INTRODUCING DNA INTO PLANT CELLS

FIELD OF THE INVENTION

The present invention relates to the field of plant molecular biology, particularly to means and methods for simple and efficient introduction of exogenous genetic material into the plant cell.

BACKGROUND OF THE INVENTION

Plants carrying one or more expressible heterologous genes have a variety of potential advantages. The plants carrying a gene expression cassette may carry one or more genes which confer desired traits, including for example, herbicide, pesticide or insect tolerance; tolerance to stress; enhanced flavor and/or shelf life of the fresh produce (fruit, vegetable, seeds etc.), as well as the ability to amplify the synthesis of useful plant endogenous and/or foreign proteins, sugars, fatty-acids or secondary metabolites for consumption by man and/or animals or for use as raw materials in a variety of industries (cosmetics, pharmaceuticals, nutraceutics, foods, paper, fibers, etc.).

Current transformation technologies provide an opportunity to engineer plants with desired traits, and major advances in plant transformation have been occurred in recent years. The most common technology is mediated by *Agrobacterium tumefaciens*. Other methods of transformation are direct DNA transfer including microinjection, electroporation, particles bombardment and viral vectors (Birch R G. 1997. Annu. Rev. Plant Physiol. Plant Mol. Biol. 48:297–326). With the exception of viral vectors, application of the above techniques results in the penetration of foreign DNA into the treated cells/tissue, its integration into the treated plant's genome and the regeneration of transgenic plants. However, in many major crop plants, serious genotype limitations still exist. Transformation of some agriculturally important crop plants continues to be both difficult and time consuming. In addition, in all the aforementioned technologies, transformation is conducted with vegetative tissues (including embryos) the efficiency of transformation is poor, markers for selection are required, and the percentage of successful regeneration of a plant from the transformed cell or tissue is rather low.

Integration of the foreign DNA into the plant genome is not always desirable,

particularly when genetically modified (GMO) plants arouse environmental and political issues. In these cases, methods enabling the expression of the heterologous gene(s) that are not incorporated into the host genome are required.

International (PCT) Application Publication No. WO 2007/141790 to some of the inventors of the present invention discloses modified Geminivirus-based constructs capable of spreading from one plant cell to the other within the treated plant and concomitantly introducing foreign DNA into the plant cells, without exerting the pathological virus symptoms. This foreign DNA is expressed in the plant tissues but is not integrated into its genome. The constructs (also referred to as expression vectors, IL-60 being one example) comprise the heterologous polynucleotide sequence that interrupts the Geminivirus replicase genes such that it is flanked by a non-contiguous nucleic acid sequence encoding a Geminivirus replicase or replicase-associated protein.

Seed priming is a process for treating plant seeds that enables them to undergo faster and more uniform germination on sowing or planting compared to non-treated seeds. Additionally, priming offers an optional simultaneous treatment with fungicide/pesticides/fertilizers or other chemicals (e.g. coating, pelleting, coloring as a trade mark, and more) providing protection and/or facilitating germination, emergence and seedlings establishment.

Priming allows the seeds to absorb enough water to enable their pre-germinative metabolic processes to begin and then arrests them at that stage. The amount of water absorbed (with or without beneficial chemicals) must be carefully controlled, as too much would simply allow the seed to germinate and too little would result in the seed ageing. Once the correct amount of water has been absorbed, the seeds may be sown or dried back to the original water content for storage. The primed seeds usually germinate and emerge more quickly and uniformly and the seedling vigor is typically higher compared to unprimed seeds, particularly under suboptimal conditions. The benefits gained by priming, such as rate and uniformity of germination are usually attributed to the initiation of DNA-repair processes, protein hydration enzyme activation and additional processes occurring in the early stages of germination.

The three major techniques used for controlled water uptake include priming with aqueous solutions, with hydrated solid particulate systems or by controlled hydration with water. Priming with solution is based on immersing the seeds in osmotic solution,

typically PEG solutions characterized by osmotic potential that enables limited imbibition that is insufficient for full hydration and seed germination. Alternatively, the same effect is achieved by mixing the seeds with hydrated absorbent medium such as clay or peat (e.g., U.S. Patent No. 4,912,874). Controlled hydration with aqueous solutions may be achieved, for example, by utilizing semi-permeable membrane to mediate the transfer of water from a solution of a given osmotic pressure to the seed (U.S. Patent No. 5,992,091). Priming is performed under a variety of temperatures and aeration methods (e.g., stirring, agitation, bubbling, etc.) using any of the techniques for controlled water uptake (Taylor A G. et al. 1998. Seed Science Technology 8:245-256).

