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(54) Title: FATTY ACID DESATURASES FROM TETRASELMIS SUECICA

(57) Abstract: The invention relates generally to methods and compositions concerning desaturase enzymes that modulate the number and location of double bonds in long chain poly-unsaturated fatty acids (LC-PUFA's). In particular, the invention relates to methods and compositions for improving omega-3 fatty acid profiles in plant products and parts using desaturase enzymes and nucleic acids encoding for such enzymes. In particular embodiments, the desaturase enzymes are Tetraselmis suecica delta 6 desaturases. Also provided are improved soybean oil compositions having GLA and SDA.



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DESCRIPTION

FATTY ACID DESATURASES FROM *Tetraselmis suecica*

BACKGROUND OF THE INVENTION

This application claims the priority of U.S. Provisional Patent Application Ser.
5 No. 60/831,838, filed July 19, 2006, the entire disclosure of which is specifically incorporated herein by reference.

1. Field of the Invention

The invention relates generally to desaturase enzymes that modulate the number and location of double bonds in long chain poly-unsaturated fatty acids (LC-
10 PUFA's). In particular, the invention relates to improvement of fatty acid profiles using delta 6 desaturase enzymes and nucleic acids encoding such desaturase enzymes.

2. Description of the Related Art

The primary products of fatty acid biosynthesis in most organisms are 16- and
15 18-carbon compounds. The relative proportion of chain lengths and degree of unsaturation of these fatty acids vary widely among species. Mammals, for example, produce primarily saturated and monounsaturated fatty acids, while most higher plants produce fatty acids with one, two, or three double bonds, the latter two comprising polyunsaturated fatty acids (PUFA's).

20 Two main families of PUFAs are the omega-3 fatty acids (also represented as "n-3" fatty acids), exemplified by stearidonic acid (SDA, 18:4, n-3), and the omega-6 fatty acids (also represented as "n-6" fatty acids), exemplified by γ -linolenic acid (GLA, 18:3, n-6). PUFAs are important components of the plasma membrane of the cell and adipose tissue, where they may be found in such forms as phospholipids and
25 as triglycerides, respectively. PUFAs are necessary for proper development in mammals, particularly in the developing infant brain, and for tissue formation and repair.

Several disorders respond to treatment with fatty acids. Supplementation with PUFAs has been shown to reduce the rate of restenosis after angioplasty. The health benefits of certain dietary omega-3 fatty acids for cardiovascular disease and rheumatoid arthritis also have been well documented (Simopoulos *et al.*, 1999; James *et al.*, 2000). Further, PUFAs have been suggested for use in treatments for asthma and psoriasis. Evidence indicates that PUFAs may be involved in calcium metabolism, suggesting that PUFAs may be useful in the treatment or prevention of osteoporosis and of kidney or urinary tract stones. The majority of evidence for health benefits applies to the long chain omega-3 fats, eicosapentaenoic acid (EPA, 20:5, n-3) and docosahexaenoic acid (DHA, 22:6, n-3) which are found in fish and fish oil. With this base of evidence, health authorities and nutritionists in Canada (Scientific Review Committee, 1990, Nutrition Recommendations, Minister of National Health and Welfare, Ottawa, Canada), Europe (de Deckerer, *Eur. J. Clin. Nutr.*, 52:749, 1998), the United Kingdom (The British Nutrition Foundation, 1992, Unsaturated fatty-acids - nutritional and physiological significance: The report of the British Nutrition Foundation's Task Force, Chapman and Hall, London), and the United States (Simopoulos *et al.*, 1999) have recommended increased dietary consumption of these PUFAs.

PUFAs also can be used to treat diabetes (U.S. Pat. No. 4,826,877; Horobin *et al.*, 1993). Altered fatty acid metabolism and composition have been demonstrated in diabetic animals. These alterations have been suggested to be involved in some of the long-term complications resulting from diabetes, including retinopathy, neuropathy, nephropathy and reproductive system damage. Primrose oil, which contains GLA, has been shown to prevent and reverse diabetic nerve damage. Administration of an omega-3 fatty acid, such as SDA, has been shown to inhibit biosynthesis of leukotrienes (U.S. Pat. No. 5,158,975). The consumption of SDA has been shown to lead to a decrease in blood levels of proinflammatory cytokines TNF- α and IL-1 β (PCT US 0306870).

PUFAs, such as linoleic acid (LA, 18:2, Δ 9, 12) and α -linolenic acid (ALA, 18:3, Δ 9, 12, 15), are regarded as essential fatty acids in the diet because mammals lack the ability to synthesize these acids. LA is produced from oleic acid (OA, 18:1, Δ 9) by a Δ 12-desaturase while ALA is produced from LA by a Δ 15-desaturase. However, when ingested, mammals have the ability to metabolize LA and ALA to

form the n-6 and n-3 families of long-chain polyunsaturated fatty acids (LC-PUFA). These LC-PUFA's are important cellular components conferring fluidity to membranes and functioning as precursors of biologically active eicosanoids such as prostaglandins, prostacyclins, and leukotrienes, which regulate normal physiological functions. Arachidonic acid (ARA, 20:4, n-6) is the principal precursor for the synthesis of eicosanoids, which include leukotrienes, prostaglandins, and thromboxanes, and which also play a role in the inflammation process.

In mammals, the formation of LC-PUFA is rate-limited by the step of $\Delta 6$ desaturation, which converts LA to GLA and ALA to SDA. Many physiological and pathological conditions have been shown to depress this metabolic step even further, and consequently, the production of LC-PUFA. To overcome the rate-limiting step and increase tissue levels of EPA, one could consume large amounts of ALA. However, consumption of just moderate amounts of SDA provides an efficient source of EPA, as SDA is about four times more efficient than ALA at elevating tissue EPA levels in humans (U.S. Patent Publication 20040039058 (Ursin *et al.*). In the same studies, SDA administration was also able to increase the tissue levels of docosapentaenoic acid (DPA), which is an elongation product of EPA. Alternatively, bypassing the $\Delta 6$ -desaturation via dietary supplementation with EPA or DHA can effectively alleviate many pathological diseases associated with low levels of PUFA. However, as set forth in more detail below, currently available sources of PUFA are not desirable for a multitude of reasons. The need for a reliable and economical source of PUFA's has spurred interest in alternative sources of PUFA's.

Major long chain PUFAs of importance include DHA and EPA, which are primarily found in different types of fish oil, and ARA, found in filamentous fungi such as *Mortierella*. For DHA, a number of sources exist for commercial production including a variety of marine organisms, oils obtained from cold water marine fish, and egg yolk fractions. Commercial sources of SDA include the plant genera *Trichodesma*, *Borago* (borage) and *Echium*. Commercial sources of GLA include the plant genera *Borago*, *Oenothera* and *Ribes*. However, there are several disadvantages associated with commercial production of PUFAs from natural sources. Natural sources of PUFAs, such as animals and plants, tend to have highly heterogeneous oil compositions. The oils obtained from these sources therefore can require extensive

purification to separate out one or more desired PUFAs or to produce an oil which is enriched in one or more PUFAs.

Natural sources of PUFAs also are subject to uncontrollable fluctuations in availability. Fish stocks may undergo natural variation or may be depleted by over
5 fishing. In addition, even with overwhelming evidence of their therapeutic benefits, dietary recommendations regarding omega-3 fatty acids are not heeded. Fish oils have unpleasant tastes and odors, which may be impossible to economically separate from the desired product, and can render such products unacceptable as food supplements. Animal oils, and particularly fish oils, can accumulate environmental
10 pollutants. Foods may be enriched with fish oils, but again, such enrichment is problematic because of cost and declining fish stocks worldwide. This problem is also an impediment to consumption and intake of whole fish. Nonetheless, if the health messages to increase fish intake were embraced by communities, there would likely be a problem in meeting demand for fish. Furthermore, there are problems with
15 sustainability of this industry, which relies heavily on wild fish stocks for aquaculture feed (Naylor *et al.*, 2000).

Other natural limitations favor a novel approach for the production of PUFAs. Weather and disease can cause fluctuation in yields from both fish and plant sources. Cropland available for production of alternate oil-producing crops is subject to
20 competition from the steady expansion of human populations and the associated increased need for food production on the remaining arable land. Crops that do produce PUFAs, such as borage, have not been adapted to commercial growth and may not perform well in monoculture. Growth of such crops is thus not economically competitive where more profitable and better-established crops can be grown. Large-
25 scale fermentation of organisms such as *Mortierella* is also expensive. Natural animal tissues contain low amounts of ARA and are difficult to process. Microorganisms such as *Porphyridium* and *Mortierella* are difficult to cultivate on a commercial scale.

Therefore, it would be advantageous to obtain genetic material involved in PUFA biosynthesis and to express the isolated material in a plant system, in
30 particular, a land-based terrestrial crop plant system, which can be manipulated to provide production of commercial quantities of one or more PUFA's. In commercial oilseed crops, such as canola, soybean, corn, sunflower, safflower, or flax, the conversion of some fraction of the mono and polyunsaturated fatty acids that typify

their seed oil to SDA and GLA requires the seed-specific expression of multiple desaturase enzymes that includes delta 6- and delta 15-desaturases. Oils derived from plants expressing elevated levels of $\Delta 6$ - and $\Delta 15$ -desaturases are rich in SDA and GLA. As there is also a need to increase omega-3 fatty acid intake in humans and animals, there is a need to provide a wide range of omega-3 enriched foods and food supplements so that subjects can choose feed, feed ingredients, food and food ingredients which suit their usual dietary habits. It is also advantageous to provide commercial quantities of GLA. Thus, there exists a strong need for novel nucleic acids of $\Delta 6$ -desaturases for use in transgenic crop plants with oils enriched in PUFAs, as well as the improved food and feeds produced thereby.

SUMMARY OF THE INVENTION

In one aspect, the invention provides isolated nucleic acids encoding a polypeptide capable of desaturating a fatty acid molecule at carbon 6. These may be used to transform cells or modify the fatty acid composition of a plant or the oil produced by a plant. One embodiment of the invention is isolated polynucleotide sequences isolated from *Tetraselmis suecica* having unique desaturase activity. In certain further embodiments of the invention, the polynucleotides encode a polypeptide having at least 75% sequence identity to the polypeptide sequence of SEQ ID NO:2 or SEQ ID NO:4, including at least about 80%, 82%, 85%, 87%, 90%, 92%, 95%, 98% and 99% homology to these sequences. Those of skill in the art will recognize that, as these sequences are related, a given polypeptide may simultaneously share 75% or greater homology to more than one of these polypeptide sequences.

In another aspect, the invention provides an isolated polynucleotide that encodes a polypeptide having desaturase activity that desaturates a fatty acid molecule at carbon 6, comprising a sequence selected from the group consisting of: (a) a polynucleotide encoding the polypeptide of SEQ ID NO:2 or SEQ ID NO:4; (b) a polynucleotide comprising the nucleic acid sequence of SEQ ID NO:1 or SEQ ID NO:3; (c) a polynucleotide hybridizing to SEQ ID NO:1 or SEQ ID NO:3, or a complement thereof, under conditions of 5X SSC, 50% formamide and 42°C; and (d) a polynucleotide encoding a polypeptide with at least 75%, 85%, 95%, 98%, or 99% sequence identity to a polypeptide sequence of SEQ ID NO:2 or SEQ ID NO:4. In

another aspect, the invention provides an isolated polypeptide comprising the polypeptide sequences of SEQ ID NO:2 or SEQ ID NO:4 or a fragment thereof having desaturase activity that desaturates a fatty acid molecule at carbon 6.

5 In yet another aspect, the invention provides a DNA construct comprising the isolated polynucleotide that encodes a polypeptide having desaturase activity that desaturates a fatty acid molecule at carbon 6, comprising a sequence selected from the group consisting of: (a) a polynucleotide encoding the polypeptide of SEQ ID NO:2 or SEQ ID NO:4; (b) a polynucleotide comprising the nucleic acid sequence of SEQ ID NO:1 or SEQ ID NO:3; (c) a polynucleotide hybridizing to SEQ ID NO:1 or SEQ ID NO:3, or a complement thereof, under conditions of 5X SSC, 50% formamide and 42°C; and (d) a polynucleotide encoding a polypeptide with at least 75%, 85%, 95%, 98%, or 99% sequence identity to a polypeptide sequence of SEQ ID NO:2 or SEQ ID NO:4. In a further embodiment, the DNA construct further comprises a heterologous promoter operably linked to the isolated polynucleotide described above. In other 15 embodiments, the promoter is functional in a prokaryotic cell or a eukaryotic cell. In certain embodiments, the eukaryotic cell in which the promoter is functional is a plant cell. In a further embodiment, the promoter is a seed-enhanced promoter. In yet another embodiment, the DNA construct further comprises at least one additional polynucleotide sequence encoding a fatty acid desaturase.

20 In still yet another aspect, the invention provides a host cell transformed with a DNA construct comprising the isolated polynucleotide that encodes a polypeptide having desaturase activity that desaturates a fatty acid molecule at carbon 6 provided by the invention. The host cell may be a plant, animal, fungal or bacterial cell. In a further embodiment, the host cell of the invention provides a host cell that exhibits 25 altered fatty acid biosynthesis relative to a cell of the same genotype as the host cell but lacking the DNA construct. In yet another aspect, the host cell has inherited the DNA construct from a progenitor of the cell.

In still yet another aspect, the invention provides a plant and its progeny comprising the host cells transformed with a DNA construct of the invention. Such a 30 plant may be defined as comprising altered fatty acid metabolism relative to a plant of the same genotype lacking the DNA construct. In yet another aspect, such a plant may further comprise at least one additional polynucleotide sequence encoding a fatty acid desaturase. In one embodiment, the plant is selected from the group consisting of

canola, *Brassica campestris*, oilseed rape, rapeseed, soybean, crambe, mustard, castor bean, peanut, sesame, cottonseed, linseed, safflower, oil palm, flax, sunflower, corn, rice, barley, millet, rye, wheat, oat, alfalfa and sorghum. The invention also provides seed of the plant of the invention. In another aspect, the invention provides an oil composition extracted from corn seed comprising a GLA content from about 5% to about 15%, about 20%, or about 26% by weight of total fatty acids. In one embodiment, the oil composition further comprises an SDA content of from about 3% to about 13% by weight of total fatty acids, including intermediate SDA content, such as about 5%, about 8%, or about 10% SDA content by weight of total fatty acids. The invention is also embodied by an oil composition extracted from corn seed comprising a GLA content of at least about 3%, at least about 5%, or at least about 10% by weight of total fatty acids; and an SDA content of at least about 3%, about 5%, about 8%, about 10%, about 13%, or about 20% by weight of total fatty acids, wherein the ratio of GLA/SDA is between about 1.3 and about 3.7. In yet another aspect, the invention provides an oil composition extracted from soybean seed having a GLA content from about 9% to about 51% by weight of total fatty acids, including about 20%, about 30%, or about 40% by weight of total fatty acids. In one embodiment, the oil composition further comprises an SDA content of from about 0.5% to about 10% by weight of total fatty acids. The invention is also embodied by an oil composition extracted from soybean seed comprising a GLA content of at least about 1%, about 3% , about 5%, about 10%, about 13%, or about 20% by weight of total fatty acids and an SDA content of at least 1% by weight of total fatty acids, wherein the ratio of GLA/SDA is between about 2.8 and about 18.3.

In still yet another aspect, the invention provides a method of producing food or feed, comprising the steps of (a) obtaining the transgenic plant of the invention; and (b) producing the food or feed. The food or feed may be oil, silage, meal, grain, starch, flour or protein. The food or feed composition is defined as comprising a detectable polynucleotide sequence or detectable polypeptide provided by the invention. Additionally, the invention provides animal feed and human food compositions comprising GLA or SDA.

In still yet another aspect, the invention provides a method of increasing the nutritional value of an edible product for human or animal consumption, comprising

adding transformed plants or plant parts, or derivatives thereof provided by the invention to the edible product. In certain embodiments, the product is human and/or animal food. The edible product may also be animal feed and/or a food supplement.

5 In still yet another aspect, the invention provides a method of manufacturing food or feed, comprising adding transformed plants or plant parts, or derivatives thereof provided by the invention to starting food or feed ingredients to produce the food or feed. In certain embodiments, the method is further defined as a method of manufacturing food and/or feed. The invention also provides food or feed made by the method.

10 **BRIEF DESCRIPTION OF THE FIGURES**

The following drawings form part of the present specification and are included to further demonstrate certain aspects of the present invention. The invention may be better understood by reference to one or more of these drawings in combination with the detailed description of specific embodiments presented herein.

15 **FIG. 1** shows an amino acid alignment of *Tetraselmis suecica* $\Delta 6$ desaturases TsD6D-1 and TsD6D-2 (SEQ ID NOs: 2 and 4), *Isochrysis galba* Ig6D-1 (SEQ ID NO: 11) and *Mortierella alpina* D6D (SEQ ID NO: 12).

FIG. 2 shows a map of vector pMON94002.

FIG. 3 shows a map of vector pMON82848.

20 **FIG. 4** shows a map of vector pMON82849.

FIG. 5 shows a map of vector pMON94502.

FIG. 6 shows a map of vector pMON94503.

FIG. 7 show a map of vector pMON94060

DETAILED DESCRIPTION OF THE INVENTION

25 The invention overcomes the limitations of the prior art by providing methods and compositions for creation of plants with improved PUFA content. The modification of fatty acid content of an organism such as a plant presents many advantages, including improved nutrition and health benefits. Modification of fatty

acid content can be used to achieve beneficial levels or profiles of desired PUFA's in plants, plant parts, and plant products, including plant seed oils. For example, when the desired PUFA's are produced in the seed tissue of a plant, the oil may be isolated from the seeds typically resulting in an oil high in desired PUFAs or an oil having a
5 desired fatty acid content or profile, which may in turn be used to provide beneficial characteristics in food stuffs and other products.

Various aspects of the invention include methods and compositions for modification of PUFA content of a cell, for example, modification of the PUFA content of a plant cell(s). Compositions related to the invention include novel isolated
10 polynucleotide sequences, polynucleotide constructs and plants and/or plant parts transformed by polynucleotides of the invention. The isolated polynucleotide may encode a *Tetraselmis suecica* $\Delta 6$ -desaturase. Host cells may be manipulated to express a polynucleotide encoding a delta 6 desaturase polypeptide(s) which catalyze(s) desaturation of a fatty acid(s).

15 The following definitions are provided as an aid to understanding this invention. The phrases "DNA sequence," "nucleic acid sequence," "nucleic acid molecule," "polynucleotide" and "nucleic acid segment" refer to a physical structure comprising an orderly arrangement of nucleotides. The DNA segment, sequence, or nucleotide sequence may be contained within a larger nucleotide molecule, vector, or
20 the like. In addition, the orderly arrangement of nucleic acids in these sequences may be depicted in the form of a sequence listing, figure, table, electronic medium, or the like.

