X-rays, 150 Gy	Large pods and kernels; suitable for HPS export	3:11

TG 14	India 1976	Inter mutant cross	Uniform maturity; higher yield under irrigation	12:15
TG 17	India 1977	Inter mutant cross	Higher yield; short plants; no secondary branches	12:15
BP-2	India 1979	Gamma rays, 450 Gy	Higher yield; semi-erect; gigas type; large kernels	32:19
BP-1	India 1979	Gamma rays, 450 Gy	Higher yield; semi-erect; large kernels	32:19
Co-2	India 1985	EMS, 0.2%	Higher yield; and shelling percentage; resistance to Tikka disease	26:12
TAG 24	India 1989	Cross: (TG 18A x M-13) x (line x TG-9)	Higher yield; resistance to bud necrosis	41:24
Somnath	India 1989	Cross: TG 18A x M-13	Early; large kernel size; higher oil content	41:24
TG 26	India 1996	Cross involving mutant derivatives	Semi-dwarf plant type; early maturity; higher HI; seed dormancy; field tolerance to major diseases	43:25
Sin Padetha	Myanmar 1982	Gamma rays, 400 Gy	10-15 days early	20:16
ANK-G1(Tissa)	Sri Lanka 1995	Gamma rays, 200 Gy	Higher yield; low input requirements	43:39
N.C. 4-X	USA 1959	X-rays	High yield; tough hulls resists damage during harvest and transport; good quality	3: 7
B 5000	Vietnam 1985	Gamma rays, 50Gy	Vigorous growth; early maturity; higher shelling percentage; white testa	31: 9
***Brassica juncea oleifera* (Indian mustard)**				
Shambal (BAU-M/248)	Bangladesh, 1984	EMS 0.64%	13.6% higher yield, 10 days early	34:27
Agrani	Bangladesh, 1991	Gamma rays 700 Gy	Earliness, blight resistance	42:26
Safal	Bangladesh, 1991	Gamma rays 700 Gy	Yield, oil content, blight resistance	42:27
RLM 198	India, 1975	Radiation	Increased yield and oil content	7:13
RLM 514	India, 1980	Gamma rays	Yield, large seed size. early maturity, high oil content, shattering resistance	17:13

RL 1359	India, 1987	Cross: RLM 514 x Varuna	Short duration, high yield, large seed size erect plant type, relatively more tolerant to aphids	31:11
TM-2	India, 1978	X-rays 750 Gy	High yield, pod architecture	43:39
TM-4	India, 1978	Cross: Varuna x TM-1	Seed coat colour, high yield and oil %	43:39
***Brassica* sp. (white mustard)**				
Svalof's Primex	Sweden, 1950	X-rays 350 Gy	Higher seed yield and oil content	IAEA, 1974
Seco	Sweden, 1961	Cross: Primex x Rumanian white mustard	Yield, crude fat, early maturity, stalk stiffness, resistant to shattering	6:14
Trico	Sweden, 1967	Selection from Primex	Increased seed yield and oil content over Primex	6:14
***Brassica napus* (rapeseed)**				
Binasharisha-3	Bangladesh, 1997	Gamma rays 800 Gy	Early maturity, high seed and oil yield44:	
Binasharisha-4	Bangladesh, 1997	Gamma rays 700 Gy	Early maturity, high seed and oil yield44:	
Stellar	Canada, 1987	Cross: (Mil x Regent) x Regent Mil = EMS induced mutant of Oro	Linolenic acid 3%, linoleic acid 28%, low erucic acid, and low glucosinolates	33:22
Appollo	Canada, 1993		Linolenic acid content 1.7%, shorter hydrogenation time, greater stability higher yield over Stellar	CJPS, 75:203
Ganyou No. 5	China, 1984	Gamma rays, 1400 Gy	Short plant height, longer inflorescence, and siliqua, larger siliqua diameter growth period reduced by 10-20 days, resistance to white rust and *Sclerotinia*	32:20
Huyou No. 4	China, 1970	Gamma rays, 600 Gy	Cold tolerant, disease resistance, higher and stable yield	27:19

Xinyou No. 1	China, 1979	Gamma rays 700 Gy	Good seedling growth, tight stature tolerant to cold, drought, salinity and alkaline soils, good quality	27:19
Xiuyou No. 1	China, 1979	Gamma rays 80 Gy, F_1 seed	Early maturity, disease and cold resistance suitable for rice-rice-rape multiple cropping	32:20
Hua-Yellow No. 1	China	Gamma rays	Viability	41:25
Abasin 95	Pakistan, 1996	Gamma rays 1400 Gy	Early flowering	44:
Regina varraps elite A	Sweden 1953	X-rays, 350 Gy	Higher seed yield and percent oil	IAEA 1974
Regina varraps elite F	Sweden 1962	X-rays, 450 Gy	Higher seed yield and percent oil	IAEA 1974
Tismenitskii	USSR, 1989	DMS 0.006%	Oil content, disease resistance	41:25
Ivana	USSR, 1990	MNH 0.0025%	Oil content, insect resistance	41:25
***Glycine max* L. (soybean)**				
Cerag No. 1	Algeria 1979	Gamma rays, 300 Gy	Mutant selected in 1974 in Romania by I. Nicolae; early; resistant to spring cold; very productive; drought resistant; short plant type; white flowers; yellow seeds	14:11
Nitrobean-60	Australia 1995	EMS 1%, 6 h	Hyper nodulation; nitrogen carry over; nitrate tolerant nodulation	43:44
Boriana	Bulgaria 1981	Gamma rays 100 Gy + 1% EMS for 4 h	Maturing in 105-110 d; 30 d earlier; and 6% higher yield than parent cv Beeson; 5% higher protein	23:18
Zarya	Bulgaria 1984	Gamma rays 80 Gy	Early; high yield and protein content	32:23
Bisser	Bulgaria 1984	Gamma rays 100 Gy + EMS 0.1%	High yield, and protein content; early; stem resistant to lodging	31:20
Tainung No. 1	China(Taiwan) 1962	Thermal neutrons	Vigorous variety with less pod shedding tendency; long branches; higher yield	3:34