Combination between the common transformation techniques described hereinabove and seed priming has been disclosed. For example, U.S. Patent No. 6,646,181 discloses a method of introducing genes into plants comprising synchronizing the stage of development of the plant at a stage that includes large amounts of 4C DNA in seeds of the plants and transfecting the cells of the seeds, in which synchronizing the stage of development comprises admixing a particulate solid matrix material and a seed priming amount of water, with aeration of seeds, for a time and at a temperature sufficient to cause a substantial number of the cells of the seeds to reach a desired stage of a cell cycle.

U.S. Patent Application Publication No. 2006/0005273 discloses maize explants suitable for transformation. The explants comprise a maize seed split in half longitudinally, wherein the splitting exposes the scutellum, the coleoptilar ring and shoot apical meristem, each of which are independently suitable for transformation. Priming the seed prior to splitting with either callus or shoot priming medium increases the callus and shoot induction frequency after transformation.

U.S. Patent Application No. 20100154083 discloses compositions and methods to screen, identify, select, isolate, and/or regenerate targeted integration events using seed priming. Seed priming provides the identification of a seed having stably incorporated into its genome a site-specific recombinase mediated integration of a selectable marker at a target locus operably linked to a promoter active in the seed.

These combination methods employ the known methods of transformation and are aimed at increasing the efficacy of foreign gene integration into the plant genome. As described hereinabove, the available methods have limitations with regard to

applicability and efficacy. In addition integration of the foreign DNA to the plant genome is not always desirable.

There is a recognized need for, and it would be highly advantageous to have means and methods for simple and efficient introduction of DNA into plant cells that further enable efficient plant regeneration.

SUMMARY OF THE INVENTION

The present invention provides means and methods for simple and efficient delivery of heterologous DNA into a plant cell, part, tissue, organ, or the entire organism, particularly to the cells of a seed embryo within an intact seed. The seed comprising the introduced heterologous DNA is easily grown to a mature plant under standard growth conditions, without the need of regeneration cultures and hardening conditions.

The present invention is based in part on the unexpected discovery that introduction of heterologous DNA into plant seeds is possible during seed priming by supplementing the priming medium with a virus-based DNA construct, particularly with a Geminivirus based expression construct. As exemplified hereinbelow, the present invention now shows that supplementing a priming medium with a Geminivirus based construct designated IL-60, which comprises the heterologous polynucleotide sequence flanked by non-contiguous nucleic acid sequences encoding a Geminivirus replicase or replicase associated proteins, result in the uptake, replication and symptomless spreading of the DNA construct within the seed cells.

The teachings of the present invention are advantageous over previously known methods for plant cell transformation or introduction of foreign DNA in that the DNA is introduced into the embryo of the intact seed which is naturally capable of developing into a whole plant. The teachings of the present invention for DNA introduction does not involve damage to the cells (as occurs when direct DNA transfer, particularly via bombardment is employed) or cell functioning. Furthermore, when Geminivirus-based expression constructs are employed, the heterologous DNA is not incorporated into the plant genome, again preventing the trauma accompanying DNA introduction into the cell which typically leads to cell cycle arrest and apoptosis or programmed cell death. The simple methods of the present invention can be employed with seeds of any plant of interest, and is fast and highly efficient. When the DNA construct used is such that the

heterologous DNA does not incorporate into the plant genome, the method is further advantageous as the plant expresses the desired product but is not defined as genetically modified.

Thus, according to one aspect, the present invention provides a method for introducing heterologous DNA into at least one cell of a plant seed embryo comprising contacting a plant seed with a priming medium containing a virus-based DNA construct comprising the heterologous DNA under conditions enabling priming, thereby obtaining the seed embryo comprising the heterologous DNA.

According to certain embodiments, the method further comprises the step of providing suitable conditions for subsequent seed germination and growth so as to obtain a plant or part thereof comprising the heterologous DNA.

According to certain embodiments, the virus-based DNA construct comprises viral genes or parts thereof enabling replication and symptomless spreading of the construct into adjacent plant cells.

According to typical embodiments, the DNA construct is a Geminivirus based construct. According to these embodiments, the construct comprises the heterologous DNA flanked by a non-contiguous nucleic acid sequences encoding Geminivirus replicase or replicase-associated protein.