The phrases "coding sequence," "coding region," "structural sequence," and "structural nucleic acid sequence" refer to all or a segment of a DNA sequence,
25 nucleic acid sequence, nucleic acid molecule in which the nucleotides are arranged in a series of triplets that each form a codon. Each codon encodes a specific amino acid. Thus, the coding sequence, coding region, structural sequence, and structural nucleic acid sequence encode a series of amino acids forming a protein, polypeptide, or peptide sequence. The coding sequence, coding region, structural sequence, and
30 structural nucleic acid sequence may be contained within a larger nucleic acid molecule, vector, or the like. In addition, the arrangement of nucleotides in these

sequences may be depicted in the form of a sequence listing, figure, table, electronic medium, or the like.

The term “cDNA” refers to a double-stranded DNA that is complementary to and derived from mRNA.

5 “Desaturase” refers to a polypeptide that can desaturate or catalyze formation of a double bond between consecutive carbons of one or more fatty acids to produce a mono- or poly-unsaturated fatty acid or a precursor thereof. Of particular interest are polypeptides that can catalyze the conversion of OA to LA, LA to ALA, or ALA to SDA, which includes enzymes which desaturate at the 12, 15, or 6 positions.

10 Considerations for choosing a specific polypeptide having desaturase activity include, but are not limited to, the pH optimum of the polypeptide, whether the polypeptide is a rate limiting enzyme or a component thereof, whether the desaturase used is essential for synthesis of a desired PUFA, and/or whether a co-factor is required by the polypeptide. The expressed polypeptide preferably has characteristics that are

15 compatible with the biochemical environment of its location in the host cell. For example, the polypeptide may have to compete for substrate(s).

 “Expression” refers to the process by which a gene’s coded information is converted into structures present and operating in the cell. Expressed genes include those that are transcribed into RNA and then translated into protein and those that are

20 transcribed into RNA but not translated into protein (*e.g.*, transfer RNA and ribosomal RNA).

 As used herein, “gene” refers to a nucleic acid fragment that expresses a specific protein, including regulatory sequences preceding (5’ non-coding sequences) and following (3’ non-coding sequences) the coding sequence. “Native gene” refers

25 to a gene as found in nature with its own regulatory sequences. “Chimeric gene” refers to any gene that is not a native gene, comprising regulatory and coding sequences that are not found together in nature. Accordingly, a chimeric gene may comprise regulatory sequences and coding sequences that are derived from different sources, or regulatory sequences and coding sequences derived from the same source,

30 but arranged in a manner different than that found in nature. “Endogenous” gene refers to a native gene in its natural location in the genome of an organism. An

“exogenous” gene or “transgene” refer to a gene that has been introduced into the genome by a transformation procedure. A transgene includes genomic DNA introduced by a transformation procedure (e.g., a genomic DNA linked to its active promoter).

5 “Heterologous” refers to the relationship between 2 or more nucleic acid or protein sequences that are derived from different sources. For example, a promoter is heterologous with respect to a coding sequence if such a combination is not normally found in nature. In addition, a particular nucleic acid sequence may be “heterologous” with respect to a cell or organism into which it is inserted if it does not
10 naturally occur in that particular cell or organism.

“Sequence homology” refers to the level of similarity between 2 or more nucleic acid or amino acid sequences in terms of percent of positional identity. The term homology is also used to refer to the concept of similar functional properties among different nucleic acids or proteins.

15 “Hybridization” refers to the ability of a first strand of nucleic acid to join with a second strand *via* hydrogen bond base pairing when the nucleic acid strands have sufficient sequence complementarity. As used herein, a nucleic acid molecule is said to be the “complement” of another nucleic acid molecule if they exhibit complete complementarity. As used herein, molecules are said to exhibit “complete
20 complementarity” when every nucleotide of one of the molecules is complementary to a nucleotide of the other. Thus 2 nucleic acid strands are said to have sufficient complementarity when they can hybridize to one another with sufficient stability to permit them to remain annealed to one another under appropriate conditions.

The phrase “isolated” means having been removed from its natural
25 environment, regardless of its eventual disposition. For example, a nucleic acid sequence “isolated” from rice, such as by cloning from a rice cell, remains “isolated” when it is inserted into the genome of a corn cell.

The phrase “operably linked” refers to the spatial arrangement of two or more nucleic acid regions or nucleic acid sequences so that they exert their appropriate
30 effects with respect to each other. For example, a promoter region may be positioned

relative to a nucleic acid sequence such that transcription of the nucleic acid sequence is directed by the promoter region. The promoter region and the nucleic acid sequence are “operably linked.”

“Upstream” and “downstream” are positional terms used with reference to the location of a nucleotide sequence and the direction of transcription or translation of coding sequences, which normally proceeds in the 5' to 3' direction.

The terms “promoter” or “promoter region” refer to a nucleic acid sequence, usually found upstream (5') to a coding sequence, capable of directing transcription of a nucleic acid sequence into an RNA molecule. The promoter or promoter region typically provides a recognition site for RNA polymerase and the other factors necessary for proper initiation of transcription. As contemplated herein, a promoter or promoter region includes variations of promoters derived by inserting or deleting regulatory regions, subjecting the promoter to random or site-directed mutagenesis, and the like. The activity or strength of a promoter may be measured in terms of the amounts of RNA it produces, or the amount of protein accumulation in a cell or tissue, relative to a second promoter that is similarly measured.

The phrase “3' non-coding sequences” refers to nucleotide sequences located downstream of a coding sequence and include polyadenylation recognition sequences and other sequences encoding regulatory signals capable of affecting mRNA processing or gene expression. These are commonly referred to as 3'-untranslated regions or 3'-UTRs. The polyadenylation signal is usually characterized by affecting the addition of polyadenylic acid tracts to the 3' end of the mRNA precursor. The use of different 3' non-coding sequences is exemplified by Ingelbrecht *et al.* (1989).

“Translation leader sequence” or “5'-untranslated region” or “5'-UTR” all refer to a nucleotide sequence located between the promoter sequence of a gene and the coding sequence. The 5'-UTR is present in the fully processed mRNA upstream of the translation start sequence. The 5'-UTR may affect processing of the primary transcript to mRNA, mRNA stability or translation efficiency. Examples of translation leader sequences have been described (Turner and Foster, 1995).

“RNA transcript” refers to the product resulting from RNA polymerase-catalyzed transcription of a DNA sequence. When the RNA transcript is a perfect complementary copy of the DNA sequence, it is referred to as the primary transcript. An RNA sequence derived from posttranscriptional processing of the primary transcript is referred to as the mature RNA. “Messenger RNA” (mRNA) refers to the RNA that is without introns and that can be translated into polypeptide by the cell.

“DNA construct” refers to the heterologous genetic elements operably linked to each other making up a recombinant DNA molecule and may comprise elements that provide expression of a DNA polynucleotide molecule in a host cell and elements that provide maintenance of the construct. A plant expression cassette comprises the operable linkage of genetic elements that when transferred into a plant cell provides expression of a desirable gene product.

“Recombinant vector” refers to any agent by or in which a nucleic acid of interest is amplified, expressed, or stored, such as a plasmid, cosmid, virus, autonomously replicating sequence, phage, or linear single-stranded, circular single-stranded, linear double-stranded, or circular double-stranded DNA or RNA nucleotide sequence. The recombinant vector may be synthesized or derived from any source and is capable of genomic integration or autonomous replication.

“Regulatory sequence” refers to a nucleotide sequence located upstream (5'), within, or downstream (3') with respect to a coding sequence, or an intron, whose presence or absence affects transcription and expression of the coding sequence

“Substantially homologous” refers to two sequences that are at least about 90% identical in sequence, as measured by the CLUSTAL W algorithm in, for example DNASTar (DNASTar, Madison, WI).

“Substantially purified” refers to a molecule separated from substantially all other molecules normally associated with it in its native state. More preferably, a substantially purified molecule is the predominant species present in a preparation. A substantially purified molecule may be greater than about 60% free, preferably about 75% free, more preferably about 90% free, and most preferably about 95% free from the other molecules (exclusive of solvent) present in the natural mixture. The phrase

“substantially purified” is not intended to encompass molecules present in their native state. Preferably, the nucleic acid molecules and polypeptides of this invention are substantially purified.

5 The term “transformation” refers to the introduction of nucleic acid into a recipient host. The term “host” refers to bacteria cells, fungi, animals or animal cells, plants or seeds, or any plant parts or tissues including plant cells, protoplasts, calli, roots, tubers, seeds, stems, leaves, seedlings, embryos, and pollen.

As used herein, a “transgenic plant” is a plant having stably introduced into its genome, for example, the nuclear or plastid genomes, an exogenous nucleic acid.

10 The term “isogenic” as a comparative term between plants or plant lines having or lacking a transgene means plants or lines having the same or similar genetic backgrounds, with the exception of the transgene in question. For example, so-called sister lines representing phenotypically similar or identical selections from the same parent F2 population are considered to be “isogenic.” When the progeny of a stable
15 transformant plant are crossed and backcrossed with the plants of the untransformed parent line for 3 to 6 generations (or more) using the untransformed parent as the recurrent parent while selecting for type (genotype by molecular marker analysis, phenotype by field observation, or both) and for the transgene, the resulting transgenic line is considered to be highly “isogenic” to its untransformed parent line.

20 The terms “seeds” “kernels” and “grain” are understood to be equivalent in meaning. The term kernel is frequently used in describing the seed of a corn or rice plant. In all plants the seed is the mature ovule consisting of a seed coat, embryo, aleurone, and an endosperm.

Nucleic acids encoding delta 6 desaturases

25 The invention provides, in one embodiment, novel nucleic acids encoding delta 6 desaturases from *Tetraselmis suecica*, a motile green flagellate alga. In a particular embodiment, the nucleic acids are isolated from *Tetraselmis suecica* strain CCMP904 (available from CCMP; Center for Culture of Marine Phytoplankton; West Boothbay Harbor, Maine, USA). In certain embodiments, the nucleic acids comprise
30 SEQ ID NOs:1 or 3. The invention also provides methods of using such nucleic

acids, including SEQ ID NOs:1 and 3. In one embodiment, these nucleic acid molecules are used in the context of this invention for altering the oil composition of a seed from a plant.

Such nucleic acid can be amplified using cDNA, mRNA or genomic DNA as a
5 template and appropriate oligonucleotide primers according to standard PCR™
amplification techniques. Alternatively, they can be synthesized using standard
synthetic techniques, such as an automated DNA synthesizer. Polynucleotides
encoding desired delta 6 desaturases can be identified in a variety of ways. As an
example, a source of the desired delta 6 desaturases, for example a library from
10 *Tetraselmis*, is screened with detectable enzymatically- or chemically-synthesized
probes, which can be made from DNA, RNA, or non-naturally occurring nucleotides,
or mixtures thereof. Probes may be enzymatically synthesized from polynucleotides
of known delta 6 desaturases for normal or reduced-stringency hybridization methods.
Oligonucleotide probes also can be used to screen sources and can be based on
15 sequences of known delta 6 desaturases, including sequences conserved among
known delta 6 desaturases, or on peptide sequences obtained from the desired purified
protein. Oligonucleotide probes based on amino acid sequences can be degenerate to
encompass the degeneracy of the genetic code, or can be biased in favor of the
preferred codons of the source organism. Oligonucleotides also can be used as
20 primers for PCR™ from reverse transcribed mRNA from a known or suspected
source; the PCR™ product can be the full length cDNA or can be used to generate a
probe to obtain the desired full length cDNA. Alternatively, a desired protein can be
entirely sequenced and total synthesis of a DNA encoding that polypeptide performed.

Once the desired genomic or cDNA has been isolated, it can be sequenced by
25 known methods. It is recognized in the art that such methods are subject to errors,
such that multiple sequencing of the same region is routine and is still expected to
lead to measurable rates of mistakes in the resulting deduced sequence, particularly in
regions having repeated domains, extensive secondary structure, or unusual base
compositions, such as regions with high GC base content. When discrepancies arise,
30 resequencing can be done and can employ special methods. Special methods can
include altering sequencing conditions by using: different temperatures; different
enzymes; proteins which alter the ability of oligonucleotides to form higher order

structures; altered nucleotides such as ITP or methylated dGTP; different gel compositions, for example adding formamide; different primers or primers located at different distances from the problem region; or different templates such as single stranded DNAs. Sequencing of mRNA also can be employed.

5 If desired, the sequences of nucleic acids that code for delta 6 desaturases can be modified without changing the resulting amino acid sequence of the expressed protein so that the sequences are more amenable to expression in plant hosts. A coding sequence can be an artificial DNA. An artificial DNA, as used herein means a DNA polynucleotide molecule that is non-naturally occurring. Artificial DNA
10 molecules can be designed by a variety of methods, such as, methods known in the art that are based upon substituting the codon(s) of a first polynucleotide to create an equivalent, or even an improved, second-generation artificial polynucleotide, where this new artificial polynucleotide is useful for enhanced expression in transgenic plants. The design aspect often employs a codon usage table produced by compiling
15 the frequency of occurrence of codons in a collection of coding sequences isolated from a plant, plant type, family or genus. Other design aspects include reducing the occurrence of polyadenylation signals, intron splice sites, or long AT or GC stretches of sequence (U.S. Patent 5,500,365). Full length coding sequences or fragments thereof can be made of artificial DNA using methods known to those skilled in the art.
20 Modifications of the nucleotide sequences or regulatory elements disclosed herein which maintain the functions contemplated herein are within the scope of this invention. Such modifications include insertions, substitutions and deletions, and specifically substitutions which reflect the degeneracy of the genetic code.

 The inventors have isolated DNA sequences from *Tetraselmis suecica* that
25 produce polypeptides with delta 6 desaturase activity. The sequences encoding the delta 6 desaturases may be expressed in transgenic plants, microorganisms or animals to modify fatty acid content. Other polynucleotides which are substantially identical to the delta 6 desaturase polynucleotides provided herein, or which encode polypeptides which are substantially identical to the delta 6 desaturase polypeptides,
30 also can be used. "Substantially identical" refers to an amino acid sequence or nucleic acid sequence exhibiting in order of increasing preference at least 75%, 80%, 82%, 85%, 87%, 90%, 92%, 95%, 98 or 99% identity to the delta 6 desaturase

polypeptide sequence in SEQ ID NO:2, SEQ ID NO:4 or sequences encoding these polypeptides. Polypeptide or polynucleotide comparisons may be carried out using sequence analysis software, for example, the Sequence Analysis software package of the GCG Wisconsin Package (Accelrys, San Diego, CA) and MEGAlign (DNAS[®] Inc., 1228 S. Park St., Madison, Wis. 53715). Such software matches similar sequences by assigning degrees of similarity or identity.

DNA Constructs

The invention provides DNA constructs comprising a heterologous promoter operably linked to a nucleic acid described herein. The selection of promoters, *e.g.*, promoters that may be described as strongly expressed, weakly expressed, inducibly expressed, tissue-enhanced expressed (*i.e.*, specifically or preferentially expressed in a tissue), organ-enhanced expressed (*i.e.*, specifically or preferentially expressed in an organ) and developmentally-enhanced expressed (*i.e.*, specifically or preferentially expressed during a particular stage(s) of development), is within the skill in the art. Similarly, the combining of a nucleic acid molecule as described above with a promoter is also within the skill in the art (see, *e.g.*, Sambrook *et al.*, 2001, 1989).

Promoters for use with the invention include, but are not limited to, promoters that function in bacteria, bacteriophages, fungi or plant cells. Useful promoters for bacterial expression are the *lacZ*, Sp6, T7, T5 or *E. coli glgC* promoters. Useful promoters for fungi include *Saccharomyces cerevisiae gal1* (West *et al.*, 1984), *Saccharomyces pombe nmt1* (Maundrell, 1990), *Neurospora crassa ccg-1* (Freitag and Selker, 2005) and *Pichia methanolica* AUG1 (Invitrogen). Useful promoters for plants cells include the gamma zein Z27 promoter (see, for example, Prem Das *et al.*, 1991), L3 oleosin promoter (U.S. Patent No. 6,433,252, Kriz *et al.*), barley PER1 promoter (Stacey *et al.*, 1996), CaMV 35S promoter (US Patent No. 5,530,196 (Fraley *et al.*)), nos promoter (Ebert *et al.*, 1987), rice actin promoter (US Patent No. 5,641,876), and PEPCase promoter (Hudspeth *et al.*, 1989). The Figwort Mosaic Virus (FMV) promoter (US Patent No. 6,051,753 (Comai *et al.*)), arcelin, tomato E8, patatin, ubiquitin, mannopine synthase (*mas*) and tubulin promoters are other examples of useful promoters.

There are a wide variety of plant promoter sequences which may be used to drive tissue-specific expression of polynucleotides encoding delta 6 desaturases and

other desaturases in transgenic plants. Indeed, in particular embodiments of the invention, the promoter used is a seed specific promoter. Examples of such promoters include the 5' regulatory regions from such genes as napin (Kridl *et al.*, 1991), phaseolin (Bustos, *et al.*, 1989), soybean a' subunit of β -conglycinin (P-Gm7S alpha', see for example, Chen *et al.*, 1986), *Vicia faba* USP (P-Vf.Usp, see for example, SEQ ID NO:1, 2, and 3, U.S. Patent Publication 20030229918), the globulin promoter (see for example Belanger and Kriz, 1991), and soybean alpha subunit of β -conglycinin (7S alpha) (U.S. Patent Publication 20030093828, incorporated by reference).

Other seed-expression enhanced promoters known to function in maize and in other plants include the promoters for the following genes: Waxy (granule bound starch synthase), Brittle and Shrunken 2 (ADP glucose pyrophosphorylase), Shrunken 1 (sucrose synthase), branching enzymes I and II, starch synthases, debranching enzymes, oleosins, glutelins, and Bet1l (basal endosperm transfer layer). Other promoters useful in the practice of the invention that are known by one of skill in the art are also contemplated by the invention.

Moreover, transcription enhancers or duplications of enhancers can be used to increase expression from a particular promoter. Examples of such enhancers include, but are not limited to the Adh intron1 (Callis *et al.*, 1987), a rice actin intron (McElroy *et al.*, 1991, U.S. Patent No. 5,641,876), sucrose synthase intron (Vasil *et al.*, 1989), a maize HSP70 intron (also referred to as Zm.DnaK) (U.S. Patent 5,424,412, Brown *et al.*) a TMV omega element (Gallie *et al.*, 1999), the CaMV 35S enhancer (U.S. Patents 5,359,142 & 5,196,525, McPherson *et al.*) or an octopine synthase enhancer (U.S. Patent 5,290,924, Last *et al.*). As the DNA sequence between the transcription initiation site and the start of the coding sequence, *i.e.* the untranslated leader sequence, can influence gene expression, one may also wish to employ a particular leader sequence. Any leader sequence available to one of skill in the art may be employed. Preferred leader sequences direct optimum levels of expression of the attached gene, for example, by increasing or maintaining mRNA stability and/or by preventing inappropriate initiation of translation (Joshi, 1987). The choice of such sequences is at the discretion of those of skill in the art.