Tainung No. 2	China(Taiwan) 1962	X-rays	Vigorous variety with less pod shedding tendency; short internodes; large seeds; adaptable to acid or alkaline soils	3:34
Heinoun No. 4	China 1967	Gamma rays 100 Gy	Compact; branched type	25:10
Heinoun No. 5	China 1967	Gamma rays 100 Gy	Good root system; short internodes, larger number of branches and pods	25:10
Heinoun No. 7	China 1967	Gamma rays; 100Gy	Higher branch number; short internodes; drought tolerance; wide adaptability	25:10
Heinoun No. 8	China 1967	Gamma rays, 100 Gy	10 days earlier than the parent cv. Dongnoun No.4; humidity tolerance	25:10
Heinoun No. 6	China 1967	Seeds, Gamma rays, 10O Gy	Tall plants; tolerance to drought	27:20
Fengshou No. 11	China 1970	Gamma rays, 140 Gy	Matures 30 days earlier than parent; strong stem; resistance to lodging; large number of branches	27:20
Heinoun No. 16	China 1970	Gamma rays, 100 Gy	Large number of branches; short internodes tolerance to drought; wide adaptability	25:11
Tiefeng 18	China 1970	Gamma rays, 120 Gy	Suitable for high fertility soils; lodging resistance higher yield; good quality	25:11
Heinong No. 26	China 1975	Cross: HAR 63-2294 x Xiaojinuang No.1	Good stature; tolerant to cold, drought, and water logging; good quality	25:11
Mushi No. 6	China 1980	Gamma rays, F_2 (Fengshou No.10 x Jilin No.3)	Early maturity; lodging resistance; strong plants higher yield; better quality	25:11
Liadou No. 3	China 1983	Gamma rays, (6405 x Amuson)	Early maturity; strong stem; resistant to lodging; virus and *Sclerophotora macrospora*; tolerant to water logging	27:20
Wei 7610-13	China 1983	Gamma rays and fast neutrons	Maturity 6 d earlier; resistant to sporotrichosis; 20% increase in yield	32:23
Heinong 28	China 1986	Seeds, thermal neutrons, 5×10^{11} n/cm^2 (Heinong No. 16 x Zyuushoo Nagaka)	Growth period 121 d; strong stem; higher yield; good quality; protein 38.7%; fat 21.3%	30:21

Heilong 32	China 1987	Thermal neutrons, 5×10^{11} thn/cm^2, dry seeds (F_4 of Har 70-5072 x Har No. 53)	High yield; resistant to virus; drought tolerant; good adaptability; 22.8% fat; 40.7% protein	32:22
Heilong 31	China 1987	Thermal neutrons 5×10^{11} thn/cm^2, F_4 (Har 70-5072 x Har No. 53)	Tolerant to diseases and drought; high yield; growing period 119 d; TGW 180 g; 41.4% protein; 23.2% fat.	32:22
Heinong 34	China 1988	Cross: Heinong 16 x Tokachinogaha	High yield, high protein	44:
Liaonong 1	China 1988	Gamma rays, 200 Gy; F_2 seeds of [Heinong 11 x Tieefeng 9]	7-10 days earlier; 10% higher yield than check cv. “Heihe 3”	34:29
Fengdou	China 1988	Gamma rays; 200 Gy; F_2 (Qunxuan 1 x Qun Ying Dou) x Tiefeng 9]	110-120 d till maturity	34:29
Heinong 35	China 1990	Cross: Hei Nong 16	High yield, high protein content	44:
Sui Nong 12	China 1996	Gamma rays, 120 Gy	Increased yield	44:
Heinong 41	China 1997	Cross: mutant x mutant	Increased yield, large seed size, tolerance to alkaline soils	44:
Aida	CSFR 1984	Seeds, EMS	Matures 10 days earlier than Dunajka (140 days)	26:13
Dorado	GDR 1988	Seeds, NMH 1mM	Higher grain yield; longer stem; higher insertion of the lowest pod	34:29
Noventa	Hungary 1989	Gamma rays, 100-300 Gy	Extremely early	41: 8
Muria	Indonesia 1987	Gamma rays, 200 Gy	High yield; short stature; better lodging resistance	35:35
Tidar	Indonesia 1987	Selection from gamma ray induced mutant G-2120 from AVRDC	Early maturity (7 d); high yield; yellowish green seed coat colour	35:35
Tengger	Indonesia 1991	Gamma rays, 200 Gy	Earliness; eating quality; seed colour	42:27
Raiden	Japan 1966	Gamma rays, 100 Gy	Earlier maturity; shorter stem; resistance to lodging; maintains high yield and nematode resistance of the parent cv	6: 8
Raiko	Japan 1969	Gamma rays, 10 Gy	Early maturity; short stem; resists lodging; higher yield; maintains nematode resistance of the parent cv Nemashirau	IAEA 1986