According to other embodiments, the construct further comprises a polynucleotide sequence encoding a modified Geminivirus coat protein (CP). According to typical embodiments, the modified Geminivirus coat protein encoding polynucleotide comprises a mutation or deletion in nucleotides encoding the N-terminal 100 amino acids.

According to further typical embodiments the expression construct further comprises a polynucleotide sequence encoding a modified Geminivirus V2 protein.

According to additional typical embodiments the expression construct further comprises a polynucleotide sequence encoding a modified Geminivirus C4 protein. According to these embodiments, the modified Geminivirus C4 protein includes a mutation or deletion. According to certain embodiments the expression construct further comprises a bacterial polynucleotide sequence.

According to certain currently preferred embodiments, the Geminivirus is Tomato

Yellow Leaf Curl Virus (TYLCV). According to these embodiments, the Geminivirus-based construct is selected from the group consisting of IL-60 having the nucleic acids sequence set forth on SEQ OD NO:1 and IL-60-BS having the nucleic acids sequence set forth in SEQ ID NO:2.

According to certain embodiments, the DNA construct is designed as an expression construct such that the heterologous DNA is expressed in the plant cell. According to these embodiments, the DNA construct further comprises at least one regulatory element selected from the group consisting of an enhancer, a promoter, and a transcription termination sequence.

According to additional embodiments, the DNA construct further comprises a marker for identifying the seeds and/or plants comprising the heterologous DNA.

The heterologous DNA can encode any desired product, including peptides, polypeptide, proteins and RNAs. The proteins or RNAs can be of plant origin or of other origin, including but not limited to bacterial and mammal origin. According to certain embodiments, the DNA encodes an inhibitory RNA selected from the group consisting of antisense RNA, dsRNA, siRNA and the like, such that the expression of a target gene is silenced. According to other embodiments, the heterologous DNA encodes a product the expression of which confers a desirable agronomic trait including, but not limited to, resistance to biotic or a-biotic stress, increased yield, increased yield quality, preferred growth pattern and the like. According to additional embodiments, the encoded protein products are useful in the cosmetic or pharmaceutical industry. According to still further embodiments, the encoded protein enhances the production of desired metabolites within the plant cells and tissues.

According to yet other embodiments the heterologous DNA dose not encode a desired product but is present merely as a label to the origin of the seed, or to the plant grown from said seed , for example to prevent illegal distribution of proprietary seeds, plants and tissues.

The heterologous DNA may be transiently expressed in the cells and cells derived therefrom or it may be incorporated into the cell genome. The heterologous DNA may be present in the cytoplasm of the plant cell, in its organelles or in the nucleolus as an integrated or non-integrated DNA sequence.

According to certain currently preferred embodiments the DNA construct is a

Geminivirus-based construct designed such that the heterologous DNA is not incorporated into the cell genome but the construct is capable of replicating and spreading within the cells of the plant grown from the seed comprising said heterologous DNA.

Any priming system and conditions as is known to a person skilled in the art can be used according to the teachings of the present invention, including systems comprising aqueous solutions with adequate osmotic potential and systems comprising solid particulates. The water potential of the medium enables water uptake that is insufficient for complete seed imbibitions, and allows only the initial stages of germination but not radicle emergence (completion of germination). The system and conditions are typically selected according to the species of the plant seed.

According to yet additional embodiments, the present invention provides a seed produced by the methods of the invention, the seed comprises a virus-based DNA construct comprising heterologous DNA, and plants or parts thereof produced from said seed.

According to certain embodiments, the plant seed is of a monocot origin. According to other embodiments, the plant seed is of a dicot origin.

Other objects, features and advantages of the present invention will become clear from the following description and drawings.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 demonstrates the effect of seed priming on germination uniformity.

FIG. 2 is an illustration of the Geminivirus based constructs used in the seed priming experiments described herein. Fig 2A: IL-60-BS. Fig. 2B: pIR-GUS.

FIG. 3 shows the presence of GUS sequences in true tomato leaves following seed priming in the presence of the Geminivirus based constructs, detected by PCR. The dashed and solid arrows indicate the position of a size marker of 1,500 bp and the position of GUS (ca. 1,800 bp) respectively (lane 1). Lane 8 and 12 are negative controls: PCR from plants grown from non-treated seeds and from plant from seeds imbibed with no DNA construct, respectively.