DNA constructs of the invention may include a sequence near the 3' end of the cassette that acts as a signal to terminate transcription from a heterologous nucleic acid and that directs polyadenylation of the resultant mRNA. These are commonly referred to as 3' untranslated regions or 3' UTRs. Some 3' elements that can act as transcription termination signals include those from the nopaline synthase gene (*nos*) of *Agrobacterium tumefaciens* (Bevan *et al.*, 1983), a napin 3' untranslated region (Kridl *et al.*, 1991), a globulin 3' untranslated region (Belanger and Kriz, 1991), 3' untranslated region from the *Adr12* gene of soybean (auxin down regulated) (Wang *et al.*, PCT Publication WO200250295) or one from a zein gene, such as Z27 (Lopes *et al.*, 1995). Other 3' regulatory elements known to the art also can be used in the vectors of the invention.

A nucleic acid molecule as described herein can be cloned into any suitable vector and can be used to transform or transfect any suitable host. The selection of vectors and methods to construct them are commonly known to the art and are described in general technical references (see, in general, Recombinant DNA Part D, 1987). The vector will preferably comprise regulatory sequences, such as transcription and translation initiation and termination codons, which are specific to the type of host (*e.g.*, bacterium, fungus, or plant) into which the vector is to be introduced, as appropriate and taking into consideration whether the vector is DNA or RNA.

Vectors that are circular or linear can be prepared to contain an entire nucleic acid sequence as described above or a portion thereof ligated to a replication system functional in a prokaryotic or eukaryotic host cell. Replication systems can be derived from ColE1, 2 μ plasmid, λ phage, f1 filamentous phage, *Agrobacterium* species (*e.g.*, *A. tumefaciens* and *A. rhizogenes*), and the like.

In addition to the replication system and the inserted nucleic acid sequence, the vector can include one or more marker genes that allow for selection of transformed or transfected hosts. Marker genes include biocide resistance, such as resistance to antibiotics, heavy metals, herbicides, *etc.*, complementation in an auxotrophic host to provide prototrophy, and the like.

The invention provides host cells comprising a nucleic acid molecule described herein, optionally in the form of a vector. Suitable hosts include plant, bacterial and fungal cells, including *Escherichia coli*, *Bacillus subtilis*, *Agrobacterium tumefaciens*, *Saccharomyces cerevisiae* and *Neurospora crassa*. *E. coli* hosts include

5 TB-1, TG-2, DH5 α , XL-Blue MRF' (Stratagene, Austin, TX), SA2821, Y1090 and TG02. Plant cells include, but not limited to, soybean, *Brassica campestris*, canola, oilseed rape, rapeseed, crambe, mustard, castor bean, peanut, sesame, cottonseed, linseed, safflower, oil palm, flax, sunflower, alfalfa, corn, wheat, barley, oats, rye, millet, sorghum, and rice.

10 Expression in a host cell can be accomplished in a transient or stable fashion. Transient expression can occur from introduced constructs which contain expression signals functional in the host cell, but which constructs do not replicate and rarely integrate in the host cell, or where the host cell is not proliferating. Transient expression also can be accomplished by inducing the activity of a regulatable

15 promoter operably linked to the gene of interest, although such inducible systems frequently exhibit a low basal level of expression. Stable expression can be achieved by introduction of a construct that can integrate into the host genome or that autonomously replicates in the host cell. Stable expression of the gene of interest can be selected for through the use of a selectable marker located on or transfected with

20 the expression construct, followed by selection for cells expressing the marker. When stable expression results from integration, integration of constructs can occur randomly within the host genome or can be targeted through the use of constructs containing regions of homology with the host genome sufficient to target recombination with the host locus. Where constructs are targeted to an endogenous

25 locus, all or some of the transcriptional and translational regulatory regions can be provided by the endogenous locus.

Expression in a host cell may involve fermentation techniques known to one skilled in the art. The fermented host cell may be a prokaryote, such as *Escherichia coli*, or a eukaryote, such as the yeast *Saccharomyces cerevisiae* or *Neurospora*

30 *crassa*, a filamentous fungi. Examples of production of PUFA by fermentation include *Mortierella* (U.S. Patent 6,319,698) and *Thraustochytriales* (U.S. Patent 6,451,567).

It is contemplated that more than one gene may be introduced and propagated in a host cell through the use of episomal or integrated expression vectors. Where two or more genes are expressed from separate replicating vectors, it is desirable that each vector has a different means of replication. Each introduced construct, whether
5 integrated or not, should have a different means of selection and should lack homology to the other constructs to maintain stable expression and prevent reassortment of elements among constructs. Judicious choices of regulatory regions, selection means and method of propagation of the introduced construct can be experimentally determined so that all introduced polynucleotides are expressed at the
10 necessary levels to provide for synthesis of the desired products.

Polypeptides

The invention provides delta 6 desaturases encoded by nucleic acid molecules described herein. Delta 6 desaturases are enzymes that can desaturate or catalyze formation of a double bond between consecutive carbons at the 6 position of one or
15 more fatty acids to produce a mono- or poly-unsaturated fatty acid or a precursor thereof. The polypeptide can comprise D-amino acids, L-amino acids or a mixture of D- and L-amino acids.

Alterations of the native amino acid sequence to produce variant polypeptides can be prepared by a variety of means known to those ordinarily skilled in the art. For
20 instance, amino acid substitutions can be conveniently introduced into the polypeptides by changing the sequence of the nucleic acid molecule at the time of synthesis. Site-specific mutations can also be introduced by ligating into an expression vector a synthesized oligonucleotide comprising the modified sequence. Alternately, oligonucleotide-directed, site-specific mutagenesis procedures can be
25 used, such as disclosed in Walder *et al.* (1986); Bauer *et al.* (1985); and U.S. Patents 4,518,584 and 4,737,462.

It is within the skill of the ordinary artisan to select synthetic and naturally-occurring amino acids that effect conservative or neutral substitutions for any particular naturally-occurring amino acids. The ordinarily skilled artisan desirably
30 will consider the context in which any particular amino acid substitution is made, in addition to considering the hydrophobicity or polarity of the side-chain, the general

size of the side chain and the pK value of side-chains with acidic or basic character under physiological conditions. For example, lysine, arginine, and histidine are often suitably substituted for each other, and more often arginine and histidine. As is known in the art, this is because all three amino acids have basic side chains, whereas

5 the pK value for the side-chains of lysine and arginine are much closer to each other (about 10 and 12) than to histidine (about 6). Similarly, glycine, alanine, valine, leucine, and isoleucine are often suitably substituted for each other, with the proviso that glycine is frequently not suitably substituted for the other members of the group. This is because each of these amino acids is relatively hydrophobic when incorporated

10 into a polypeptide, but glycines lack of an α -carbon allows the phi and psi angles of rotation (around the α -carbon) so much conformational freedom that glycyl residues can trigger changes in conformation or secondary structure that do not often occur when the other amino acids are substituted for each other. Other groups of amino acids frequently suitably substituted for each other include, but are not limited to, the

15 group consisting of glutamic and aspartic acids; the group consisting of phenylalanine, tyrosine and tryptophan; and the group consisting of serine, threonine and, optionally, tyrosine. Additionally, the ordinarily skilled artisan can readily group synthetic amino acids with naturally-occurring amino acids.

If desired, the polypeptides can be modified, for instance, by glycosylation,

20 amidation, carboxylation, or phosphorylation, or by the creation of acid addition salts, amides, esters, in particular C-terminal esters, and N-acyl derivatives of the polypeptides of the invention. The polypeptides also can be modified to create protein derivatives by forming covalent or noncovalent complexes with other moieties in accordance with methods known in the art. Covalently-bound complexes can be

25 prepared by linking the chemical moieties to functional groups on the side chains of amino acids comprising the polypeptides, or at the N- or C-terminus. Desirably, such modifications and conjugations do not adversely affect the activity of the polypeptides (and variants thereof). While such modifications and conjugations can have greater or lesser activity, the activity desirably is not negated and is characteristic of the

30 unaltered polypeptide.

The polypeptides (and fragments, variants and fusion proteins) can be prepared by any of a number of conventional techniques. The polypeptide can be

isolated or substantially purified from a naturally occurring source or from a recombinant source. For instance, in the case of recombinant proteins, a DNA fragment encoding a desired protein can be subcloned into an appropriate vector using well-known molecular genetic techniques (see, *e.g.*, Maniatis *et al.*, 1989) and other references cited herein under "EXAMPLES"). The fragment can be transcribed and the protein subsequently translated in vitro. Commercially available kits also can be employed (*e.g.*, such as manufactured by Clontech, Mountain View, CA; Amersham Life Sciences, Inc., Arlington Heights, IL; Invitrogen, Carlsbad, CA and the like). The polymerase chain reaction optionally can be employed in the manipulation of nucleic acids.

Polypeptides can be synthesized using an automated peptide synthesizer in accordance with methods known in the art. Alternately, the polypeptide (and fragments, variants, and fusion proteins) can be synthesized using standard peptide synthesizing techniques well-known to those of ordinary skill in the art (*e.g.*, as summarized in Bodanszky, 1984). In particular, the polypeptide can be synthesized using the procedure of solid-phase synthesis (see, *e.g.*, Merrifield, 1963; Barany *et al.*, 1987 and U.S. Patent 5,424,398). If desired, this can be done using an automated peptide synthesizer. Removal of the t-butyloxycarbonyl (t-BOC) or 9-fluorenylmethyloxycarbonyl (Fmoc) amino acid blocking groups and separation of the protein from the resin can be accomplished by, for example, acid treatment at reduced temperature. The polypeptide-containing mixture then can be extracted, for instance, with diethyl ether, to remove non-peptidic organic compounds, and the synthesized protein can be extracted from the resin powder (*e.g.*, with about 25% w/v acetic acid). Following the synthesis of the polypeptide, further purification (*e.g.*, using HPLC) optionally can be done in order to eliminate any incomplete proteins, polypeptides, peptides or free amino acids. Amino acid and/or HPLC analysis can be performed on the synthesized polypeptide to validate its identity. For other applications according to the invention, it may be preferable to produce the polypeptide as part of a larger fusion protein, either by chemical conjugation, or through genetic means known to the art. In this regard, this invention also provides a fusion protein comprising the polypeptide (or fragment thereof) or variant thereof and one or more other polypeptides/protein(s) having any desired properties or effector functions.

Assays for the production and identification of specific proteins are based on various physical-chemical, structural, functional, or other properties of the proteins. Unique physical-chemical or structural properties allow the proteins to be separated and identified by electrophoretic procedures, such as native or denaturing gel electrophoresis or isoelectric focusing, or by chromatographic techniques such as ion exchange or gel exclusion chromatography. The unique structures of individual proteins offer opportunities for use of specific antibodies to detect their presence in formats such as an ELISA assay. Combinations of approaches can be used to achieve even greater specificity such as western blotting in which antibodies are used to locate individual gene products that have been separated by electrophoretic techniques. Additional techniques can be used to absolutely confirm the identity of the product of interest such as evaluation by amino acid sequencing following purification. Although these are among the most common, other procedures can also be used.

Assay procedures can identify the expression of proteins by their functionality, particularly where the expressed protein is an enzyme capable of catalyzing chemical reactions involving specific substrates and products. For example, in plant extracts these reactions can be measured by providing and quantifying the loss of substrates or the generation of products of the reactions by physical and/or chemical procedures.

In many cases, the expression of a gene product is determined by evaluating the phenotypic results of its expression. Such evaluations may be simply as visual observations, or may involve assays. Such assays can take many forms, such as analyzing changes in the chemical composition, morphology, or physiological properties of the plant. Chemical composition may be altered by expression of genes encoding enzymes or storage proteins that change amino acid composition and these changes can be detected by amino acid analysis, or by enzymes that change starch quantity, which can be analyzed by near infrared reflectance spectrometry or by enzymes that change oil composition, which can be detected by gas chromatography. Morphological changes may include greater stature or thicker stalks.

The nucleic acid molecules, DNA constructs and polypeptides of this invention can be used in agricultural methods and various screening assays. For example, a nucleic acid molecule can be used to express a delta 6 desaturase via a

vector in a host cell, to detect mRNA transcripts encoding delta 6 desaturases in a biological sample, to detect a genetic alteration in a gene encoding delta 6 desaturase *via* a Southern blot, to suppress delta 6 desaturases, or to up-regulate delta 6 desaturases. The polypeptides can be used to compensate for deficiencies in delta 6 desaturases or for the presence of a mutated delta 6 desaturases having reduced or no activity in a plant, or to treat excessive levels of substrates, whether direct or indirect, for delta 6 desaturases in a plant. Alternatively, the polypeptides can be used to screen agents for the ability to modulate their activity. The antibodies can be used to detect and isolate the respective polypeptides as well as decrease the availability of such polypeptides *in vivo*.

Plant transformation

In a preferred embodiment of the invention, a transgenic plant expressing the desired protein or proteins is produced. Various methods for the introduction of a desired polynucleotide sequence encoding the desired protein into plant cells are known to the art, including: (1) physical methods such as microinjection, electroporation, and microparticle-mediated delivery (biolistics or gene gun technology); (2) virus-mediated delivery; and (3) *Agrobacterium*-mediated transformation.

The most commonly used methods for transformation of plant cells are the *Agrobacterium*-mediated DNA transfer process and the biolistics or microprojectile microparticle bombardment mediated process. Typically, nuclear transformation is desired but where it is desirable to specifically transform plastids, such as chloroplasts or amyloplasts, plant plastids may be transformed utilizing a microparticle-mediated delivery of the desired polynucleotide.

Agrobacterium-mediated transformation is achieved through the use of a genetically engineered soil bacterium belonging to the genus *Agrobacterium*. A number of wild-type and disarmed strains of *Agrobacterium tumefaciens* and *Agrobacterium rhizogenes* harboring Ti or Ri plasmids can be used for gene transfer into plants. Gene transfer is done via the transfer of a specific DNA known as “T-DNA” that can be genetically engineered to carry any desired piece of DNA into

many plant species, as further elaborated, for example, in U.S. Patent 6,265,638 to Bidney *et al.*, the disclosures of which are hereby incorporated herein by reference.

Agrobacterium-mediated genetic transformation of plants involves several steps. The first step, in which the virulent *Agrobacterium* and plant cells are first brought into contact with each other, is generally called “inoculation”. Inoculation is preferably accompanied by some method of injury to some of the plant cells, which releases plant cellular constituents, such as coumaryl alcohol, sinapinate (which is reduced to acetosyringone), sinapyl alcohol, and coniferyl alcohol, that activate virulence factors in the *Agrobacterium*. Following the inoculation, the *Agrobacterium* and plant cells/tissues are permitted to grow together for a period of several hours to several days or more under conditions suitable for growth and T-DNA transfer. This step is termed “co-culture”. Following co-culture and T-DNA delivery, the plant cells are treated with bactericidal or bacteriostatic agents to kill the *Agrobacterium* remaining in contact with the explant and/or in the vessel containing the explant. If this is done in the absence of any selective agents to promote preferential growth of transgenic versus non-transgenic plant cells, then this is typically referred to as the “delay” step. If done in the presence of selective pressure favoring transgenic plant cells, then it is referred to as a “selection” step. When a “delay” is used, it is typically followed by one or more “selection” steps.

With respect to microparticle bombardment (U.S. Patent 5,550,318 (Adams *et al.*); U.S. Patent 5,538,880 (Lundquist *et al.*), U.S. Patent 5,610,042 (Chang *et al.*); and PCT WO 95/06128 (Adams *et al.*); each of which is specifically incorporated herein by reference in its entirety), microscopic particles are coated with nucleic acids and delivered into cells by a propelling force. Exemplary particles include those comprised of tungsten, platinum, and preferably, gold.

An illustrative embodiment of a method for delivering DNA into plant cells by acceleration is the Biolistics Particle Delivery System (BioRad, Hercules, CA), which can be used to propel particles coated with DNA or cells through a screen, such as a stainless steel or Nytex screen, onto a filter surface covered with monocot plant cells cultured in suspension.

Microparticle bombardment techniques are widely applicable, and may be used to transform virtually any plant species. Examples of species that have been transformed by microparticle bombardment include monocot species such as maize (International Publication No. WO 95/06128 (*Adams et al.*)), barley, wheat (U.S. Patent 5,563,055 (Townsend *et al.*)) incorporated herein by reference in its entirety), rice, oat, rye, sugarcane, and sorghum; as well as a number of dicots including tobacco, soybean (U.S. Patent 5,322,783 (Tomes *et al.*)), incorporated herein by reference in its entirety), sunflower, peanut, cotton, tomato, and legumes in general (U.S. Patent 5,563,055 (Townsend *et al.*)) incorporated herein by reference in its entirety).

To select or score for transformed plant cells regardless of transformation methodology, the DNA introduced into the cell contains a gene that functions in a regenerable plant tissue to produce a compound that confers upon the plant tissue resistance to an otherwise toxic compound. Genes of interest for use as a selectable, screenable, or scoreable marker would include but are not limited to β -glucuronidase (GUS), green fluorescent protein (GFP), luciferase (LUX), antibiotic or herbicide tolerance genes. Examples of antibiotic resistance genes include the penicillins, kanamycin (and neomycin, G418, bleomycin); methotrexate (and trimethoprim); chloramphenicol; kanamycin and tetracycline. Polynucleotide molecules encoding proteins involved in herbicide tolerance are known in the art, and include, but are not limited to a polynucleotide molecule encoding 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) described in U.S. Patent 5,627,061 (Barry, *et al.*), U.S. Patent 5,633,435 (Barry, *et al.*), and U.S. Patent 6,040,497 (Spencer, *et al.*) and *aroA* described in U.S. Patent 5,094,945 (Comai) for glyphosate tolerance; a polynucleotide molecule encoding bromoxynil nitrilase (Bxn) described in U.S. Patent 4,810,648 (Duerrschnabel, *et al.*) for Bromoxynil tolerance; a polynucleotide molecule encoding phytoene desaturase (*crtI*) described in Misawa *et al.* (1993); Misawa *et al.* (1994) for norflurazon tolerance; a polynucleotide molecule encoding acetohydroxyacid synthase (AHAS, aka ALS) described in Sathasiivan *et al.* (1990) for tolerance to sulfonylurea herbicides; and both the *pat* gene described in Wohlleben *et al.*, (1988) and bar gene described in DeBlock *et al.* (1987), each of which provides glufosinate and bialaphos tolerance.