Nanbushirome	Japan 1977	Raiden x Kitaminagaha	Intermediate maturity; long leaves; high yield; resistant to cyst nematode	12:13
Wase-suzunari	Japan 1983	Gamma rays, 100 Gy	Very early; maintaining good quality and high yield of parent cv Okushirome	32:23
Kosuzu	Japan 1986	Gamma rays, 100 Gy	Early; lodging resistance; maintaining most of the other characters of parent cv Natto-Kotubu	32:22
Ryokusui	Japan 1990	Gamma rays, 200 Gy	Lateness; eating quality	42:27
KEX-2	Rep. of Korea 1973	X-rays, 240 Gy	Early maturity; 11 days early; higher yield (16%); large seed size	4:14
Bangsa-Kong	Rep. of Korea 1985	Seeds, X-rays, 250 Gy	High yield due to large number of pods; smaller seed size for good soybean sprout; resistant to soybean virus N	26:13
Doi Kham	Thailand 1986	Gamma rays, 300 Gy	High resistance to rust (*Phakospora pachyrrhizi*);15% higher yield than the parent SJ4 in rainy season with rust incidence; larger seed size	33:24
TAEK C10	Turkey 1994	Gamma rays, 100 Gy	Oil content; earliness; yield	43:45
TAEK A3	Turkey 1994	Gamma rays, 200 Gy	Yield; protein; pod position	43:45
Universal 1	USSR 1965	Gamma rays	Lodging resistance; can be used as grain crop or as green fodder. Surpasses initial variety by 500 kg/ha in grain yield	19:14
Chudo Gruzil 7	USSR 1974	Gamma rays	na	37:25
Dioskuriye	USSR 1980?	Gamma rays	na	37:25
Kartuli 7	USSR 1980?	Gamma rays	na	37:25
Mutant 2	USSR 1980?	Gamma rays	na	37:25
Arkadiya Odes	USSR 1986	DMS, 1mM, seeds	Early ripening; good for rainfed conditions	31:20
Luchezarnaya	USSR 1990	MNH	Earliness	40:13
Paripatskaya	USSR 1991	ENH, 0.125%	Disease resistance - bacteriosis, ascochytosis and peronosis	40:13
Mageva (Lastochka-out)	USSR 1991	Chemical mutagen	Earlyness; disease resistance	40:13
DT 83	Vietnam 1987	EI, 0.04%	Seed colour; yield	43:44

DT 90	Vietnam 1993	Gamma rays, 180 Gy F_1 from (G7002 x Cocchum)	Yield; protein content	43:44
DT 84	Vietnam 1994	Gamma rays, 180 Gy F_1 from(DT-80 x DH-4)	Yield; cold tolerance	43:44
S-31	Vietnam 1995	Gamma rays, 180 Gy +EI 0.04%	Yield; cold tolerance	43:44
***Helianthus annuus* L. (sunflower)**				
Pervenets	USSR, 1977	DMS	High oil content, altered fatty acid composition	13:20
***Linum usitatissimum* L. (flax, linseed)**				
Wallaga	Australia, 1992	Chemical mutagen treatment: two mutants with reduced linolenic acid crossed to isolate double mutant <u>Zero</u> x Croxton	Linola* type, low linolenic acid, yellow seed coat color	Green and Dribnenki, [19]
Eyre	Australia, 1992	<u>Zero</u> x Glenelg	Linola* type	Green and Dribnenki, [19]
Argyle	Australia, 1994	<u>Zero</u> x	Linola* type	Green and Dribnenki, [19]
Linola 947	Canada, 1993	McGregor/<u>Zero</u>//CPI 84495/3/ McGregor	Linola* type	Dribnenki and Green, [8]
Linola 989	Canada, 1993	McGregor/<u>Zero</u>//CPI 84495/3/ McGregor	Linola* type	Dribnenki *et al.* [9]
Redwood 65	Canada, 1965	X-rays	Oil content	5:13
Dufferin	Canada, 1979	Cross: <u>Redwood 65</u> x (4013 x Raja)	Similar to Redwood 65 with higher oil content and better resistance to *Melampsora lini*	18:17
Heiya No. 4	China, 1978	Cross of Gamma ray induced mutant x 6409-640	Early maturity, resistant to lodging tolerant to moisture, salinity and alkalinity	27:20

Ningya No. 10	China, 1982	Gamma rays 100 Gy	Early maturity, good branching, lodging high yield, and quality	29:20 32:26
Heiya No. 6	China, 1984	Cross: r7107-2-4 x r7005-21-6-7	High yield, lodging, disease, salt and alkali resistance	32:26
Coniston	UK, 1992	As for Wallaga	Linola* type	Green and Dribnenki, [19]
Derwent	UK, 1992	As for Wallaga	Linola* type	Green and Dribnenki, [19]
Zarya 87	USSR, 1984	Ethylamine	Late flowering, high yield	31:26
Baltyuchai	USSR, 1991	ENH 0.012%	Disease and lodging resistance	41:27
M-5	USSR, 1991	DMS 0.05%	Disease and lodging resistance	41:27
***Ricinus communis* L. (castorbean)**				
Aruna	India, 1969	Thermal neutrons 1400 rad	Very early maturity 120 days versus 270 of the parent cv.	IAEA 1974
Sowbhagya (157-B)	India, 1976	Cross: Aruna x dwarf mutant of HC-6 x dwarf mutant of HC-6 x Mauthners dwarf	Long duration, dwarf type, non-shattering, suitable for inter-cropping	11:17
RC8	India, 1978	Gamma rays, 400 Gy	Growth period longer than Aruna; higher TKW	16:18
Khersonskaya 10	USSR, 1981	Chemical mutagen	Oil content, yield	41:29
***Sesamum indicum* L.(sesame)**				
Ningya No. 10	China, 1982	Gamma rays 100 Gy	Early flowering, branchy, resistant to lodging, good quality	27:24
Cairo White 8	Egypt, 1992	Gamma rays 200 Gy	Non branching, capsule number, seed colour	42:34
Sinai White 48	Egypt, 1992	Gamma rays 200 Gy	Seed colour, capsule number, wilt resistance	42:34
Kalika (BM 3-7)	India, 1980	EMS	Dwarf plant type	17:14