FIG. 4A and **4B** show cross sections of tomato leaves stained for GUS activity

following seed priming in the presence of IL-60-BS and pIR-GUS (Fig. 4B mag. X40)

DETAILED DESCRIPTION OF THE INVENTION

Definitions

The term "priming" as used herein refers to the pre-sowing restricted hydration treatment of seeds to improve germination and seedling establishment and to the biochemical, physiological and biological processes occurring within the seed prior to full hydration and germination. The priming process controls and manipulates the water availability to the seeds such that water availability suffice to initiate and affect the early events of germination, but is not sufficient to permit radicle emergence. Depending of the plant species and growers requirements, the above-described controlled hydration is subsequently followed by partial or complete drying, such that the seeds can be further stored for short or long time periods until sowing.

As used herein, the term "priming medium" refers either to solutions (inorganic, e.g., salts/nutrients, or organic, e.g., PEG) or to solid particulate systems (for example comprising kaolin) resulting in controlled hydration with water. Examples of such mediums are specified in. Taylor G P. et al. (1998. Seed Science Technology 8:245-256).

The term "conditions enabling priming" refers to suitable conditions of medium composition (e.g. osmotic PEG or other components solutions, solid water absorbents, and more); duration; temperatures; light/dark regimes; and aeration (e.g., stirring, agitation, bubbling, etc.) to induce seed priming using any technique as is known in the art for controlled water uptake.

The term "treated plants" refers to plants into which the heterologous DNA has been introduced, regardless if it has been integrated into the plant genome, into its organelles, or remained free in the cytoplasm, or resided as an episome in the nucleus without integration.

The term "plant" is used herein in its broadest sense. It includes, but is not limited to, any species of woody, herbaceous, perennial or annual plant. It also refers to a plurality of plant cells that are largely differentiated into a structure that is present at any stage of a plant's development. Such structures include, but are not limited to, a root, stem, shoot, leaf, flower, petal, fruit, any storage organ (e.g., tuber, bulb, corm, false

stem, leaves etc). The term "plant tissue" includes differentiated and undifferentiated tissues of plants including those present in roots, shoots, leaves, pollen, seeds and tumors, as well as cells in culture (e.g., single cells, protoplasts, embryos, callus, etc.). Plant tissue may be within the plant, in organ culture, tissue culture, or cell culture. The term "plant part" as used herein refers to a plant organ or a plant tissue.

The term "gene" refers to a nucleic acid (e.g., DNA or RNA) sequence that comprises coding sequences necessary for the production of RNA or a polypeptide. The term comprises natural as well as man tailored (synthetic) genes. A polypeptide can be encoded by a full-length coding sequence or by any part thereof. The term "parts thereof" when used in reference to a gene refers to fragments of that gene ranging in size from a few nucleotides to the entire gene sequence minus one nucleotide. Thus, "a nucleic acid sequence comprising at least a part of a gene" may comprise fragments of the gene or the entire gene.

The term "gene" also encompasses the coding regions of a structural gene and includes sequences located adjacent to the coding region on both the 5' and 3' ends for a distance of about 1 kb on either. The sequences which are located 5' of the coding region and which are present on the mRNA are referred to as 5' non-translated (or untranslated) sequences (5' UTR). The sequences which are located 3' or downstream of the coding region and which are present on the mRNA are referred to as 3' non-translated (or untranslated) sequences (3' UTR).

The term "nucleic acid" as used herein refers to RNA or DNA that is linear or branched, single or double stranded, or a hybrid thereof. The term also encompasses RNA/DNA hybrids.

The terms "heterologous DNA" or "exogenous DNA" refer to a polynucleotide that is not present in its natural environment (i.e., has been altered by the hand of man). For example, a heterologous DNA includes a polynucleotide from one species introduced into another species. A heterologous DNA also includes a polynucleotide native to an organism that has been altered in some way (e. g., mutated, added in multiple copies, linked to a non- native promoter or enhancer sequence, etc.). Heterologous DNA may comprise gene sequences of plants bacteria and mammal origin. The gene sequences may comprise cDNA forms of a gene; the cDNA sequences may be expressed in either a sense (to produce mRNA) or anti-sense orientation (to

produce an anti-sense RNA transcript that is complementary to the mRNA transcript). Heterologous plant genes are distinguished from endogenous plant genes in that the heterologous gene sequences are typically joined to nucleotide sequences comprising regulatory elements such as promoters that are not found naturally associated with the gene for the protein encoded by the heterologous gene or with plant gene sequences in the chromosome, or are associated with portions of the chromosome not found in nature (e.g., genes expressed in loci where the gene is not normally expressed).