The regeneration, development, and cultivation of plants from various transformed explants are well documented in the art. This regeneration and growth process typically includes the steps of selecting transformed cells and culturing those individualized cells through the usual stages of embryonic development through the rooted plantlet stage. Transgenic embryos and seeds are similarly regenerated. The resulting transgenic rooted shoots are thereafter planted in an appropriate plant growth medium such as soil. Cells that survive the exposure to the selective agent, or cells that have been scored positive in a screening assay, may be cultured in media that supports regeneration of plants. Developing plantlets are transferred to soil less plant growth mix, and hardened off, prior to transfer to a greenhouse or growth chamber for maturation.

This invention can be used with any transformable cell or tissue. By transformable as used herein is meant a cell or tissue that is capable of further propagation to give rise to a plant. Those of skill in the art recognize that a number of plant cells or tissues are transformable in which after insertion of exogenous DNA and appropriate culture conditions the plant cells or tissues can form into a differentiated plant. Tissue suitable for these purposes can include but is not limited to immature embryos, scutellar tissue, suspension cell cultures, immature inflorescence, shoot meristem, nodal explants, callus tissue, hypocotyl tissue, cotyledons, roots, and leaves. The Tomes *et al.* '783 patent, cited above, describes a method of treatment with a cytokinin followed by incubation for a period sufficient to permit undifferentiated cells in cotyledonary node tissue to differentiate into meristematic cells and to permit the cells to enter the phases between the G1 and division phases of development, which is stated to improve susceptibility for transformation.

Any suitable plant culture medium can be used. Suitable media include but are not limited to MS-based media (Murashige and Skoog, 1962) or N6-based media (Chu *et al.*, 1975) supplemented with additional plant growth regulators including but not limited to auxins, cytokinins, ABA, and gibberellins. Those of skill in the art are familiar with the variety of tissue culture media, which when supplemented appropriately, support plant tissue growth and development and are suitable for plant transformation and regeneration. These tissue culture media can either be purchased

as a commercial preparation, or custom prepared and modified. Those of skill in the art are aware that media and media supplements such as nutrients and growth regulators for use in transformation and regeneration and other culture conditions such as light intensity during incubation, pH, and incubation temperatures that can be optimized for the particular variety of interest.

After a DNA construct is stably incorporated in transgenic plants and confirmed to be operable, it can be introduced into other plants of the same or another sexually compatible species by sexual crossing. Any of a number of standard breeding techniques can be used, depending upon the species to be crossed.

Therefore, the current invention not only encompasses a plant directly transformed or regenerated from cells which have been transformed in accordance with the current invention, but also the progeny of such plants. As used herein the term "progeny" denotes the offspring of any generation of a parent plant prepared in accordance with the instant invention, wherein the progeny comprises a selected DNA construct prepared in accordance with the invention. "Crossing" a plant to provide a plant line having one or more added transgenes or alleles relative to a starting plant line, as disclosed herein, is defined as the techniques that result in a particular sequence being introduced into a plant line by crossing a starting line with a donor plant line that comprises a transgene or allele of the invention. To achieve this one could, for example, perform the following steps: (a) plant seeds of the first (starting line) and second (donor plant line that comprises a desired transgene or allele) parent plants; (b) grow the seeds of the first and second parent plants into plants that bear flowers; (c) pollinate a flower from the first parent plant with pollen from the second parent plant; and (d) harvest seeds produced on the parent plant bearing the fertilized flower.

Backcrossing is herein defined as the process including the steps of: (a) crossing a plant of a first genotype containing a desired gene, DNA sequence or element to a plant of a second genotype lacking said desired gene, DNA sequence or element; (b) selecting one or more progeny plant containing the desired gene, DNA sequence or element; (c) crossing the progeny plant to a plant of the second genotype; and (d) repeating steps (b) and (c) for the purpose of transferring a desired DNA sequence from a plant of a first genotype to a plant of a second genotype.

Introgression of a DNA element into a plant genotype is defined as the result of the process of backcross conversion. A plant genotype into which a DNA sequence has been introgressed may be referred to as a backcross converted genotype, line, inbred, or hybrid. Similarly a plant genotype lacking the desired DNA sequence
5 may be referred to as an unconverted genotype, line, inbred, or hybrid.

Seeds, Meal, Oil and Products Comprising Seeds, Meal and Oil

This invention also provides a container of over about 1000, more preferably about 20,000, and even more preferably about 40,000 seeds where over about 10%, more preferably about 25%, more preferably about 50%, and even more preferably
10 about 75% or more preferably about 90% of the seeds are seeds derived from a plant of this invention.

This invention also provides a container of over about 10 kg, more preferably about 25 kg, and even more preferably about 50 kg seeds where over about 10%, more preferably about 25%, more preferably about 50%, and even more preferably
15 about 75% or more preferably about 90% of the seeds are seeds derived from a plant of this invention.

Any of the plants or parts thereof of this invention may be harvested and, optionally, processed to produce a feed, meal, or oil preparation. A particularly preferred plant part for this purpose is harvested grain, but other plant parts can be
20 harvested and used for stover or silage. Methods to produce feed, meal, and oil preparations are known in the art. *See*, for example, U.S. Patents 4,957,748; 5,100,679; 5,219,596; 5,936,069; 6,005,076; 6,146,669; and 6,156,227. The grain or meal of this invention may be blended with other grains or meals.

The invention provides an oil composition extracted from corn seed having a
25 GLA content of from about 5% to about 26% by weight of total fatty acids and further comprising and SDA content from about 3% to about 13%. The invention is also embodied by an oil composition extracted from corn seed comprising a GLA content of at least 3% by weight of total fatty acids and an SDA content of at least 3% by weight of total fatty acids, wherein the ratio of GLA/SDA is between about 1.3 and
30 about 3.7. The invention also provides an oil composition extracted from soybean seed having a GLA content from about 9% to about 51% by weight of total fatty acids

and may further comprise an SDA content of from about 0.5% to about 10% by weight of total fatty acids. The invention is also embodied by an oil composition extracted from soybean seed comprising a GLA content of at least 1% by weight of total fatty acids and an SDA content of at least 1% by weight of total fatty acids, wherein the ratio of GLA/SDA is between about 2.8 and about 18.3.

Methods

The present invention provides a method for providing transgenic plants with an increased content of GLA or SDA. This method may include, for example, introducing DNA encoding a delta 6 desaturase and optionally at least one additional desaturase into plant cells and regenerating plants with increased GLA or SDA content from the transgenic cells.

More specifically, the invention provides a method of producing food or feed, comprising the steps of (a) obtaining the transgenic plant of the invention; and (b) producing the food or feed. The food or feed may be oil, silage, meal, grain, starch, flour or protein. The food or feed composition is defined as comprising a detectable polynucleotide sequence or detectable polypeptide provided by the invention. Additionally, the invention provides animal feed and human food compositions comprising GLA or SDA.

For dietary supplementation, the purified PUFAs, transformed plants or plant parts, or derivatives thereof, may be incorporated into cooking oils, fats or margarines formulated so that in normal use the recipient would receive the desired amount. The PUFAs may also be incorporated into infant formulas, nutritional supplements or other food products, and may find use as anti-inflammatory or cholesterol lowering agents.

As used herein, "edible composition" is defined as compositions which may be ingested by a mammal such as foodstuffs, nutritional substances and pharmaceutical compositions. As used herein "foodstuffs" refer to substances that can be used or prepared for use as food for a mammal and include substances that may be used in the preparation of food (such as frying oils) or food additives. For example, foodstuffs include animals used for human consumption or any product therefrom, such as, for example, eggs. Typical foodstuffs include but are not limited

to beverages, (*e.g.*, soft drinks, carbonated beverages, ready to mix beverages), infant formula, infused foods (*e.g.* fruits and vegetables), sauces, condiments, salad dressings, fruit juices, syrups, desserts (*e.g.*, puddings, gelatin, icings and fillings, baked goods and frozen desserts such as ice creams and sherbets), soft frozen products (*e.g.*, soft frozen creams, soft frozen ice creams and yogurts, soft frozen toppings such as dairy or non-dairy whipped toppings), oils and emulsified products (*e.g.*, shortening, margarine, mayonnaise, butter, cooking oil, and salad dressings) and intermediate moisture foods (*e.g.*, rice and dog foods).

Furthermore, edible compositions described herein can also be ingested as an additive or supplement contained in foods and drinks. These can be formulated together with a nutritional substance such as various vitamins and minerals and incorporated into substantially liquid compositions such as nutrient drinks, soymilks and soups; substantially solid compositions; and gelatins or used in the form of a powder to be incorporated into various foods. The content of the effective ingredient in such a functional or health food can be similar to the dose contained in a typical pharmaceutical agent.

The purified PUFAs, transformed plants or plant parts may also be incorporated into animal, particularly livestock, feed. In this way, the animals themselves may benefit from a PUFA rich diet, while human consumers of food products produced from such livestock may benefit as well.

For pharmaceutical use (human or veterinary), the compositions may generally be administered orally but can be administered by any route by which they may be successfully absorbed, *e.g.*, parenterally (*i.e.* subcutaneously, intramuscularly or intravenously), rectally, vaginally or topically, for example, as a skin ointment or lotion. The PUFAs, transformed plants or plant parts of the present invention may be administered alone or in combination with a pharmaceutically acceptable carrier or excipient. Where available, gelatin capsules are the preferred form of oral administration. Dietary supplementation as set forth above can also provide an oral route of administration. The unsaturated acids of the present invention may be administered in conjugated forms, or as salts, esters, amides or prodrugs of the fatty acids. Any pharmaceutically acceptable salt is encompassed by the present invention;

especially preferred are the sodium, potassium or lithium salts. Also encompassed are the N-alkylpolyhydroxamine salts, such as N-methyl glucamine, found in PCT publication WO 96/33155. The preferred esters are the ethyl esters. As solid salts, the PUFAs also can be administered in tablet form. For intravenous administration, the PUFAs or derivatives thereof may be incorporated into commercial formulations such as Intralipids.

EXAMPLES

The following examples are included to illustrate embodiments of the invention. It should be appreciated by those of skill in the art that the techniques disclosed in the examples that follow represent techniques discovered by the inventor to function well in the practice of the invention. However, those of skill in the art should, in light of the present disclosure, appreciate that many changes can be made in the specific embodiments which are disclosed and still obtain a like or similar result without departing from the concept, spirit and scope of the invention. More specifically, it will be apparent that certain agents which are both chemically and physiologically related may be substituted for the agents described herein while the same or similar results would be achieved. All such similar substitutes and modifications apparent to those skilled in the art are deemed to be within the spirit, scope and concept of the invention as defined by the appended claims.

Example 1

Cloning of *Tetraselmis suecica* $\Delta 6$ Desaturase Sequences

Cloning of the *Tetraselmis suecica* $\Delta 6$ desaturase (TsD6D) was achieved by PCR amplification of a partial internal genomic DNA region using degenerate oligonucleotides, followed by RACE library screening. Genomic DNA was isolated from *T. suecica* strain CCMP904 (CCMP, West Boothbay Harbor, ME, USA) using DNAsol (Invitrogen, Carlsbad, CA). A 578 bp internal region was amplified by PCR using the degenerate oligonucleotide primers D6DegF2: 5'-TGGTGGGAARRMSAAGCAYAAC-3' (SEQ ID NO: 5) and D6DegR3: 5'-ARDCCWCCVBDRAACCARTY-3' (SEQ ID NO: 6). These primers were designed using DNA sequence alignments of related $\Delta 6$ desaturases. The resulting PCR fragment was ligated into the pCR2.1-TOPO (Invitrogen), giving the plasmid pMON67050. After sequencing, the cloned insert was found to contain the conserved

amino acid sequence QXXHH (SEQ ID NO:22), which is found in all front-end desaturases (Napier *et al.*, 1997, Napier *et al.*, 2003, Sperling and Heinz, 2001). Examples of front-end desaturases include the $\Delta 4$, $\Delta 5$, and $\Delta 6$ fatty acid desaturases, in addition to the sphingolipid $\Delta 8$ desaturases. This genomic sequence allowed for the design of gene-specific primers so that a full-length putative $\Delta 6$ desaturase cDNA could be cloned.

Total RNA was isolated from *T. suecica* cells by a modified CTAB procedure (Jones *et al.*, 1995) and the RNA was used to generate a GeneRacer™ library following the manufacturer's instructions (Invitrogen). A 5' RACE reaction using the gene specific primer, Phy D6 R2: 5'-AGTAGCCAGGCATAGTGCAGCGCAAT-3' (SEQ ID NO: 7) and the GeneRacer 5' Primer: 5'-CGACTGGAGCACGAGGACACTGA-3' (Invitrogen; (SEQ ID NO:23)) yielded a 1264 bp fragment that overlapped with pMON67050 by 310 bp. A 3' RACE reaction using the gene-specific primer D6DegF3: 5'-TTCAACGATTGGTTCACGGGTGGC-3' (SEQ ID NO: 8) and the GeneRacer 3' Primer: 5'-GCTGTCAACGATACGCTACGTAACG-3' (Invitrogen (SEQ ID NO:24)) yielded a 405 bp fragment that overlapped by 56 bp with the 5' RACE product to give a combined virtual fragment with an open reading frame (ORF) of 1529 nucleotides. The predicted amino acid sequence from the ORF contained conserved sequences that are diagnostic for a $\Delta 6$ fatty acid desaturase including an N-terminal cytochrome *b₅* domain which is found in all front-end desaturases (Napier *et al.*, 2003) and three conserved histidine boxes that are characteristic of all membrane-bound desaturases (Shanklin *et al.*, 1994). A distinguishing feature found in all front-end desaturases including the putative TsD6D herein is that the third histidine box contains a glutamine residue in the first position (Q-x-x-H-H) instead of a histidine (Napier *et al.*, 1997, Napier *et al.*, 2003, Sperling and Heinz, 2001).

Using the *T. suecica* RACE sequences described above, specific oligonucleotide primers were designed to amplify the complete ORF for the putative TsD6D. The first primer (TsD6D-F1: 5'-AACATGGGCAGGGGTGGGTTTACTG-3' (SEQ ID NO: 9)) added a yeast Kozak sequence 5' of the ATG start site and the reverse primer (TsD6D-R1: 5'-CTAAGCAAGTGCCGCGATGTCCG-3' (SEQ ID NO: 10)) added a stop codon to the 3' end of the amplified product. These primers were used to generate a 1536 bp fragment by PCR amplification from the RACE

library that was ligated into the yeast expression vector pYES2.1/V5-His-TOPO (Invitrogen). Two distinct versions of the full-length ORFs were identified which differed by 22 nucleotides and 5 amino acids. The nucleic acid sequences of the two putative *T. suecica* $\Delta 6$ fatty acid desaturases, referred to as TsD6D-1 and TsD6D-2, are shown in SEQ ID NO: 1 and SEQ ID NO: 3, respectively. The corresponding amino acid sequences for TsD6D-1 and TsD6D-2 are shown in SEQ ID NO: 2 and SEQ ID NO: 4, respectively. Both sequences encode a potential polypeptide of 510 amino acids.

Alignment of the two *T. suecica* amino acid sequences with $\Delta 6$ desaturases from *Isochrysis galbana* and *Mortierella alpina* shows extensive diversity across the entire protein with regions of high homology surrounding the conserved histidine boxes (FIG. 1). *I. galbana* and *T. suecica* are marine algae and *M. alpina* is an oleaginous fungus that accumulates high levels of arachidonic acid. The percent identities for these amino acid sequences are shown in Table 1.

Table 1: Pair-wise alignment percentage identities for deduced amino acid sequences of D6 desaturases.

1	2	3	4	Organism
-----	22	22	22	1 <i>Isochrysis galbana</i> SEQ ID NO: 11
	-----	37	37	2 <i>Mortierella alpina</i> SEQ ID NO: 12
		-----	99	3 TsD6D-1 SEQ ID NO: 2
			-----	4 TsD6D-2 SEQ ID NO: 4

I. galbana: Accession AX577009, deduced amino acid from SEQ ID NO: 34, WO02081668.

M. alpina: Accession AAF08685

Example 2

Yeast Transformation and Expression

The pYES2.1/V5-His clones containing TsD6D-1 and TsD6D-2 were introduced into the host strain *Saccharomyces cerevisiae* INVSc1 (auxotrophic for uracil) (Invitrogen) using the PEG/Li Ac protocol as described in the Invitrogen manual for pYES2.1/V5-His-TOPO. Transformants were selected on plates made of SC minimal media minus uracil with 2% glucose. Colonies of transformants were used to inoculate 8 ml of SC minimal media minus uracil and 2% glucose grown overnight at 30°C. For induction, stationary phase yeast cells were pelleted and re-suspended in SC minimal media minus uracil supplemented with 2% galactose and grown for 3 days at 15°C. When exogenous fatty acids were provide to the cultures, 0.01% LA ($\Delta 9,12-18:2$) or 0.01% ALA ($\Delta 9,12,15-18:3$) was added with the

emulsifier 0.1% Tergitol. The cultures were grown for 3 days at 15°C, and subsequently harvested by centrifugation. Cell pellets were washed once with sterile TE buffer pH 7.5, to remove the media, and lyophilized to dryness. The host strain transformed with the vector containing the LacZ gene was used as a negative control
5 in all experiments.

Lipids were extracted from lyophilized yeast pellets by adding 0.1 mL toluene and incubating over-night at room temperature. Extracted lipids were converted to fatty acid methyl esters (FAMES) *in situ* by addition of 0.5 mL 0.6N sodium methoxide in methanol and incubating for 45 min at room temperature. The FAMES
10 were extracted by addition of 0.8 mL 10% (w/v) NaCl and 0.15 mL of heptane. The heptane layer containing FAMES was removed and used directly for gas chromatography (GC). The FAMES were identified on a Hewlett-Packard 5890 II Plus GC (Hewlett-Packard, Palo Alto, CA) equipped with a flame-ionization detector and a capillary column (omegawax 250; 30m x 0.25mm i.d. x 0.25µm; Supelco,
15 Bellefonte, PA). A 100:1 split ratio was used for injections. The injector was maintained at 250°C and the flame ionization detector was maintained at 270°C. The column temperature was maintained at 180°C for 1.5 min following injection, increased to 240°C at 40°C/min, and held at 245°C for 3.38 min.

The results shown in Table 2 demonstrate that *T. suecica* clones TsD6D-1 and
20 TsD6D-2 exhibit $\Delta 6$ desaturase activity in a yeast expression system. The substrate preference was deduced from a yeast induction assay, whereby yeast cultures induced to express recombinant desaturase are fed LA, ALA, or equal volumes of LA and ALA. The yeast incorporates these fatty acids into their membranes where they become substrates for the recombinant desaturase. The products of LA and ALA $\Delta 6$
25 desaturation are GLA and SDA, respectively. Two individual colonies were selected for each vector. Both *T. suecica* clones demonstrated substrate selectivity for ALA that is 2 to 2.6 fold higher than for LA. The negative control is pYES2.1 vector containing a LacZ insert.

Table 2: Delta 6 desaturase activity of *T. suecica* TsD6D-1 and TsD6D-2 in a yeast expression system.