UMA	India, 1990	Chemical mutagen, 10% Arsenic-Q	Uniform, early maturity, oil content	43:53
USHA	India, 1990	Chemical mutagen, 10% 10% Arsenic-Q	Yield, uniform maturity, disease resistance	43:53
Babil	Iraq, 1992	Gamma rays, 50 Gy	Earliness, oil content	43:52
Eshtar	Iraq, 1992	Gamma rays, 40 Gy	Capsule size, habit, oil content	43:52
Rafiden	Iraq, 1992	Gamma rays, 40 Gy	Earliness, oil content	43:53
Ahnsanggae	Korea, 1984	Gamma rays	Disease resistance	29:26
Suwonkkae	Korea, 1992	Cross: Kyum (local) x ME-93-4	Protein content, lodging and disease resistance	42:34
Suwon 155	Korea, 1998	Gamma rays, 200 Gy	High oil quality, yield	44:
Yangbaeckkae	Korea, 1995	NaN3, 2mM; 3hrs	Oil quality and yield	42:34
Pungsankkae	Korea, 1996	Cross: dt-45 x Hansumkkae (dt-45 mutant from Israel with determinate growth habit)	Determinate growth, seed retention	43:52
Seodunkkae	Korea, 1997	NaN3	Disease resistance	44:
ANK-S2	Sri Lanka, 1995	Gamma rays, 200 Gy	Disease resistance, yield	43:52

* Linola is a trade mark for a new form of linseed that has been bred to produce an oil suitable for human consumption developed by the Commonwealth Scientific and Industrial Research organization (CSIRO), Australia and United grain growers of Canada. Yellow seeded Linola types are designated as Solin types in Canada. CJPS = Canadian Journal of Plant Sciences

TABLE 2. Cultivars of oilseed crops developed with the help of induced mutations in different countries

Country	Released mutant cultivars
Algeria	1
Argentina	3
Australia	4
Bangladesh	5
Bulgaria	3
Canada	6
China	58
CSFR	1
Egypt	2
GDR	1
Hungary	1
India	22
Indonesia	3
Iraq	3
Japan	6
Korea	8
Myanmar	1
Pakistan	1
Sri Lanka	2
Sweden	5
Thailand	1
Turkey	2
UK	2
USA	1
USSR	16
Vietnam	5

TABLE 3. Mutagenic treatments used for the development of cultivars in oilseed crops

Species	Total No. of cultivars	As direct mutants induced by:						Using induced mutations in crossing program
		Gamma or X-rays	Neutrons	Radiations not specified	Chemical mutagens	Radiations plus chemical mutagen	Others	
Arachis hypogaea	44	18		2	1		1 (laser)	22
Brassica spp.	3	2						1
Brassica juncea	8	4		1	1			2
Brassica napus	14	10		2				2
Glycine max	58	38	5		8	2		5
Helianthus annuus	1				1			
Linum usitatissimum	15	2			3			10
Ricinus communis	4	1	1		1			1
Sesamum indicum	16	9			5			2

Total number of cultivars may be higher than the sum of the figures given under each due to incomplete information

TABLE 4. Successful gamma or x-ray doses used for the development of cultivars in different oilseed crops

Crop species	No. of cvs. developed using gamma or x-rays	Successful doses in Gy (No. of cultivars)	Successful dose range in Gy
Arachis hypogaea	18	50(1); 150(3); 200(5); 240 (1); 250(2); 400(1); 450(2)	150-250(11)
Brassica spp.	2	350(1)	
Brassica juncea	4	700(2); 750(1)	700 (2)
Brassica napus	10	350(1); 450(1); 600(1); 700(2), 800(1); 1400(2)	600-800(4)
Glycine max	38	80(1); 100(11); 120(2); 140(1); 200(4); 240(1); 250(1); 300(2)	100-200(18)
Helianthus annuus	nil		
Linum usitatissimum	2	100(1)	
Ricinus communis			
Sesamum indicum	8	40(2); 50(1); 100(1);200(3)	100-200(4)

Successful dose used is not known for some cultivars. Therefore the total number of cultivars in columns 2 and 3 are not the same

TABLE 5. Most frequent and other characters of the cultivars obtained in different oilseed crops using induced mutations

Crop species	Most frequent characters, after yield*	Other characters
Arachis hypogaea	Plant type, large pods and kernels, early flowering HI, and maturity	Higher shelling percentage, thick or thin pod cover, higher resistance/tolerance to diseases, oil content
Brassica spp.	Oil content, plant type	Early maturity, stalk stiffness
Brassica juncea	Early maturity, oil content	Seed coat colour, large seed size, blight resistance, relative tolerance to aphids, pod architecture, pod shattering
Brassica napus	Oil content, plant type, early flowering/ maturity	Siliqua characters, tolerance to cold, drought, salinity, low linolenic acid, low erucic acid, low glucosinolates
Glycine max	Plant type, early flowering / maturity	Seed size, seed coat colour, non-shattering pods, hyper-nodulation, nitrate tolerance, root system, disease resistance, cold and drought tolerance, oil and protein content
Helianthus annuus	Higher oil content, altered fatty acid composition	
Linum usitatissimum	Early maturity, resistance to stress conditions, higher oil percent	Resistance to lodging, oil quality
Ricinus communis	Early maturity, plant type	Non shattering pods, oil content
Sesamum indicum	Plant type, branching pattern, early flowering	Capsule size and number, seed coat colour, disease resistance, lodging resistance, oil content

* All new cultivars are approved on the basis of their higher yield.

TABLE 6. Fatty acid mutants in soybean

Parent cultivar; mutagen used; mutated gene	Main characteristics	Reference
	Palmitic acid (16:0)	
Parent A1937 NMU	Palmitic acid, 12.1%	
A1937NMU-85 **(A21)** *fap2-B*	Palmitic acid >180 g/kg	Fehr *et al.* [11] Schnebly *et al.* [64]
NMU173 (**A22**) *fap3*	Palmitic acid, 7.7%	Fehr *et al.* [12] Schnebly *et al.* [64] Hartman *et al.* [23]
Parent Elgin EMS	Palmitic acid, 110 g/kg	
ElginEMS421**(A24)** *fap4*	Palmitic acid >180 g/kg	Fehr *et al.* [12] Schnebly *et al.* [64]
A18 (A22 x C1726)	Palmitic acid <40 g/kg[1], increase in oleate. Low palmitate content in roots, leaves and stem	Fehr *et al.* [12] Schnebly *et al.* [64]
A19 (A21 x A24)	Palmitic acid >250 g/kg, decrease in oleate and linoleate, high palmitate content in vegetative parts	Schnebly *et al.* [64]
A24 *fap4 fap4*	High palmitic acid, 17.9%	Schnebly *et al.* [64]
ELLP2 *fap*	Low palmitic acid, 6.9%	Stojsin *et al.* [66]
ELLP2 x C1762 *fap fap1*	Low palmitic acid, 4.4%	Stojsin *et al.* [66]
Parent Bay X-rays (210 - 250 Gy)	Palmitic acid, 11.4%	 Takagi *et al.* [71]
J3 *sop1*	Reduced palmitic acid, 5.3%	Takagi *et al.* [71]
J10 *sop2*	Elevated palmitic acid, 16.0%	Takagi *et al.* [71]

Parent Century EMS	Palmitic acid, 11.2%	
C1726 *fap1*	Palmitic acid, 8.5%	Erickson *et al.* [10] Wilcox and Cavins, [83] Schnebly *et al.* [64]
C1727 *fap2*	Increased palmitic acid, 17.7%	Wilcox and Cavins, [83] Nickell *et al.* [36] Fehr *et al.* [12]
A22 x C1726	Low palmitic acid, 4.4%	Fehr *et al.* [11]
(AX5152-34) *fap1 fap3*		Horejsi *et al.* [25]
A22 x C1726 **(AX5152-105)** *fap1 fap3*	Low palmitic, 4.4%	Fehr *et al.* [11] Horejsi *et al.* [25]
Parent FA26315 EMS	Palmitic acid, 9.3%	
PA1	Increased palmitic acid, 15%	Bubeck *et al.* [5]
Parent FA47437 EMS	Palmitic acid, 10%	
PA2	Increased palmitic acid, 13.5%	Bubeck *et al.* [5]
Parent FA47451 EMS	Palmitic acid, 9.0%	
PA3	Increased palmitic acid, 15.5%	Bubeck *et al.* [5]
Parent FA 27019 EMS	Palmitic acid, 9.0%	
PA4 (genes not determined)	Increased palmitic acid, 13.7%	Bubeck *et al.* [5]
	Stearic acid (18:0)	
Parent FA8077 Sodium azide	Stearic acid, 4.4%	
A6 *fas*[a]	High stearic acid, 28.1%	Hammond and Fehr, [22]
Parent Coles EMS	Stearic acid. 4.3%	
FA41545 (A10) *fas*[b]	High stearic acid, 15.5%	Graef *et al.* [17]