Construct	FA In Medium	LA	GLA	ALA	SDA	SDA/GLA
neg control	-	0	0	0	0	
neg control	LA	13.69	0	0	0	
neg control	ALA	0	0	25.02	0	
neg control	LA+ALA	7.96	0	12.17	0	
neg control	-	0	0	0	0	
neg control	LA	14.07	0	0	0	
neg control	ALA	0	0	26.82	0	
neg control	LA+ALA	8.62	0	13.44	0	
TsD6D-1	-	0	0	0	0	
TsD6D-1	LA	12.08	1.39	0	0	
TsD6D-1	ALA	0	0	19.87	1.27	
TsD6D-1	LA+ALA	8.65	0.44	13.54	1.08	2.45
TsD6D-1	-	0	0	0	0	
TsD6D-1	LA	11.61	1.2	0	0	
TsD6D-1	ALA	0.53	0	20.81	1.21	
TsD6D-1	LA+ALA	8.44	0.39	13.68	1.02	2.62
TsD6D-2	-	9.43	0	1.24	0	
TsD6D-2	LA	16.85	0.76	0	0	
TsD6D-2	ALA	0	0	31.62	1.7	
TsD6D-2	LA+ALA	5.83	0.35	8.02	0.69	1.97
TsD6D-2	-	0	0	0	0	
TsD6D-2	LA	9.07	0.61	0	0	
TsD6D-2	ALA	0	0	25.78	1.54	
TsD6D-2	LA+ALA	9.43	0.5	15.15	1.23	2.46

5

Example 3**Expression of *Tetraselmis suecica* $\Delta 6$ -desaturase in Soybean**

The activity of the *T. suecica* $\Delta 6$ -desaturase was evaluated in soybean seed by combining it with a dicot codon-enhanced $\Delta 15$ -desaturase from *Neurospora crassa* (NcFad3nno) (SEQ ID NO: 13) to give pMON94002 (FIG. 2). The vector pMON94002 was constructed in 3 steps. First, the restriction sites, SalI and Sse8387 I were added to the ends of the TsD6D-1 coding sequence (CDS) by PCR amplification from pMON67034 (TsD6D-1 in pYES2.1) using the oligonucleotides TsD6D-F3: 5'-GTCGACAAACAATGGGCAGGGGTGGGTTTA-3' (SEQ ID NO: 14), and TsD6D-R3: 5'-CCTGCAGGCTAAGCAAGTGCCGCGATGTC-3' (SEQ ID NO: 15) to give pMON67051. The TsD6D-1 CDS was next placed behind the seed-

specific 7S α promoter by digesting pMON67051 with SalI and Sse8387I and ligating the resulting fragment into XhoI/Sse8387I-digested pMON67052 to give pMON67053. The resulting 7S α ::TsD6D-1::E9 expression cassette was moved into a plant binary vector containing the NcFad3nno driven by the seed-specific promoter, USP99. This was accomplished by digesting the vector pMON67053 with NotI and then ligating the resulting fragment into partially NotI-digested pMON67046 (vector containing USP99::NcFAD3nno::nos) to give pMON94002.

Transformed explants containing pMON94002, were obtained via *Agrobacterium tumefaciens*-mediated transformation. Plants were regenerated from transformed tissue. The greenhouse-grown plants were then analyzed for oil composition. The effect of expression of the TsD6D-1 coding sequence in conjunction with the NcFad3nno was measured by determining the fatty acid composition of mature seed by gas chromatography of lipid methyl ester derivatives (PCT US03/16144, filed May 21, 2003, the entire disclosure of which is specifically incorporated herein by reference). The levels of OA (oleic acid), LA (linoleic acid), GLA (γ -linolenic acid), ALA (α -linolenic acid) and SDA (stearidonic acid) are expressed as a percentage of the total weight of measured fatty acids and are shown in Table 3. The non-transgenic line A3525 is included as a negative control. Values are expressed as an average of non-nulls from as many as 6 individual R1 seeds.

Table 3: Relative Area Percent Results from single R1 seed of soy transformed with pMON94002.

	Fatty Acid (percent wt)						
Pedigree	Gen	Oleic	LA	ALA	GLA	SDA	GLA/SDA
A3525	-	17.44	56.1	9.1	-	-	-
GM_A74156	R1	15.5	47.7	16.1	3.1	0.4	7.2
GM_A74004	R1	14.4	37.2	12.4	13.7	4.9	2.8
GM_A73961	R1	15.8	38.6	7.0	19.2	1.5	13.0
GM_A73654	R1	14.5	28.1	5.7	27.4	4.6	5.9
GM_A73962	R1	14.0	25.7	6.4	28.4	4.9	5.8
GM_A73657	R1	13.5	17.3	8.7	31.8	9.2	3.5
GM_A74165	R1	17.9	20.3	4.7	33.8	3.9	8.6
GM_A74162	R1	15.2	19.5	5.1	35.3	5.3	6.7
GM_A73612.	R1	22.6	8.1	3.1	38.1	4.3	8.8
GM_A73597	R1	18.4	6.7	3.7	39.3	6.2	6.3
GM_A74496	R1	18.5	10.6	4.3	39.4	6.5	6.0
GM_A73977	R1	15.6	10.6	4.9	41.1	7.9	5.2
GM_A73611	R1	18.4	12.2	3.9	41.4	4.7	8.9

GM_A74014	R1	16.3	11.0	3.9	41.9	5.5	7.6
GM_A74462	R1	15.4	10.1	4.8	42.3	7.0	6.0
GM_A74410	R1	15.7	8.1	4.0	42.6	7.2	6.0
GM_A73997	R1	13.0	13.6	4.8	42.8	6.0	7.1
GM_A73590	R1	14.8	8.4	4.3	42.8	8.0	5.3
GM_A73633	R1	18.3	9.3	3.4	43.3	4.8	9.1
GM_A73645	R1	14.4	8.0	4.5	43.4	8.0	5.4
GM_A74474	R1	15.1	11.4	3.9	43.5	5.6	7.8
GM_A74440	R1	15.5	7.7	4.4	43.8	7.6	5.7
GM_A74155	R1	12.5	8.8	4.3	43.9	8.8	5.0
GM_A73603	R1	15.1	8.1	4.5	44.0	7.3	6.0
GM_A74170	R1	14.5	13.6	3.6	44.1	3.7	11.8
GM_A73675	R1	15.4	12.8	3.9	44.4	4.2	10.5
GM_A74016	R1	14.0	10.7	4.1	44.6	6.1	7.3
GM_A73963	R1	11.8	8.0	4.2	44.9	9.0	5.0
GM_A73617	R1	15.6	7.4	3.7	45.0	6.8	6.6
GM_A74263	R1	13.3	9.4	4.6	45.0	8.2	5.5
GM_A74511	R1	12.6	7.0	4.1	45.2	9.3	4.9
GM_A74422	R1	12.0	8.1	4.7	45.6	9.8	4.7
GM_A74176	R1	13.8	8.6	4.2	45.7	7.6	6.0
GM_A73598	R1	14.6	8.8	3.6	45.8	5.9	7.8
GM_A74463	R1	15.3	9.3	3.9	45.9	5.3	8.7
GM_A74259	R1	13.5	12.4	4.2	46.1	5.8	7.9
GM_A74166	R1	14.0	10.3	3.8	46.1	5.5	8.4
GM_A73588	R1	10.6	10.3	4.6	46.3	7.6	6.1
GM_A74160	R1	16.9	10.1	2.8	46.4	2.5	18.3
GM_A73971	R1	15.5	10.4	2.9	47.0	3.1	15.0
GM_A74451	R1	12.7	10.5	3.7	47.9	6.0	7.9
GM_A73981	R1	12.9	7.2	2.8	50.3	5.3	9.5

All of the pMON94002 transgenic events in Table 3 accumulate measurable amounts of GLA and SDA. In all cases, the levels of GLA were greater than those of SDA, with GLA values ranging from 3.1% to 50.3% and SDA values ranging from 0.4% to 9.8%. The highest single seed value for GLA was observed from event GM_A73981, which contained 50.3% GLA and 5.3% SDA. Event GM_A74160 has the highest GLA/SDA ratio of 18.3. Of the 41 events shown above, 31 had GLA values >40% in at least three out of four seeds. As GLA values increase, the levels of LA decrease significantly with values starting at 56% and going as low as 6.7%. OA and ALA values also decreased with increasing PUFA but not to the same extent as the LA.

Example 4

Activity of the *Tetraselmis suecica* $\Delta 6$ -desaturase in Canola and *Arabidopsis*

The activity of the *Tetraselmis suecica* $\Delta 6$ -desaturase was evaluated by transforming *Arabidopsis* and canola with pMON82848 (TsD6D-1, FIG. 3) and
5 pMON82849 (TsD6D-2, FIG. 4). The native *T. suecica* TsD6D-1 and -2 genes are both driven by a 35S constitutive promoter.

pMON82848 was constructed in 2 steps. First, a consensus dicot Kozak sequence was added to the TsD6D coding sequence by PCR from pMON67034 using the primers TsD6D-F2: 5'- AAAAATGGGCAGGGGTGGGTTTACT-3' (SEQ ID
10 NO: 16) and TsD6D-R1: 5'- CTAAGCAAGTGCCGCGATGTCCG -3' (SEQ ID NO: 10) and then ligating the resulting fragment into pCR2.1-TOPO (Invitrogen) to give pMON82833. The vector pMON82833 was then digested with XhoI and SacI and the resulting fragment was ligated into SalI/SacI-digested pMON73273 to give pMON82848. The pMON82849 binary vector was constructed in a similar fashion
15 using the TsD6D-2 variant.

Transformed explants containing pMON82848 and pMON82849 were obtained via *Agrobacterium tumefaciens*-mediated transformation. Plants were regenerated from transformed tissue. The greenhouse-grown plants were then analyzed for oil composition. The fatty acid composition of lyophilized leaves was
20 determined by GC analysis of methyl ester-derived lipids as done above for soybean transformants and are shown in Tables 4 and 5. The levels of OA, LA, GLA, ALA, and SDA are expressed as a percentage of the total weight of measured fatty acids.

The GC analysis of canola leaf from plants transformed with pMON82848 yielded 33 events with GLA levels ranging from 0.7% to 21.5% and SDA levels
25 ranging from 0.5% to 12.9%, respectively. The GLA values are consistently greater than the SDA values giving GLA/SDA ratios of 1.1 to 2.2. The non-transgenic Ebony line is included as a negative control showing high levels of ALA at 54.6%, lower levels of LA at 13.5%, and no measurable amounts of GLA and SDA. Event BN_13396 has the highest level of GLA at 21.5% with LA at 6.6%. Event
30 BN_G13295 contained 12.9% SDA, which is the highest value observed for this set of canola plants. Oleic acid showed a slight increase from the Ebony control of 1.3%

to a high of 3.6% in event BN_G13299. ALA was negatively affected starting at 54.6% in the Ebony control and decreasing to a low of 22.2% in event BN_G13296.

Table 4: Relative Area Percent Results from R1 leaves of Canola transformed with pMON82848

Event	Fatty Acid (percent wt)						
	Gen	Oleic	LA	GLA	ALA	SDA	GLA/SDA
EBONY	VARIETY	1.4	14.3	0.0	54.2	0.0	-
BN_G13292	R0	1.9	16.8	0.7	49.5	0.5	1.4
BN_G13286	R0	1.9	16.1	2.1	47.6	1.9	1.1
BN_G13320	R0	1.7	11.2	7.2	40.8	5.3	1.3
BN_G9283	R0	1.0	6.7	9.4	32.1	8.1	1.2
BN_G9282	R0	0.9	6.0	10.1	30.6	7.8	1.3
BN_G13336	R0	2.3	14.3	10.5	34.0	6.6	1.6
BN_G9281	R0	1.1	6.1	10.9	28.9	8.7	1.2
BN_G13299	R0	3.6	11.0	12.7	30.0	9.0	1.4
BN_G13367	R0	2.3	8.1	14.5	30.1	9.8	1.5
BN_G13351	R0	2.4	7.4	14.7	29.8	10.8	1.4
BN_G13297	R0	2.8	7.9	14.9	26.6	12.0	1.2
BN_G13289	R0	2.5	8.8	15.2	29.0	9.9	1.5
BN_G13339	R0	2.7	8.0	15.6	26.7	10.0	1.6
BN_G13291	R0	2.0	6.5	16.2	29.1	10.3	1.6
BN_G13337	R0	2.4	9.0	16.2	27.9	10.1	1.6
BN_G13369	R0	2.8	8.1	16.4	27.4	9.3	1.8
BN_G13334	R0	2.0	8.9	16.5	29.0	9.6	1.7
BN_G13295	R0	2.8	6.5	16.6	24.1	12.9	1.3
BN_G13346	R0	2.6	9.3	16.7	26.6	9.3	1.8
BN_G13298	R0	2.7	9.0	16.8	27.9	9.6	1.7
BN_G13342	R0	3.4	11.5	17.0	26.3	9.1	1.9
BN_G13327	R0	2.2	9.3	17.0	28.2	9.2	1.8
BN_G13344	R0	2.7	7.6	17.2	26.6	9.8	1.8
BN_G13294	R0	2.5	5.9	17.4	27.5	9.9	1.8
BN_G13324	R0	1.4	7.0	17.5	27.8	11.3	1.6
BN_G13341	R0	2.6	8.9	18.3	26.0	9.4	1.9
BN_G13332	R0	2.7	8.1	18.8	24.7	10.0	1.9
BN_G13288	R0	2.5	7.4	18.8	25.5	9.9	1.9
BN_G13296	R0	3.0	7.2	20.0	22.2	11.7	1.7
BN_G13340	R0	2.4	9.0	20.1	25.5	9.6	2.1
BN_G13383	R0	2.5	6.1	20.5	23.5	10.0	2.1
BN_G13347	R0	2.1	7.4	20.5	25.0	10.1	2.0
BN_G13396	R0	2.3	6.6	21.5	24.0	9.9	2.2

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The GC results for 31 pMON82849 Canola events are shown in Table 5. The pattern of more GLA than SDA is consistent with that observed for pMON82848 plants with ratios of GLA/SDA ranging from 1.0 to 2.3. Event BN_G13422 has the

highest level of GLA at 21.9%, which is very similar to the highest pMON82848 value of 21.5% (event BN_G13396).

Table 5: Relative Area Percent Results from R1 leaves of Canola transformed with pMON82849

Event	Fatty Acid (percent wt)						
	Gen	Oleic	LA	GLA	ALA	SDA	GLA/SDA
BN_G9624	R0	1.4	13.2	3.0	45.4	2.5	1.2
BN_G13441	R0	3.0	15.5	5.6	39.9	5.3	1.1
BN_G9307	R0	0.6	5.0	9.9	32.7	9.5	1.0
BN_G13425	R0	2.3	9.6	11.6	32.4	10.0	1.2
BN_G13460	R0	3.2	13.2	11.7	32.3	7.6	1.5
BN_G13309	R0	2.1	8.3	11.8	30.9	11.3	1.0
BN_G13440	R0	2.9	13.8	12.1	31.9	8.0	1.5
BN_G9364	R0	1.0	4.9	13.5	29.0	8.6	1.6
BN_G13448	R0	2.5	7.7	14.6	28.0	11.9	1.2
BN_G13433	R0	2.8	11.5	14.6	29.1	9.3	1.6
BN_G13313	R0	2.1	6.4	15.3	28.3	11.0	1.4
BN_G13305	R0	2.5	6.1	15.7	25.2	12.2	1.3
BN_G13317	R0	2.6	6.3	16.2	27.6	11.4	1.4
BN_G13489	R0	3.6	7.8	16.6	24.4	13.4	1.2
BN_G13436	R0	3.2	9.9	16.7	26.9	9.7	1.7
BN_G13314	R0	3.1	7.4	16.8	22.8	12.3	1.4
BN_G13319	R0	2.7	7.2	17.1	26.0	10.8	1.6
BN_G13431	R0	1.8	7.0	17.2	29.5	9.2	1.9
BN_G13302	R0	2.5	7.3	17.9	24.0	12.6	1.4
BN_G13308	R0	2.9	10.3	17.9	24.4	10.2	1.7
BN_G13315	R0	1.5	6.5	18.1	25.1	12.8	1.4
BN_G13434	R0	2.7	9.8	18.2	25.4	9.4	1.9
BN_G13300	R0	3.0	8.5	18.6	23.0	11.4	1.6
BN_G13310	R0	1.9	6.6	18.8	25.9	10.7	1.8
BN_G13311	R0	3.0	7.5	19.3	23.8	10.5	1.8
BN_G13306	R0	2.0	7.5	19.4	21.6	13.2	1.5
BN_G13316	R0	2.6	6.1	20.1	23.9	11.1	1.8
BN_G13318	R0	2.4	6.7	20.9	23.0	11.4	1.8
BN_G13428	R0	2.6	7.3	21.3	25.8	8.9	2.4
BN_G13304	R0	2.1	6.8	21.6	22.0	11.0	2.0
BN_G13422	R0	2.5	6.4	21.9	23.7	9.7	2.3

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The fatty acid composition of mature seed collected from the same pMON82848 and pMON82849 events was determined by GC analysis of methyl ester derived lipids as done above for transgenic soybean and are shown in Table 6 and 7. The levels of OA, LA, GLA, ALA, and SDA are expressed as a percentage of the total weight of measured fatty acids.

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The GC analysis of canola seed from plants transformed with pMON82848 yielded 32 events with GLA and SDA levels ranging from 1.4% to 5.9% and 0.0% to 1.5%, respectively (weight %, 100 seed pool). The GLA values are consistently greater than the SDA values giving GLA/SDA ratios of 3.6 to 6.1. At this generation the plants are hemizygous for the transgene and therefore the pooled R1 seed represent a segregating population of homozygotes, hemizygotes and nulls. The non-transgenic Ebony line is included as a negative control with 70.9% Oleic Acid, 15.7% LA, 5.8% ALA, and no measurable amounts of GLA or SDA. Event BN_G13368 has the highest level of GLA at 5.9% with LA at 10.6%, which is down from the nontransgenic level of 15.7%. Events BN_G13295 and BN_G13368 both contained 1.5% SDA, which is the highest value observed for this set of canola plants. OA and ALA were less affected by increasing levels of GLA than LA. Although events BN_G13367 and BN_G13299 had between 1.6% and 2.0% GLA, respectively, neither contained measurable amounts of SDA.

Table 6: Average Relative Area Percent Results from 100 single R1 seed of Canola transformed with pMON82848.