Parent FA9886 EMS	Stearic acid, 3.2%	
A81-606085 **(A9)** *fas*	High stearic acid, 18.7%	Graef *et al.* [17]
Parent FA26625 EMS	Stearic acid, 5.1%	
ST1	High stearic, 28.7%	Bubeck *et al.* [5]
Parent FA 47394 EMS	Stearic acid 3.8%	
ST2	High stearic acid, 27.7%	Bubeck *et al.* [5]
Parent FA 47445 EMS	Stearic acid 3.5%	
ST3	High stearic acid, 23.5%	Bubeck *et al.* [5]
Parent FA47437 EMS	Stearic acid, 3.3%	
ST4	High stearic acid, 22.9%	Bubeck *et al.* [5]
Parent Bay X-rays (210-250 Gy)	Stearic acid, 3.3%	
M25 st_2	High stearic acid, 17.3%	Rahman *et al.* [49] Rahman *et al.* [47]
KK2 st_1	High stearic, 6.6%	Rahman *et al.* [47]
	Oleic acid (18:1)	
Parent Bay, *Ol* X-rays (210-250 Gy)	Oleic acid, 22.5%	
M11 ol^a	High oleic acid >300g/kg allele dominant over *ol* of M23 *Ol* allele of Bay completely dominant over ol^a	Rahman *et al.* [46]
M23 *ol*	High oleic acid, 46.1% *Ol* allele of cv. Bay partially dominant over *ol*	Rahman *et al.* [48] Rahman *et al.* [46] Takagi and Rahmam, [72]
	Linolenic acid (18:3)	
Parent Bay, *Lin* X-rays (210 - 250 Gy)	Linolenic acid, 8.3%	
M5(M923) *fan(M5)*	Low linolenic acid, 4.8%, yield similar to Bay	Takagi *et al.* [70] Rahman *et al.* [51] Rahman *et al.* [44] Rahman *et al.* [43]

IL-8 *fan(IL-8)*	Low linolenic acid, 4.50%	Rahman *et al.* [50]
M24 *fanxa (M24)*	Lower linolenic acid 62 g/kg, 80-90 g/kg of Bay	Rahman *et al.* [43] Wasala *et al.* [80]
M5 x M24 *fan(M5) fanxa*	Linolenic acid, 2.4%	Rahman *et al.* [43]
B739 lin^{h}	High linolenic acid, 18.4% compared to 9.4% in Bay	Rahman *et al.* [52] Takagi *et al.* [69]
KL8 *fanx(KL8)* 1997	Low linolenic acid (6.5%)	Rahman and Takagi [45] Rahman *et al.* [43]
M5 x KL8 *fan fanx(KL8)*	Low linolenic acid segregants from the cross 1997	Rahman and Takagi [45]
Parent C1640 EMS	Linolenic acid, 4.3%	
RG10 mutation at *Fan* locus	Low linolenic acid, <25 g/kg shows additive gene action with *fan* allele from C1640	Stojsin *et al.* [67]
Parent Century EMS	Linolenic 8.0%	
C1640 *fan* (C1640)	Low linolenic, 3.8% Inherited as quantitative trait when crossed to PI479750 (*FanFan*); close to RFLP marker pB194-1 and PB124 on linkage group B2	Wilcox and Cavins, [82] Erickson *et al.* [10] Wang *et al.* [79] Nickell *et al.* [36] Wilcox *et al.* [84] Brummer *et al.* [4]
	Linkage group 17, *Fas-Fan-Idh2*	Rennie and Tanner, [54, 55, 56]
	21.6 $\pm$ 1.7 units from *Fas* 26.2 $\pm$ 1.2 units from *ID2*	Rennie *et al.* [57]
Parent 9525 EMS	Linolenic acid 6.2%	
A5(M923)	Low linolenic acid, 4.1%	Hammond and Fehr, [21]
	Low in linoleic and linolenic, and high in oleic	Hildbrand and Pfeiffer, [24]
	DNA encoding omega-3 fatty acid desaturase gene is missing	Byrum *et al.* [7]

Parent A5

A6	Linolenic acid lower than A5	Fu, [16]
A16 (A5 x A23) *fan* (A5) *fan3*(A23)	Low linolenic acid <25 g/kg continuous distribution, quantitative character	Fehr *et al.* [13]
A17 (A5 x A23) *fan* (A5) *fan fan3*(A23)	Low linolenic acid <25 g/kg continuous distribution, quantitative character	Fehr *et al.* [13]
A23	Low linolenic acid 5.6%	Fehr *et al.* [13]
C1640	Low in linolenic, high linoleic	Wilcox and Cavins, [81]
LOLL	2.7% linolenic acid, yield reduction	Wasala *et al.* [80]
MS382	2.7% linolenic acid, yield reduction	Wasala *et al.* [80]
MOLL (Kl8 x M5)	3.7% linolenic acid	Wasala *et al.* [80]
GLLA (*fan fan*)	Low linolenic acid	Renie *et al.* [57]
N83-375	5.5% LNA	Mounts *et al.* [33]
N89-2009	2.9% LNA	Mounts *et al.* [33]
N85-2176	1.9% LNA	Mounts *et al.* [33]

Registered germplasm with changes in fatty acid composition

A5	Low linolenic acid, 4.1%, compared to 6.3% of the parent, EMS induced mutant	Hammond and Fehr, [21]
A6	High stearic acid 28.1%, and low oleic acid 19.8% compared to 4.4% and 42.8% of parent. Sodium azide induced mutant	Hammond and Fehr, [22]
C1726 (PI 532833) *fap1*	Palmitic acid, 8.5% EMS induced mutant of cv. Century	Wilcox and Cavins, [83]
C1727(PI 532834) *fap2*	Palmitic acid, 17.2% EMS induced mutant of cv. Century	Wilcox and Cavins, [83]
N79-2007-12 PI 568260	Reduced palmitic acid, 60 mg/g Derived from high oleic acid selection population	Burton *et al.* [6]
N87-2122-4	Reduced palmitic acid, 53 mg/g	Burton *et al.* [6]

PI568261	Derived from high oleic acid selection population	
BARC-12 PI578058	Low linoleic acid Selected from cross N85-2176 x N852124	Leffel, [29]
N94275 PI1602455	Palmitic acid, 40 g/kg	Burton *et al.* [6]
C1943 PI599811	Palmitic acid, 40 g/kg	Burton *et al.* [6]

TABLE 7. Fatty acid mutants in sunflower

Parent cultivar; mutagen used; mutant gene	Main characteristics	Reference
	Palmitic acid (16:0)	
Parent Zarya Gamma rays	Palmitic acid 7.0% (check cv.)	
275HP	Palmitic acid 25.1%	Ivanov *et al.* [26]
Parent RHA 274 NMU/EMS		
RHA 274 LP1 *fap1*	Lower palmitic acid 47 g/kg	Vick and Miller, [77] Miller and Vick, [32]
Parent BDS 2-691, *P1 p2 p3* X-rays	Palmitic acid 5.4%	
CAS-5 *p1, p2, and p3*	High palmitic acid 25.2% two alleles at each locus with partial dominance of low palmitic. High palmitic types are homologous for *p1* and, at least, one of the other two	Osorio *et al.* [40] Perez-Vich *et al.* [41]
Parent BSD-2-423 X-rays	Palmitic acid 3%, oleic acid 88%	
CAS-12	High palmitic acid 30% Reduced oleic acid 56% High palmitoleic acid 7%	Fernandez-Martinez *et al.* [14] Anon. [2]
	Stearic acid (18:0)	
Parent HA 821 NMU/EMS		
HA821 LS-1 *fas1*	Low stearic acid, 41g/kg	Miller and Vick, [31]
Parent RHA 274 NMU/EMS	Stearic acid 3.8%	
M430	Stearic acid 2.0%	Vick and Miller, [77]
RHA 274 LS-2 *fasx fas2*	Low stearic acid 20g/kg	Miller and Vick, [31]

Parent RDF 1-532 EMS/NaN_3	Stearic acid 5.5%	
CAS-3	Stearic acid 26.0%	Osorio *et al.* [40]
CAS-4	Stearic acid 11.3%	Osorio *et al.* [40]
CAS-8	Stearic acid 9.9%	Osorio *et al.* [40]
	Oleic acid (18:1)	
Parent V1M1K-8931 DMS	Oleic acid 35.9%	
Pervenets	Oleic acid 79.3%	Soldatov, [65]
Parent HA 382 EMS/NMU	Oleic acid 18.9%	
M4229	Oleic acid 86.2%	Vick and Miller, [77]
Registered germplasm **RHA 274 (restorer)** NMU/EMS		
RHA 274(LP1)	Low palmitic	Miller and Vick, [32]
RHA 274 (LP2)	Low palmitic	Miller and Vick, [32]
HA821(maintainer) NMU/EMS		
HA 821 (LP1)	Low palmitic	Miller and Vick, [32]
RHA 274 (restorer) NMU/EMS		
RH274 (LS1)	Low stearic	Miller and Vick, [31]
RH274 (LS2)	Low stearic	Miller and Vick, [31]
HA382 (maintainer) NMU/EMS		
HA 382 (LS1)	Low stearic	Miller and Vick, [31]
HA 382 (LS2)	Low stearic	Miller and Vick, [31]
HA 821 (maintainer) NMU/EMS		
HA 821 (LS1)	Low stearic	Miller and Vick, [31]

TABLE 8. Fatty acid mutants in *Brassica* species

Parent cv. mutagen used mutant gene	Main characteristics	Reference
Brassica napus		
	Palmitic acid (16:0)	
Parent Wotan EMS	Palmitic acid 4.7%	
M4963	Palmitic acid 9.0%	Rucker and Röbbelen, [63]
	Oleic acid (18:1)	
Parent Cascade EMS	Oleic acid 64.8% Linolenic acid 17.6% PUFA 27.4%	
X-82	Oleic acid >80.2% Linolenic acid 3-5% PUFA <6%	Auld *et al.* [3]
Parent Wotan EMS	Oleic acid 60.3% Linolenic acid 9.9%	
M457	Oleic acid 71.0% Linolenic acid 3.1%	Rucker and Röbbelen, [63]
M19782	Oleic acid 80.3% Linolenic acid 6.2%	Rucker and Röbbelen, [63]
	Linoleic acid (18:2)	
Parent Oro EMS	Linoleic acid 21.5%	
M11	Linoleic acid 37.9%	Röbbelen and Nitsch, [62]
	Linolenic acid (18:3)	
Parent Oro EMS/X-rays		
M57	Linolenic acid 5.2%	Röbbelen and Nitsch, [62]
M364	Linolenic acid 19.1%	Röbbelen and Nitsch, [62]
M6	Linolenic acid 3.5 %	Röbbelen and Nitsch, [62]
Parent M57 EMS	Linolenic acid 5.6%	

M47	Linolenic acid 3.2%	Röbbelen and Nitsch, [62]
Brassica rapa		
	Linoleic acid (18:1) and linolenic acid (18:3)	
Parent R-500 EMS	Linoleic acid 11.9% Linolenic acid 8.6%	
M30	Linoleic acid 2.1% Linolenic acid 3.0%	Auld *et al.* [3]
Brassica juncea		
	Linolenic acid (18:3)	
Parent Zem-1 EMS/Gamma rays	Linolenic acid 15.0%	
446-3	Linolenic acid 9.0%	Oram and Kirk, [39]
Brassica carinata		
Parent C-101 EMS	Oleic acid 9.4% Linoleic acid 18.3% Linolenic acid 12.9% Erucic acid 44.0%	
	Oleic acid (18:1)	
N2-3591	Oleic acid 23.3% Linoleic acid 8.3% Linolenic acid 6.6%	Velasco *et al.* [74]
N2-3667	Oleic acid 15.6% Linoleic acid 9.1%	Velasco *et al.* [74]
	Linolenic acid (18:3)	
N2-4961	Linolenic acid 6.3%	Velasco *et al.* [74]
	Erucic acid (22:1)	
N2-6230	Erucic acid 54.9%	Velasco *et al.* [75]
N2-7397	Low erucic acid 7.3%	Velasco *et al.* [73]