Event	Fatty Acid (percent wt)						
	Gen	Oleic	LA	GLA	ALA	SDA	GLA/SDA
EBONY	VARIETY	70.9	15.7	0.0	5.8	0.0	NA
BN_G13336	R1	67.8	17.2	1.4	6.0	0.4	3.9
BN_G13342	R1	71.8	14.3	1.5	5.1	0.3	4.5
BN_G13367	R1	71.3	14.0	1.6	5.1	0.0	NA
BN_G13299	R1	69.4	15.3	2.0	5.5	0.0	NA
BN_G13297	R1	68.9	15.2	2.3	5.0	0.5	4.9
BN_G13334	R1	65.5	17.5	2.4	7.0	0.6	4.0
BN_G13339	R1	67.5	16.5	2.5	5.6	0.6	4.6
BN_G9283	R1	65.7	17.1	2.6	6.2	0.7	3.6
BN_G9281	R1	66.7	16.6	2.6	6.4	0.7	3.9
BN_G13337	R1	70.3	14.1	2.7	5.1	0.6	4.5
BN_G13286	R1	67.0	16.4	2.7	6.0	0.7	4.0
BN_G13327	R1	69.7	14.3	2.8	5.2	0.6	4.5
BN_G13298	R1	68.2	15.7	2.9	5.1	0.6	5.0
BN_G13346	R1	67.7	15.3	3.1	5.9	0.7	4.3
BN_G13351	R1	63.9	18.2	3.2	6.7	0.7	4.3
BN_G13289	R1	66.8	15.1	3.4	4.5	0.6	6.1
BN_G13296	R1	68.7	14.5	3.4	4.8	0.7	5.2
BN_G13369	R1	65.1	16.3	3.5	7.1	0.9	3.9
BN_G13324	R1	66.5	16.2	3.5	5.9	0.8	4.2
BN_G13291	R1	65.9	15.0	3.6	5.0	0.7	5.6
BN_G13340	R1	69.3	14.4	3.8	4.3	0.8	4.9
BN_G13344	R1	67.1	15.5	4.0	5.4	0.9	4.7

BN_G9282	R1	64.5	16.5	4.0	6.2	1.2	3.4
BN_G13347	R1	66.5	15.8	4.1	5.1	0.8	5.2
BN_G13341	R1	66.6	15.9	4.1	5.0	0.8	5.4
BN_G13396	R1	68.6	13.4	4.3	5.2	1.1	4.1
BN_G13332	R1	67.2	14.9	4.7	5.0	1.0	4.7
BN_G13294	R1	63.7	17.3	4.7	5.7	1.0	4.9
BN_G13288	R1	66.9	13.4	5.0	5.7	1.3	4.0
BN_G13295	R1	67.9	11.0	5.1	4.3	1.5	3.3
BN_G13383	R1	65.9	14.7	5.7	4.9	1.2	4.9
BN_G13368	R1	68.7	10.7	5.9	4.5	1.5	3.9

The GC results for 30 pMON82849 Canola events are shown in Table7. The pattern of more GLA than SDA is consistent with that observed for pMON82848 plants with ratios of GLA/SDA ranging form 3.1 to 6.0. Event BN_G13316 has the highest level of GLA at 8.3%, which is slightly greater than the highest pMON82848 value of 5.9% (event BN_G13368).

Table 7: Average Relative Area Percent Results from 100 single R1 seed of Canola transformed with pMON82849.

Event	Fatty Acid (percent wt)						
	Gen	Oleic	LA	GLA	ALA	SDA	GLA/SDA
BN_G9397	R1	59.9	19.7	1.9	9.0	0.5	4.2
BN_G13313	R1	69.7	14.2	1.9	6.2	0.5	4.0
BN_G13425	R1	74.3	11.1	2.0	3.7	0.5	4.1
BN_G13440	R1	72.1	13.2	2.0	4.7	0.5	3.7
BN_G13433	R1	71.7	14.1	2.1	4.3	0.5	4.1
BN_G9307	R1	68.1	15.4	2.1	6.1	0.6	3.3
BN_G13460	R1	68.0	15.7	2.1	6.4	0.6	3.5
BN_G13302	R1	68.7	14.1	2.7	6.1	0.7	4.0
BN_G13306	R1	68.8	13.4	2.9	6.3	0.8	3.7
BN_G13448	R1	68.1	15.7	3.0	5.2	0.7	4.4
BN_G13431	R1	70.7	13.5	3.2	4.4	0.8	4.3
BN_G13436	R1	71.3	12.8	3.3	4.4	0.7	4.9
BN_G13319	R1	68.7	14.2	3.4	5.3	0.7	4.6
BN_G13311	R1	72.3	11.5	3.5	4.3	0.7	4.9
BN_G13434	R1	66.5	16.2	3.6	5.6	0.8	4.5
BN_G13308	R1	69.2	12.8	3.7	3.8	0.6	6.0
BN_G13309	R1	71.7	10.9	3.7	4.3	0.9	4.4
BN_G13422	R1	71.5	11.1	3.8	4.4	1.2	3.2
BN_G13300	R1	67.4	14.1	4.1	5.6	1.0	4.1
BN_G13310	R1	70.6	12.2	4.3	4.4	0.8	5.1
BN_G13428	R1	73.6	9.2	4.4	3.8	1.1	3.9
BN_G13305	R1	65.5	14.8	4.6	6.3	1.1	4.2
BN_G13314	R1	65.3	13.4	4.7	4.6	0.9	5.6
BN_G13489	R1	63.6	16.4	4.8	6.0	1.3	3.6

BN_G9364	R1	63.6	15.4	4.9	7.1	1.6	3.1
BN_G13304	R1	69.8	12.4	4.9	4.1	1.0	5.2
BN_G13318	R1	70.1	9.8	6.3	3.4	1.2	5.3
BN_G13317	R1	61.2	15.9	6.4	5.6	1.6	4.1
BN_G13315	R1	63.2	15.1	6.6	5.5	1.5	4.4
BN_G13316	R1	61.7	13.7	8.3	4.7	1.9	4.5

pMON82848 and pMON82849 were also transformed into *Arabidopsis* to determine the fatty acid composition in leaf and seed. Transformed explants containing pMON82848 and pMON82849 were obtained via *Agrobacterium tumefaciens*-mediated transformation. Plants were regenerated from transformed tissue. The greenhouse-grown plants were then analyzed for oil composition

The effect of expression of the TsD6D-1 and TsD6D-2 was measured by determining the fatty acid composition of *Arabidopsis* leaf by gas chromatography of lipid methyl ester derivatives (PCT US03/16144, filed May 21, 2003, the entire disclosure of which is specifically incorporated herein by reference). The *Arabidopsis* leaves were harvested from young plants and lyophilized to remove all moisture before derivatization. The levels of OA, LA, GLA, ALA, and SDA expressed as a percentage of the total weight of measured fatty acids for 12 pMON82848 events are shown in Table 8. The non-transgenic ecotype Columbia is included as a negative control.

Table 8: Relative Area Percent Results from R1 leaves of *Arabidopsis* transformed with pMON82848

Event	Gen	Fatty Acid (percent wt)					
		Oleic	LA	GLA	ALA	SDA	GLA/SDA
Columbia	VARIETY	1.6	13.6	0.0	53.3	0.0	-
AT_G2951	R1	3.1	14.4	4.0	38.9	3.0	1.4
AT_G2951	R1	9.7	15.4	5.5	29.1	3.4	1.6
AT_G2951	R1	5.0	14.0	5.9	34.4	3.8	1.5
AT_G2951	R1	4.3	15.5	5.9	33.4	3.9	1.5
AT_G2951	R1	5.3	14.6	5.9	34.3	4.3	1.4
AT_G2951	R1	5.2	12.8	6.4	33.8	4.6	1.4
AT_G2951	R1	7.5	14.9	7.3	29.4	4.3	1.7
AT_G2951	R1	6.9	14.4	7.9	29.3	4.8	1.7
AT_G2951	R1	7.4	14.6	9.3	26.7	6.1	1.5
AT_G2951	R1	3.7	10.8	10.4	30.7	6.8	1.5
AT_G2951	R1	5.9	12.8	10.6	27.1	6.1	1.7
AT_G2951	R1	3.2	8.2	17.4	20.5	6.8	2.5

Table 8 shows that TsD6D is capable of altering the fatty acid composition of *Arabidopsis* leaf. In all of the events listed above, the values are greater for GLA than SDA, which is similar to the fatty acid pattern observed in transgenic canola and soy seed. The increase in GLA and SDA was at the expense of ALA, which decreases from a non-transgenic value of 62.8% to a low value of 20.5% observed in event AT_G2951. This event had the highest level of GLA (17.4%) and SDA (6.8%). It is interesting to note that even though the level of ALA is 4.5 times greater than LA, the levels of GLA are consistently greater than SDA, again demonstrating the preference that TsD6D has for the omega-6 substrate.

The GC results for 12 pMON82849 *Arabidopsis* events are shown in Table 9. The pattern of more GLA than SDA is consistent with that observed for pMON82848 plants with ratios of GLA/SDA ranging from 1.4 to 1.9. Event AT_G2952 has the highest level of GLA at 9.9% as compared with the highest GLA value of 17.4% for event AT_G2951 (pMON82848).

Table 9: Relative Area Percent Results from R1 leaves of *Arabidopsis* transformed with pMON82849.

Event	Gen	Fatty Acid (percent wt)					
		Oleic	LA	GLA	ALA	SDA	GLA/SDA
AT_G2952	R1	5.5	16.1	4.6	33.5	3.0	1.6
AT_G2952	R1	4.4	14.0	5.2	36.2	3.7	1.4
AT_G2952	R1	3.7	15.3	5.4	35.6	3.7	1.5
AT_G2952	R1	6.2	15.7	5.4	32.4	3.4	1.6
AT_G2952	R1	4.8	20.1	6.2	31.8	3.3	1.9
AT_G2952	R1	3.3	14.9	6.6	33.2	4.3	1.5
AT_G2952	R1	3.7	12.1	6.8	35.3	4.7	1.4
AT_G2952	R1	3.4	15.0	7.1	32.7	4.2	1.7
AT_G2952	R1	6.7	14.8	7.5	27.0	4.1	1.9
AT_G2952	R1	3.5	13.8	7.9	31.0	5.4	1.5
AT_G2952	R1	2.9	13.1	8.2	33.1	5.5	1.5
AT_G2952	R1	3.8	13.0	9.9	31.3	5.3	1.9

The fatty acid composition of mature R2 seed from *Arabidopsis* was determined by GC analysis of methyl ester derived lipids as done above for soybean seed. Values for pooled seed from 20 transgenic events from pMON82848 are shown in Table 10 (weight %, 100 seed pool). The GLA and SDA levels ranging from 0.8% to 14.2% and 0.3% to 2.8%, respectively. The GLA values are consistently greater than the SDA values. At this R1 generation the plants are hemizygous for the

transgene and therefore the pooled R2 seed represent a segregating population of homozygotes, hemizygotes and nulls. The non-transgenic Columbia line is included as a negative control. Event AT_G2914 has the highest level of GLA at 14.3% with SDA at 2.7%.

5 **Table 10: Average Relative Area Percent Results from seed of *Arabidopsis* transformed with pMON82848.**

Event	Gen	Fatty Acid (percent wt)					
		Oleic	LA	GLA	ALA	SDA	GLA/SDA
Columbia	VARIETY	15.4	28.3	0.0	17.9	0.0	NA
AT_G2929	R2	17.4	26.8	0.8	16.5	0.3	2.7
AT_G2926	R2	15.8	25.7	1.9	17.1	0.6	3.0
AT_G2923	R2	18.3	22.5	6.0	13.2	1.7	3.5
AT_G2913	R2	17.5	22.6	6.1	13.5	1.7	3.5
AT_G2917	R2	16.1	22.6	6.1	14.5	1.9	3.3
AT_G2912	R2	17.0	21.8	6.6	13.7	1.7	3.9
AT_G2928	R2	15.2	22.2	6.7	15.1	1.5	4.4
AT_G2915	R2	16.4	22.1	7.0	14.3	1.3	5.4
AT_G2918	R2	18.0	21.5	7.5	12.7	1.6	4.6
AT_G2922	R2	16.9	20.4	8.2	12.9	2.4	3.5
AT_G2916	R2	16.7	20.5	8.4	12.8	2.2	3.8
AT_G2925	R2	16.8	20.3	8.8	12.6	2.0	4.3
AT_G2924	R2	16.5	20.1	9.8	11.9	2.2	4.4
AT_G2911	R2	16.8	19.6	9.9	12.2	2.1	4.6
AT_G2919	R2	17.1	19.8	10.2	11.0	2.3	4.4
AT_G2930	R2	15.4	19.0	11.3	12.1	2.6	4.4
AT_G2927	R2	15.6	18.5	12.0	12.2	2.3	5.2
AT_G2921	R2	16.6	17.1	13.2	10.7	2.9	4.6
AT_G2920	R2	16.4	16.2	14.2	10.7	2.8	5.1
AT_G2914	R2	17.9	16.1	14.3	9.8	2.7	5.3

The GC results for 12 pMON82849 *Arabidopsis* events are shown in Table 11. The pattern of more GLA than SDA is consistent with that observed for pMON82848 plants with ratios of GLA/SDA ranging from 3.2 to 5.1. Event AT_G2947 has the highest level of GLA at 13.3%, which is very similar to the highest GLA value of 14.3% for event AT_G2914 (pMON82848).

Table 11: Average Relative Area Percent Results from seed of *Arabidopsis* transformed with pMON82849

Event	Gen	Fatty Acid (percent wt)					
		Oleic	LA	GLA	ALA	SDA	GLA/SDA
AT_G2946	R2	16.3	25.9	1.5	17.1	0.4	3.8
AT_G2949	R2	16.4	26.2	1.9	16.6	0.4	4.4

AT G2945	R2	17.1	23.7	5.1	13.6	1.4	3.8
AT G2932	R2	17.2	22.1	6.7	13.5	1.7	4.0
AT G2936	R2	17.9	20.3	8.7	12.1	2.1	4.2
AT G2939	R2	18.6	18.1	10.3	11.1	2.1	4.9
AT G2944	R2	18.2	20.2	8.2	11.8	2.3	3.6
AT G2938	R2	16.3	21.2	7.5	13.5	2.3	3.3
AT G2943	R2	16.1	21.8	7.5	13.1	2.3	3.2
AT G2931	R2	16.5	17.5	12.5	11.6	2.5	5.0
AT G2950	R2	16.3	16.7	13.3	10.9	2.6	5.1
AT G2942	R2	16.4	19.8	9.5	12.1	2.7	3.6
AT G2935	R2	17.0	18.8	10.9	11.4	2.7	4.1
AT G2941	R2	17.1	19.0	9.3	12.1	2.7	3.4
AT G2948	R2	16.4	18.7	10.6	11.9	2.7	3.9
AT G2940	R2	17.3	17.1	13.0	9.9	2.8	4.7
AT G2934	R2	17.4	17.0	12.5	10.6	2.9	4.3
AT G2937	R2	15.9	17.8	12.4	11.6	3.1	3.9
AT G2947	R2	15.7	17.2	13.3	10.9	3.3	4.0

Example 5

Expression of *Tetraselmis suecica* $\Delta 6$ Desaturase in Corn

5 For seed-specific expression of the *Tetraselmis suecica* delta-6 desaturase in corn, TsD6D-1 was cloned under the control of the corn L3-promoter in pMON94502 (FIG. 5) with the rice glutelin 3'-UTR for translation termination. This vector also contained an L3-driven *Neurospora crassa* delta-15 desaturase (SEQ ID NO: 17) expression cassette. The delta-15 expression cassette utilized the wheat HSP17
10 translation termination sequence as 3'UTR.

Additionally, a vector containing the TsD6D-1 gene modified for expression in monocotyledonous plants was designed and constructed. It is well known in the art that non-endogenous protein-encoding sequences may not express well in plants (U.S. Patent No. 5,880,275, herein incorporated by reference). Therefore, using the native
15 TsD6D-1 polypeptide sequence (SEQ ID NO: 2), a modified TsD6D-1 protein-encoding polynucleotide sequence was designed and constructed by 1) using a codon usage bias similar to that of highly expressed monocot proteins and by 2) removal of RNA destabilizing elements previously characterized and known to affect mRNA stability *in planta* (U.S. Patent No. 5,880,275). The resulting modified TsD6D-1
20 polynucleotide sequence was designated TsD6Dnno (SEQ ID NO: 18) and encodes a polypeptide identical in sequence to the native TsD6D polypeptide (SEQ ID NO: 2).

TsD6Dnno was cloned into a binary vector that was otherwise identical to pMON94502. The new binary vector was designated pMON94503 (FIG. 6).

Transformed explants containing pMON94502 or pMON94503, respectively, were obtained via *Agrobacterium tumefaciens*-mediated transformation. Plants were regenerated from transformed tissue. The greenhouse-grown plants were then analyzed for oil composition. For every transgenic event that was obtained, ten R1 seed were analyzed for fatty acid composition. The average fatty acid compositions of those seed that exhibited the transgenic trait are shown in Tables 12 and 13. The best performing single seed contained 18.6% SDA, and the best performing seed with regard to GLA-levels contained 30.9% GLA.

Table 12: Fatty acid composition of events containing pMON94502.

Event	% OA	% LA	% ALA	% GLA	% SDA	GLA/SDA
ZM_S137162	0.3	22.5	5.4	25.7	6.9	3.7
ZM_S137159	0.9	19.5	6.7	26.1	8.7	3.0
ZM_S137155	1.3	15.0	7.6	25.1	12.6	2.0
ZM_S137149	0.1	24.0	6.6	23.2	7.7	3.0

Table 13: Fatty acid composition of events containing pMON94503.

Event	% Ole	% LA	% ALA	% GLA	% SDA	GLA/SDA
ZM_S139635	22.8	22.2	7.2	21.9	8.0	2.7
ZM_S139623	22.7	20.3	7.2	22.2	9.1	2.4
ZM_S139618	22.6	33.1	19.5	4.2	3.4	1.3
ZM_S139616	22.0	27.5	7.0	19.7	5.8	3.4
ZM_S139613	21.9	16.4	7.6	23.8	11.8	2.0
ZM_S139542	22.4	23.6	7.2	21.2	7.0	3.0
ZM_S139458	22.4	19.2	7.1	23.0	9.4	2.5

Example 6

Expression of *Tetraselmis suecica* $\Delta 6$ Desaturase in Concert with Other Desaturases

For some applications it may be advantageous to optimize GLA biosynthesis or SDA biosynthesis in order to maximize GLA or SDA levels in the oil. Each crop species varies with regard to its seed oil fatty acid composition. As a result the specific strategy to optimize GLA or SDA biosynthesis may vary slightly from crop to crop. To optimize SDA biosynthesis it is advantageous to combine the expression of a delta-6 desaturase with a delta-15 desaturase in order to maximize the substrate

pool ALA for the delta-6 desaturase to produce SDA. For example, to obtain an SDA-maximized seed oil, the *Mortierella alpina* delta-15 desaturase and the *T. suecica* delta-6 desaturase are cloned under the control of strong seed-specific promoters utilizing the stronger promoter for the delta-15 desaturase. The construct is transformed into a plant and R1 seed from those plants are analyzed for fatty acid composition.

Some plants such as canola or olives produce seed oils with substantial amounts of monounsaturated fatty acids (oleic acid). In order to convert oleic acid into a substrate for SDA-formation it is desirable to convert OA to LA. This is accomplished by the addition of a delta-12 desaturase to the desaturase combination described above. For example, an *N. crassa* delta-12 desaturase (PCT Publication WO2003099216 (Ursin *et al.*)), an *N. crassa* delta-15 desaturase, and a *T. suecica* delta-6 desaturase are cloned under the control of seed-specific promoters and transformed into plants. R1 seed of these plants are analyzed for fatty acid composition.

An example of optimizing the levels of fatty acids in soy is demonstrated. The activity of the *T. suecica* $\Delta 6$ -desaturase was evaluated in soybean seed by combining it with a dicot codon-enhanced $\Delta 15$ -desaturase from *M. alpina* (MaFad3nno) (SEQ ID NO: 19) to give pMON94060 (FIG. 7). The vector pMON94060 was constructed in 6 steps. First, the restriction sites, SalI and Sse8387 I were added to the ends of the TsD6D-1 coding sequence (CDS) by PCR amplification from pMON67034 (TsD6D-1 in pYES2.1) using the oligonucleotides TsD6D-F3: 5'-GTCGACAAACAATGGGCAGGGGTGGGTTTA-3' (SEQ ID NO: 14), and TsD6D-R3: 5'-CCTGCAGGCTAAGCAAGTGCCGCGATGTC-3' (SEQ ID NO: 15) to give pMON67051. The TsD6D-1 CDS was next placed behind the seed-specific 7S α promoter by digesting pMON67051 with SalI and Sse8387I and ligating the resulting fragment into XhoI/Sse8387I-digested pMON67052 to give pMON67053. The 7S α ::TsD6D-1::E9 expression cassette was then moved into a plant binary vector, resulting in pMON94055. Restrictions sites, SalI and Sse8387I, were added to the ends of the MaFad3nno CDS by PCR amplification from pMON10351 (MaFad3nno in pYES2.1), using the oligonucleotides MaD15D F1: 5'-GTCGACAAACAATGGCGCCACCACACGTAGTAGA-3' (SEQ ID NO: 20), and

MaD15D R1: 5'-CCTGCAGGTTAGTGCTTGTAGAACACCACATCTCC-3' (SEQ ID NO: 21) to give pMON94047. The MaFad3_{no} CDS was next placed behind the seed-specific eUSP88 promoter by digesting pMON94047 with SalI and Sse8387I and ligating the resulting fragment into XhoI/Sse8387I-digested pMON68776 to give pMON94049. The eUSP88::MaFad3_{no}::Nos expression cassette was then moved into the pMON94055, resulting in pMON94060 .

Transformed explants containing pMON94060, were obtained via *Agrobacterium tumefaciens*-mediated transformation. Plants were regenerated from transformed tissue. The greenhouse-grown plants were then analyzed for oil composition. The effect of expression of the TsD6D-1 coding sequence in conjunction with the MaFad3_{no} was measured by determining the fatty acid composition of mature seed by gas chromatography of lipid methyl ester derivatives (PCT US03/16144, filed May 21, 2003, the entire disclosure of which is specifically incorporated herein by reference). The levels of OA (oleic acid, 18:9 Δ 9), LA (linoleic acid, 18:2 Δ 9,12), GLA (γ -linolenic acid, 18:3 Δ 6,9,12), ALA (α -linolenic acid, 18:3 Δ 9,12,15) and SDA (stearidonic acid, 18:4 Δ 6,9,12,15) are expressed as a percentage of the total weight of measured fatty acids and are shown in Table 14. The non-transgenic line A3525 is included as a negative control. Values are expressed as an average of non-nulls from as many as 8 individual R1 seeds.

Table 14: Relative Area Percent Results from single R1 seed of soy transformed with pMON94060.

Event	Oleic	LA	GLA	ALA	SDA	SDA/GLA	GLA/SDA
A3525	17.4	56.1		9.1			
GM_A172392	22.8	13.0	36.1	2.8	2.2	0.1	16.2
GM_A172882	14.9	29.6	28.8	5.9	2.5	0.1	11.3
GM_A172335	18.6	10.1	43.1	2.7	2.7	0.1	15.9
GM_A172377	21.4	8.1	38.8	3.0	2.8	0.1	13.9
GM_A172386	20.9	12.7	39.0	3.7	2.9	0.1	13.7
GM_A172342	27.2	7.9	34.8	2.7	3.0	0.1	11.5
GM_A172349	19.0	8.3	40.5	2.7	3.6	0.1	11.1
GM_A172423	19.4	12.6	37.0	4.1	7.4	0.2	5.0
GM_A172352	21.9	8.2	35.6	3.4	7.5	0.2	4.7
GM_A172900	19.9	27.5	1.0	20.2	12.2	12.7	0.1
GM_A173156	20.2	13.0	2.0	35.4	12.9	6.3	0.2
GM_A172866	26.0	28.4	0.7	11.2	13.3	18.8	0.1
GM_A172400	20.6	6.9	29.3	3.8	13.7	0.5	2.1
GM_A172390	23.0	12.4	2.9	24.9	16.1	5.5	0.2
GM_A172897	25.2	25.5	1.1	8.7	16.1	15.4	0.1
GM_A172368	38.8	1.1	0.7	7.1	24.3	34.5	0.0
GM_A172343	18.6	16.2	9.4	7.1	25.1	2.7	0.4

GM_A172365	32.4	2.7	0.5	8.4	25.9	52.2	0.0
GM_A172405	30.1	2.3	2.9	8.4	27.3	9.5	0.1
GM_A172384	12.2	11.8	19.5	6.9	28.3	1.4	0.7
GM_A172883	30.4	3.6	2.1	8.6	28.4	13.7	0.1
GM_A172885	22.2	10.1	3.2	9.9	30.4	9.4	0.1
GM_A172411	22.9	8.9	2.0	9.6	31.2	15.5	0.1
GM_A172356	22.0	8.7	3.4	8.3	31.4	9.1	0.1
GM_A172855	23.7	6.0	5.9	10.7	31.6	5.4	0.2
GM_A172393	19.1	4.9	10.3	8.5	31.7	3.1	0.3
GM_A172889	23.4	4.5	3.8	8.7	32.6	8.7	0.1
GM_A172339	20.5	4.7	3.4	13.7	33.1	9.7	0.1
GM_A172849	23.2	3.7	4.2	8.9	33.7	8.0	0.1
GM_A173155	14.4	15.5	4.4	7.0	34.6	7.9	0.1
GM_A172891	15.6	15.8	5.0	8.7	34.7	6.9	0.1
GM_A172357	24.4	3.8	3.6	8.6	35.0	9.7	0.1
GM_A172888	18.5	10.4	3.4	8.7	35.1	10.5	0.1
GM_A173152	14.8	15.6	5.4	9.2	35.4	6.6	0.2
GM_A172862	21.3	4.9	5.2	8.8	35.7	6.9	0.1
GM_A172421	21.6	5.2	6.1	8.3	36.1	5.9	0.2
GM_A172370	17.0	4.7	4.5	11.9	36.7	8.1	0.1
GM_A172347	20.6	3.3	3.4	8.7	36.8	10.8	0.1
GM_A172389	18.4	5.0	6.6	8.5	37.8	5.7	0.2
GM_A172838	17.6	6.3	3.2	10.9	38.1	12.1	0.1
GM_A172896	14.6	10.4	5.3	10.2	38.1	7.2	0.1
GM_A172860	16.1	10.9	4.3	8.9	38.3	8.8	0.1
GM_A172363	22.3	5.2	6.8	7.4	38.5	5.6	0.2
GM_A172415	17.4	6.2	7.1	9.0	38.5	5.5	0.2
GM_A172852	17.5	8.5	3.9	8.4	38.7	10.0	0.1
GM_A172847	15.0	12.5	5.4	8.9	38.8	7.2	0.1
GM_A172355	12.6	12.7	6.2	8.2	38.8	6.2	0.2
GM_A172408	16.9	6.4	7.3	8.5	39.2	5.4	0.2
GM_A172371	12.5	12.2	7.0	8.0	39.4	5.7	0.2
GM_A172341	17.3	5.8	7.4	8.5	39.5	5.3	0.2
GM_A172871	16.5	9.1	3.9	8.7	40.0	10.2	0.1
GM_A172337	14.5	6.9	5.9	10.0	41.0	6.9	0.1
GM_A172387	16.6	4.3	6.7	8.2	41.1	6.1	0.2
GM_A172417	16.6	5.8	4.3	8.9	41.7	9.6	0.1
GM_A172361	20.9	3.2	2.2	9.2	41.8	19.2	0.1
GM_A172351	15.1	5.8	6.0	9.4	41.9	7.0	0.1
GM_A172880	18.1	4.5	4.2	7.9	42.1	10.0	0.1
GM_A172419	15.0	4.3	6.3	7.7	42.1	6.7	0.2
GM_A172398	14.9	5.2	7.8	7.3	42.4	5.5	0.2
GM_A172854	15.4	3.6	3.5	12.9	42.5	12.3	0.1
GM_A172843	13.5	6.7	7.9	8.0	42.6	5.4	0.2
GM_A172840	13.6	6.3	8.4	7.9	42.9	5.1	0.2
GM_A173157	12.6	6.2	9.2	8.1	43.0	4.7	0.2
GM_A172345	15.2	4.1	5.6	8.0	44.0	7.8	0.1
GM_A172853	14.8	5.1	5.4	9.2	44.0	8.2	0.1
GM_A172372	14.8	5.2	6.5	7.1	44.1	6.7	0.1
GM_A172358	15.9	6.8	3.3	7.6	45.0	13.5	0.1
GM_A172868	13.8	5.0	5.0	8.7	45.5	9.0	0.1
GM_A172884	14.0	4.4	4.9	7.9	46.2	9.4	0.1

GM_A172879	11.9	5.9	5.0	8.8	46.6	9.3	0.1
GM_A172360	12.4	6.4	7.6	7.3	46.7	6.2	0.2
GM_A172858	13.0	4.0	5.1	8.8	46.9	9.3	0.1
GM_A172873	12.7	4.3	5.3	7.9	47.5	8.9	0.1

All of the pMON94060 transgenic events in Table 14 accumulate measurable amounts of GLA and SDA. Single seed values of less than 1% were not included in calculating the average for each individual event. For 10 of the events, the levels of GLA are higher than SDA, but for the remaining events the levels of SDA/GLA ranged from 1.6% to 52.2. The highest average value for GLA is 43.1% observed in event GM_A172335, which has only 2.72% SDA. Event GM_A172365 has the highest SDA/GLA ratio of 52.2. Thirty two percent of the events have SDA values greater than 40%. The highest SDA value was 47.5% in event GM_A172873. The levels of LA decreased with increasing levels of SDA and ranged from 1.1% to 29.6%. For 38 of the events, the levels of oleic acid are higher than the 17.4% non-transgenic control value. The highest oleic acid value was 38.8% observed in event GM_A172368. The GLA values ranged from a low of 0.5 in event GM_A172365 to a high of 43.1% in event GM_A172335. The ALA levels in most of the events were close to the original non-transgenic level of 9.1%. Approximately 83.5% or 61 events out of the 73 have between 5.0% and 13.7% ALA.

All of the compositions and methods disclosed and claimed herein can be made and executed without undue experimentation in light of the present disclosure. While the compositions and methods of this invention have been described in terms of preferred embodiments, it will be apparent to those of skill in the art that variations may be applied to the compositions and methods and in the steps or in the sequence of steps of the method described herein without departing from the concept, spirit and scope of the invention. More specifically, it will be apparent that certain agents which are both chemically and physiologically related may be substituted for the agents described herein while the same or similar results would be achieved. All such similar substitutes and modifications apparent to those skilled in the art are deemed to be within the spirit, scope and concept of the invention as defined by the appended claims.

REFERENCES

The following references, to the extent that they provide exemplary procedural or other details supplementary to those set forth herein, are specifically incorporated herein by reference.

- U.S. Patent 4,518,584; U.S. Patent 4,737,462; U.S. Patent 4,810,648; U.S. Patent 4,826,877; U.S. Patent 4,957,748; U.S. Patent 5,094,945; U.S. Patent 5,100,679; U.S. Patent 5,158,975; U.S. Patent 5,196,525; U.S. Patent 5,219,596; U.S. Patent 5,290,924; U.S. Patent 5,322,783; U.S. Patent 5,359,142; U.S. Patent 5,424,398; U.S. Patent 5,424,412; U.S. Patent 5,500,365; U.S. Patent 5,530,196; U.S. Patent 5,538,880; U.S. Patent 5,550,318; U.S. Patent 5,563,055; U.S. Patent 5,610,042; U.S. Patent 5,627,061; U.S. Patent 5,633,435; U.S. Patent 5,641,876; U.S. Patent 5,880,275; U.S. Patent 5,936,069; U.S. Patent 6,005,076; U.S. Patent 6,040,497; U.S. Patent 6,051,753; U.S. Patent 6,146,669; U.S. Patent 6,156,227; U.S. Patent 6,319,698; U.S. Patent 6,433,252; U.S. Patent 6,451,567; U.S. Patent Publn. 20030093828; U.S. Patent Publn. 20030229918; U.S. Patent Publn. 20040039058
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CLAIMS

1. An isolated polynucleotide encoding a polypeptide having desaturase activity that desaturates a fatty acid molecule at carbon 6, wherein the polynucleotide is selected from the group consisting of:
 - a) a polynucleotide encoding the polypeptide sequence of SEQ ID NO:2 or SEQ ID NO:4;
 - b) a polynucleotide comprising the nucleic acid sequence of SEQ ID NO:1 or SEQ ID NO:3;
 - c) a polynucleotide hybridizing to SEQ ID NO:1 or SEQ ID NO:3 or a complement thereof, under conditions of 5X SSC, 50% formamide and 42°C; and
 - d) a polynucleotide encoding a polypeptide with at least 75% sequence identity to a polypeptide sequence of SEQ ID NO:2 or SEQ ID NO:4.
2. An isolated polypeptide comprising the polypeptide sequence of SEQ ID NO:2 or SEQ ID NO:4 or a fragment thereof having desaturase activity that desaturates a fatty acid molecule at carbon 6.
3. A DNA construct comprising the isolated polynucleotide sequence of claim 1.
4. The DNA construct of claim 3 further comprising a heterologous promoter operably linked to the isolated polynucleotide sequence of claim 1.
5. The DNA construct of claim 3 further comprising at least one additional polynucleotide sequence encoding a fatty acid desaturase.
6. A host cell transformed with the DNA construct of claim 3.
7. The host cell of claim 6, wherein the host cell is a plant cell.
8. The host cell of claim 6, wherein the host cell is a fungal or bacterial cell.
9. The host cell of claim 6, wherein the host cell exhibits altered fatty acid biosynthesis relative to a cell of the same genotype as said host cell but lacking said DNA construct.
10. The host cell of claim 6, wherein the cell has inherited said DNA construct from a progenitor of the cell.
11. A transgenic plant transformed with the DNA construct of claim 3.
12. The plant of claim 11 wherein the plant is selected from the group consisting of canola, *Brassica campestris*, oilseed rape, rapeseed, soybean, crambe, mustard,

castor bean, peanut, sesame, cottonseed, linseed, safflower, oil palm, flax, sunflower, corn, rice, barley, millet, rye, wheat, oat, alfalfa and sorghum.

13. The plant of claim 11, further comprising at least one additional polynucleotide encoding a fatty acid desaturase.

14. A seed of the plant of claim 11, wherein the seed comprises the DNA construct.

15. An oil composition extracted from corn seed comprising a GLA content of from about 5% to about 26% by weight of total fatty acids.

16. The oil composition of claim 15 further comprising an SDA content of from about 3% to about 13% by weight of total fatty acids.

17. An oil composition extracted from corn seed comprising a GLA content of at least 3% by weight of total fatty acids and an SDA content of at least 3% by weight of total fatty acids, wherein the ratio of GLA/SDA is between about 1.3 and about 3.7.

18. An oil composition extracted from soybean seed comprising a GLA content of from about 9% to about 51% by weight of total fatty acids.

19. The oil composition of claim 18 further comprising an SDA content of from about 0.5% to about 10% by weight of total fatty acids.

20. An oil composition extracted from soybean seed comprising a GLA content of at least 1% by weight of total fatty acids and an SDA content of at least 1% by weight of total fatty acids, wherein the ratio of GLA/SDA is between about 2.8 and about 18.3.

21. A method of producing food or feed, comprising the steps of:

(a) obtaining the transgenic plant according to claim 11 or a part thereof;
and

(b) producing said food or feed.

22. The method of claim 21, wherein the food or feed is oil, silage, meal, grain, starch, flour or protein.

23. A food or feed composition produced by the method of claim 21 and comprising a detectable nucleic acid molecule comprising the isolated polynucleotide

of claim 1 or a detectable polypeptide encoded by the isolated polynucleotide of claim 1.

24. A food or feed composition produced by the method of claim 21 wherein the food or feed composition comprises GLA or SDA.

Sequence logos for IgD6D, MaD6D, TsD6D-1, and TsD6D-2 across 500 positions. The logos are arranged in a grid with 10 rows and 50 columns. Each row represents a different protein, and each column represents a position from 1 to 500. The height of the letters indicates the enrichment of a specific amino acid at that position. The background color of the logos alternates between light blue and light green. The logos are labeled with their respective protein names on the right side of the grid.

Position	IgD6D	MaD6D	TsD6D-1	TsD6D-2
1	...	...	...	...
2	...	...	...	...
3	...	...	...	...
4	...	...	...	...
5	...	...	...	...
6	...	...	...	...
7	...	...	...	...
8	...	...	...	...
9	...	...	...	...
10	...	...	...	...
11	...	...	...	...
12	...	...	...	...
13	...	...	...	...
14	...	...	...	...
15	...	...	...	...
16	...	...	...	...
17	...	...	...	...
18	...	...	...	...
19	...	...	...	...
20	...	...	...	...
21	...	...	...	...
22	...	...	...	...
23	...	...	...	...
24	...	...	...	...
25	...	...	...	...
26	...	...	...	...
27	...	...	...	...
28	...	...	...	...
29	...	...	...	...
30	...	...	...	...
31	...	...	...	...
32	...	...	...	...
33	...	...	...	...
34	...	...	...	...
35	...	...	...	...
36	...	...	...	...
37	...	...	...	...
38	...	...	...	...
39	...	...	...	...
40	...	...	...	...
41	...	...	...	...
42	...	...	...	...
43	...	...	...	...
44	...	...	...	...
45	...	...	...	...
46	...	...	...	...
47	...	...	...	...
48	...	...	...	...
49	...	...	...	...
50	...	...	...	...