TABLE 9. Fatty acid mutants in linseed

Parent cultivar; mutagen used; mutant gene	Main characteristics	Reference
	Linolenic acid(18:3)	
Parent Glenelg EMS *Ln1¹ Ln1¹ Ln2¹Ln2¹*	Linolenic acid 34.1%	Green, [18]
M1589 *Ln1⁰ Ln1⁰ Ln2¹Ln2¹*	Linolenic acid 37.1%	Green and Marshall, [20] Green, [18]
M1722 *Ln1¹ Ln1¹ Ln2⁰Ln2⁰*	Linolenic acid 21.4%	Green and Marshall, [20 Green, [18]
Double zero (M1589 x M1722) *Ln1⁰ Ln1⁰ Ln2⁰Ln2⁰*	Linoleic acid 2.6%	Green, [18] Dribnenki and Green, [8]
Parent Raulinus EMS	Linolenic acid 55.4%	
Line 1	Linolenic acid 38.9%	Nichterlein *et al.* [34]
Parent McGregor EMS	Palmitic acid 6.8% Oleic acid 17.9% Linoleic acid 15.8% Linolenic acid 54.5%	
E67	Palmitic 28.4% Linolenic acid 54%	Rowland and Bhatty [59]
E1929	Oleic acid 34.7% Linoleic acid 30.1% Linolenic acid 25.2%	Rowland and Bhatty [59] Ntiamoah and Rowland, [37]
E1747 Two independent recessive genes	Linoleic acid 70.3% Linolenic acid 2.0%	Rowland, [58] Ntiamoah *et al.* [38]

Yellow seeded, low linolenic acid cultivars yielding edible oils are referred as Solin culivar in Canada [15]. The edible and non-edible cultivars with brown seeds can be easily separated during handling.

TABLE 10. Fatty acid mutants in minor oil crops

Crop; parent cultivar; mutagen used; mutant gene	Main characteristics	Reference
Cuphea viscosissima		
Inbred line Balough SN 912		
EMS	Caproic acid (6:0) 0.8% Caprylic acid (8:0) 20.7% Capric acid (10:0) 68.6% Lauric acid (12:0) 2.2% Myristic acid (14:0) 0.8%	Knapp and Tagliani, [27]
mcm-1	Eliminates: 6:0 0.0% 8:0 0.5% 10:0 6.7%	Knapp and Tagliani, [27]
cpy-1	Eliminates: 6:0 0.0% 8:0 3.9% Increases: 12:0 14.3% 14:0 7.4%	Knapp and Tagliani, [27]
VS-6 (PI 534911) EMS	8:0 175 g/kg 10:0 711 g/kg 12:0 22 g/kg 14:0 9 g/kg Palmitic acid (16:0) 18 g/kg	Tagliani *et al.* [68]
VS-6-CPR-1 (PI 574621*)	Oil percentage 1 - 2% less than VS-6 8:0 245 g/kg 10:0 383 g/kg 12:0 63 g/kg 14:0 142 g/kg 16:0 82 g/kg	Tagliani *et al.* [68]
VS-6-CPR-2	6:0 16 g/kg 8:0 294 g/kg 10:0 398 g/kg 12:0 63 g/kg 14:0 113 g/kg	Knapp *et al.* [28]
VS-6-CPR-4 (PI 574622*)	Oil percentage 14% less than VS-6 8:0 224 g/kg 10:0 659 g/kg 12:0 28 g/kg	Tagliani *et al.* [68]

VS-6-CPR-5	6:0 21 g/kg 8:0 295 g/kg 10:0 389 g/kg 12:0 63 g/kg 14:0 110 g/kg	Knapp *et al.* [28]
VS-6-CLM-1	6:0 11 g/kg 8:0 251 g/kg 10:0 652 g/kg 12:0 16 g/kg	Knapp *et al.* [28]
VS-6-CPY-1 (PI 574623*)	Oil percentage 1 - 2% less than VS-6 8:0 39 g/kg 10:0 709 g/kg 12:0 143 g/kg 14:0 74 g/kg	Tagliani *et al.* [68]
VS-6-MYR-1 (PI 574624*)	Oil percentage 1 - 2% less than VS-6 8:0 205 g/kg 10:0 704 g/kg 12:0 23 g/kg 14:0 3 g/kg	Tagliani *et al.* [68]
CPR-1 x CLM-1 F_3 line VS 320	8:0 334 g/kg 10:0 396 g/kg	Knapp *et al.* [28]
CPR-4 x CPR-5 F_3 line VS 321	8:0 247 g/kg 10:0 361 g/kg	Knapp *et al.* [28]
Camelina sativa CA13X2S-44 Gamma rays M_3 lines	Significantly high linolenic acid up to 40.8% in M_3 lines compared to 34-36% in control, and erucic acid less than 2% compared to less than 4% in control	Vollman *et al.* [78]

* These are registered germplasm lines.

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