Decoration 'Decoration #1': Shade (with solid black) residues that match the Consensus exactly. □

FIG. 2

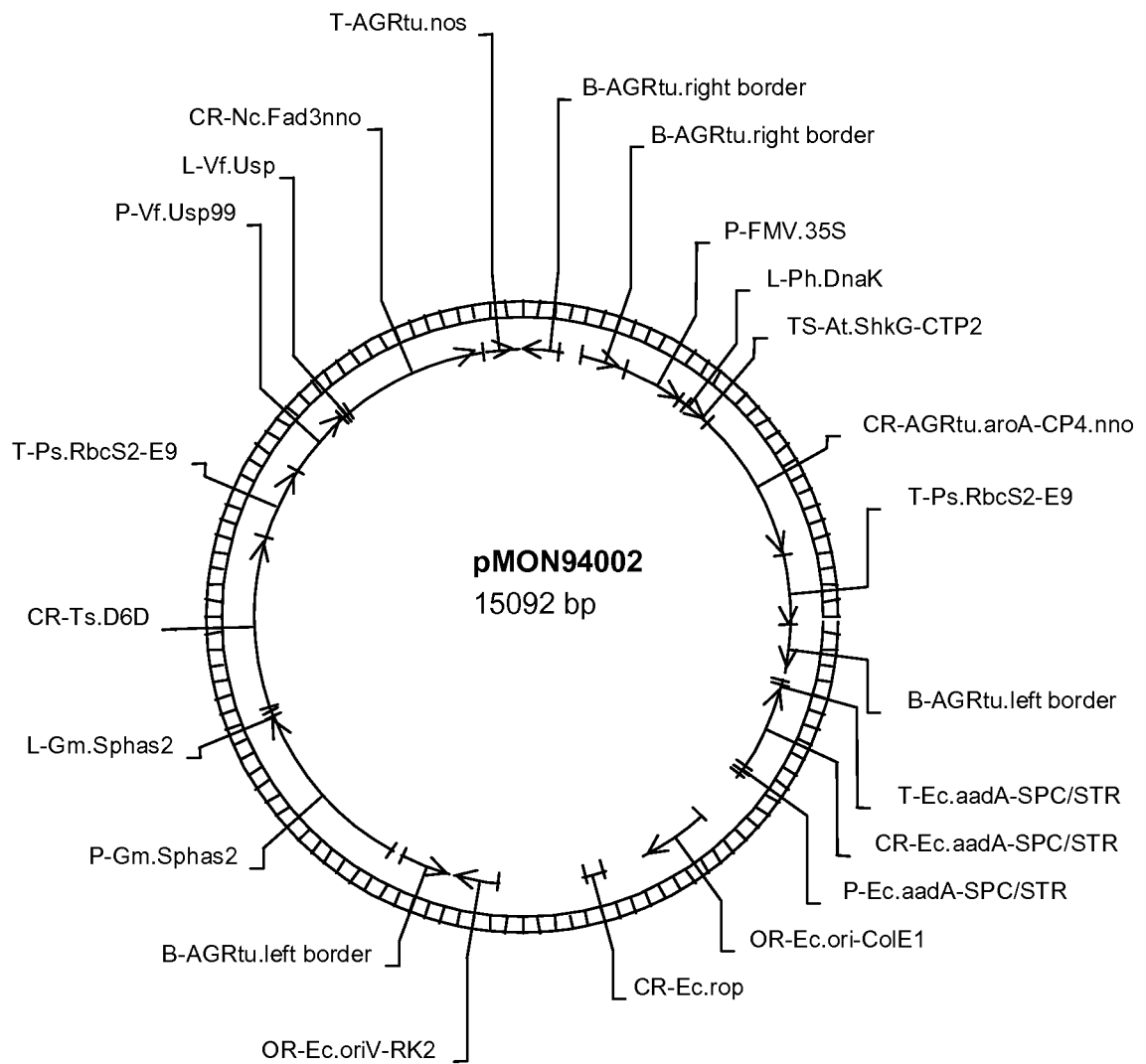


FIG. 3

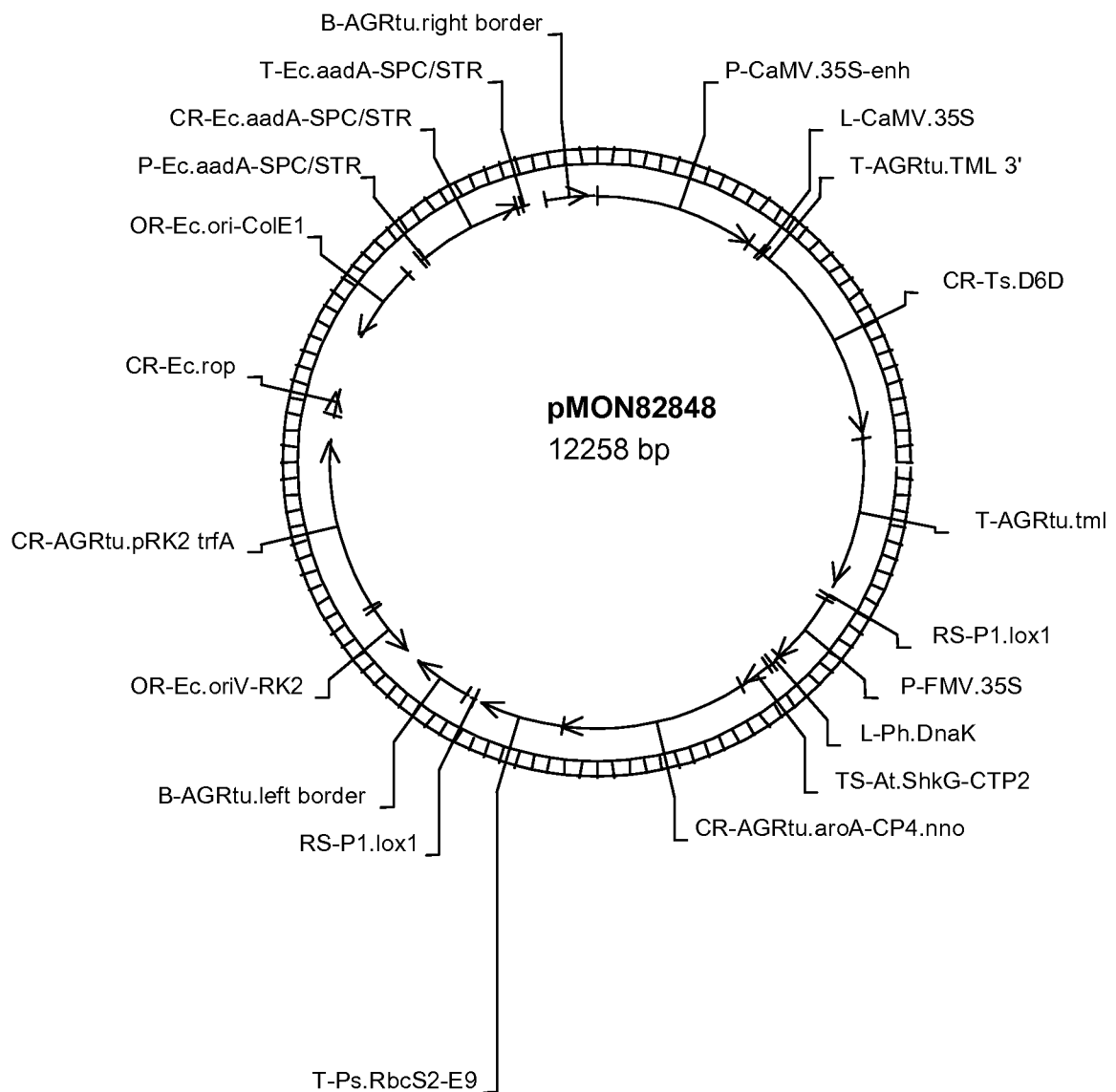


FIG. 4

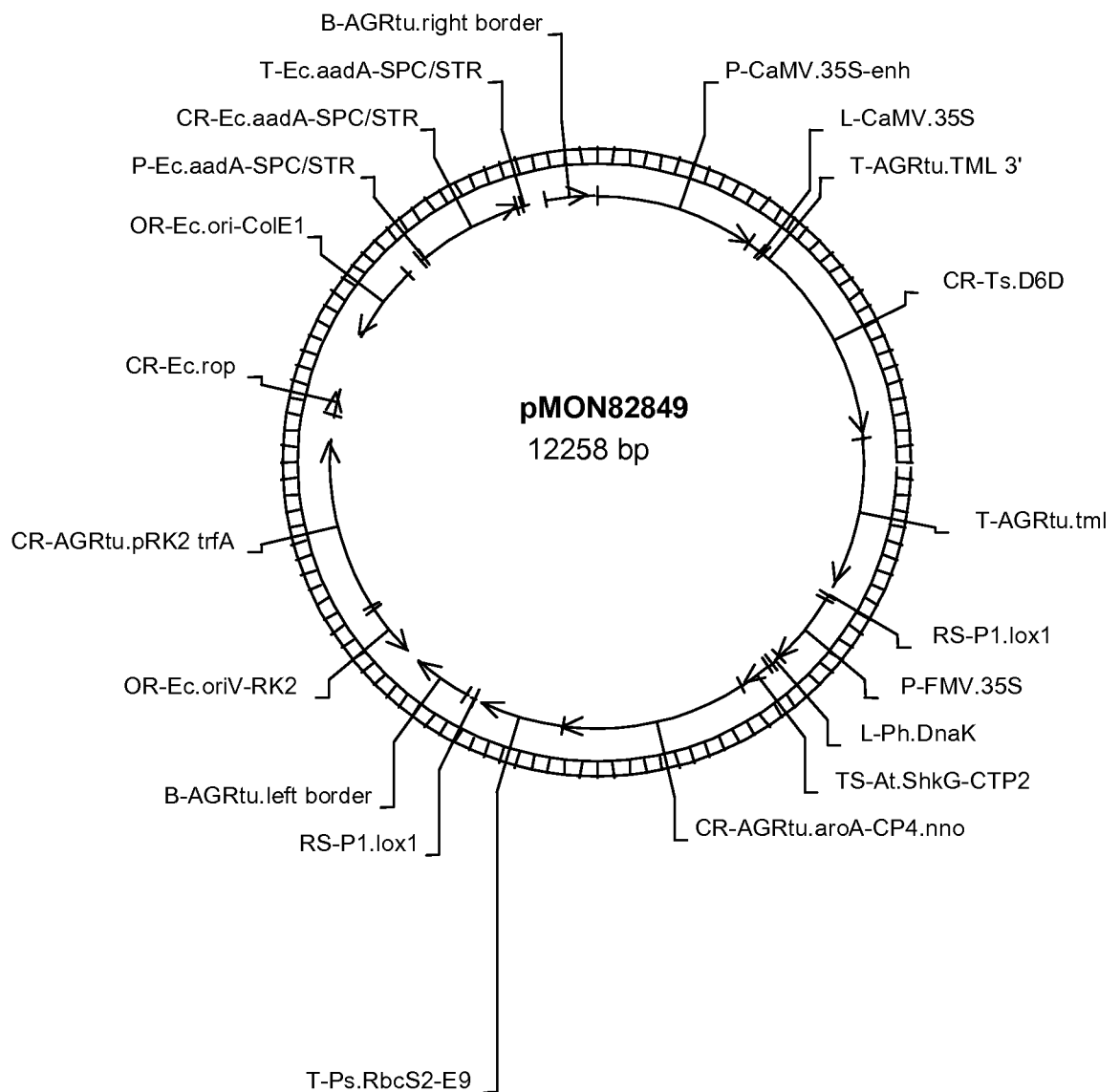


FIG. 5

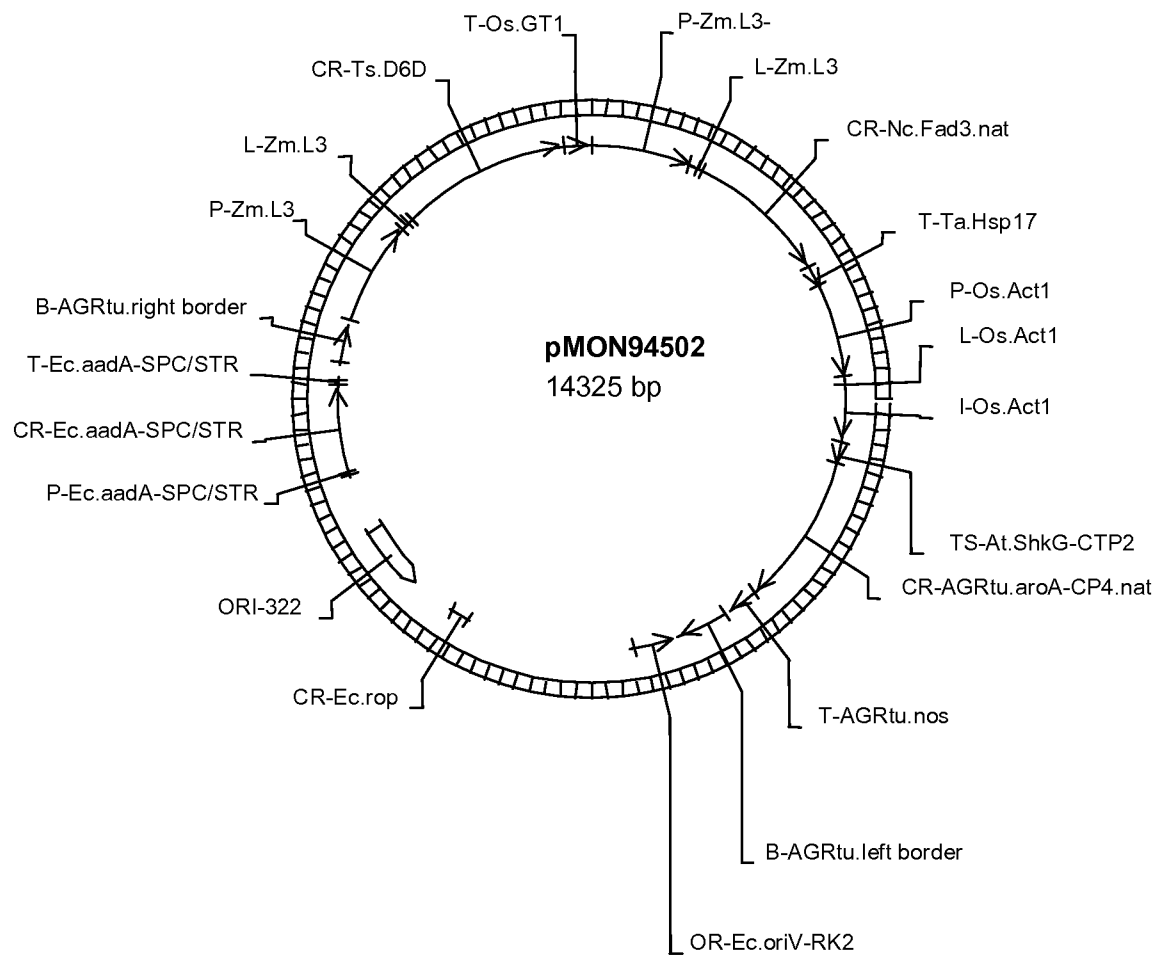


FIG. 6

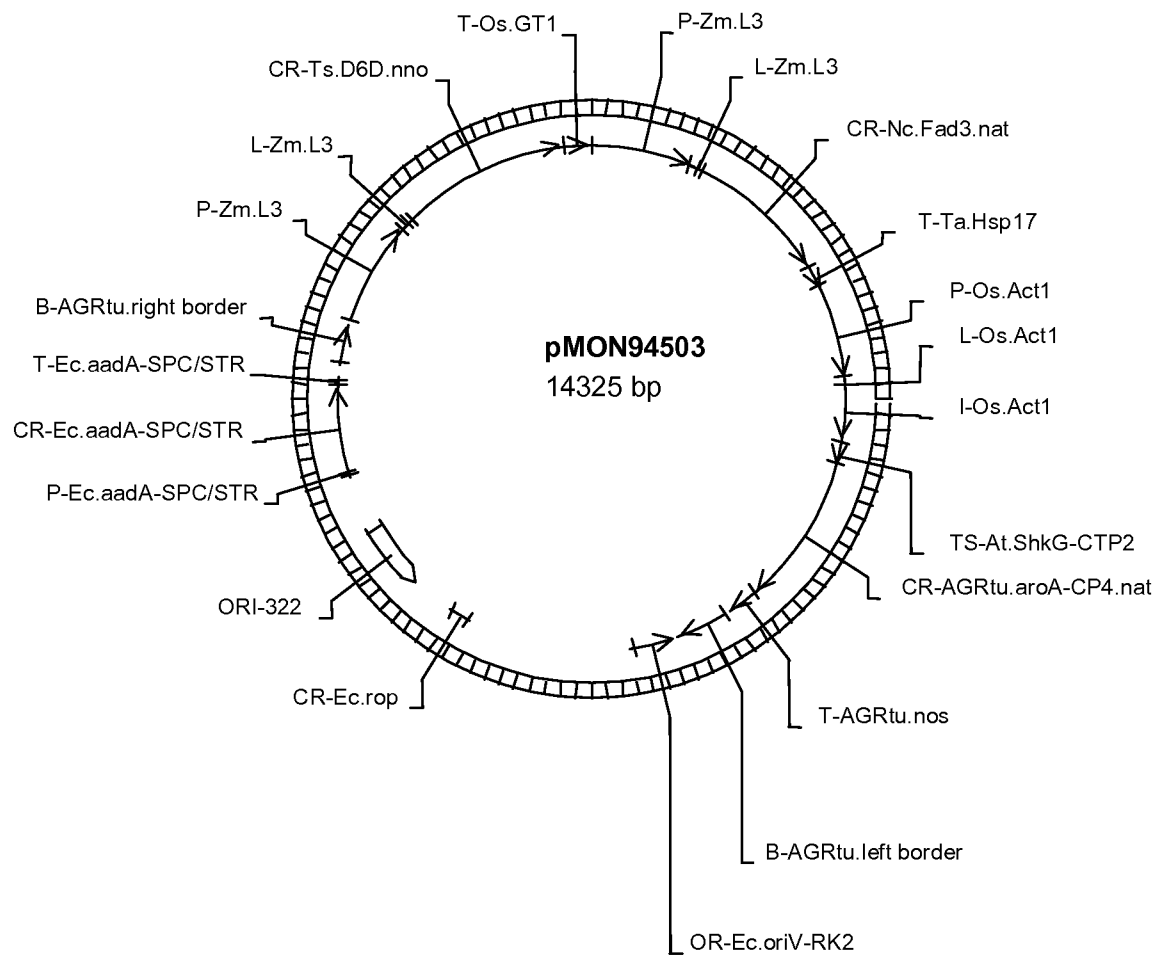


FIG. 7