The term "construct" is used herein in its broad sense, referring to an artificially assembled or isolated nucleic acid molecule which includes the heterologous DNA interest. In general a construct may include the heterologous DNA, typically a gene of interest, a marker gene which in some cases can also be the gene of interest and appropriate regulatory sequences. It should be appreciated that the inclusion of regulatory sequences in a construct is optional, for example, such sequences may not be required in situations where the regulatory sequences of a host cell are to be used. The term construct includes vectors but should not be seen as being limited thereto.

The term "operably linked" refers to the association of nucleic acid sequences on a single nucleic acid fragment so that the function of one is regulated by the other. For example, a promoter is operably linked with a coding sequence when it is capable of regulating the expression of that coding sequence (i.e., that the coding sequence is under the transcriptional control of the promoter). Coding sequences can be operably linked to regulatory sequences in a sense or antisense orientation.

The terms "promoter element," "promoter," or "promoter sequence" as used herein, refer to a DNA sequence that is located at the 5' end (i.e. precedes) the protein coding region of a DNA polymer. The location of most promoters known in nature precedes the transcribed region. The promoter functions as a switch, activating the expression of a gene. If the gene is activated, it is said to be transcribed, or participating in transcription. Transcription involves the synthesis of mRNA from the gene. The promoter, therefore, serves as a transcriptional regulatory element and also provides a site for initiation of transcription of the gene into mRNA. Promoters may be derived in their entirety from a native gene, or be composed of different elements derived from different promoters found in nature, or even comprise synthetic DNA segments. It is understood by those skilled in the art that different promoters may direct the expression

of a gene in different tissues or cell types, or at different stages of development, or in response to different environmental conditions. It is further recognized that since in most cases the exact boundaries of regulatory sequences have not been completely defined, DNA fragments of some variation may have identical promoter activity. Promoters which cause a gene to be expressed in most cell types at most times are commonly referred to as "constitutive promoters". New promoters of various types useful in plant cells are constantly being discovered; numerous examples may be found in Okamuro J K and Goldberg R B (1989) Biochemistry of Plants 15:1-82.

As used herein, the term an "enhancer" refers to a DNA sequence which can stimulate promoter activity, and may be an innate element of the promoter or a heterologous element inserted to enhance the level or tissue-specificity of a promoter.

The term "expression", as used herein, refers to the production of a functional end-product e.g., an mRNA or a protein

Preferred modes for carrying out the invention

The present invention provides methods for introducing heterologous DNA into plant cells or tissue. The methods of the invention enable a simple, easy to use, inexpensive, widely accessible, and efficient way to produce seeds and plants comprising exogenous DNA. According to the methods of the invention the desired DNA is introduced into the seeds and then plants are grown from the seeds, thus increasing considerably the efficiency of DNA introduction and saving on the costly and sometimes difficult plant regeneration process.

According to one aspect, the present invention provides a method for introducing heterologous DNA into at least one cell of a plant seed embryo comprising contacting the plant seed with a priming medium containing a virus-based DNA construct comprising the heterologous DNA under conditions enabling priming, thereby obtaining a seed embryo comprising the heterologous DNA.

According to certain embodiments, the virus-based DNA construct comprises viral genes or parts thereof enabling replication and symptomless spreading of the construct into adjacent plant cells.

According to certain embodiments, the method further comprises providing the suitable conditions for subsequent seed germination and growth so as to obtain a plant

or part thereof comprising the heterologous DNA.

The term "comprising the heterologous DNA" when used in reference to a plant or seed refers to a plant or seed that contains at least one heterologous DNA in one or more of its cells. The term refers broadly to a plant, a plant structure, a plant tissue, a plant seed or a plant cell that contains at least one heterologous DNA in at least one of its cells. This term includes the primary cell to which the DNA was introduced and cultures and plants derived from that cell without regard to the number of transfers. All progeny may not be precisely identical in DNA content, due to deliberate or inadvertent mutations. Mutant progeny that have the same functionality as screened for in the originally cell to which the DNA was introduced are included in the definition of transformants.

Introduction of a heterologous DNA into a cell may be stable or transient. The term "transient" refers to the introduction of one or more exogenous polynucleotides into a cell in the absence of integration of the exogenous polynucleotide into the host cell's genome. This type of DNA introduction may be also referred to as "transient transformation". The term "transient transformant" thus refers to a cell which has transiently incorporated one or more exogenous polynucleotides. Transiently transformed cells are typically referred to as “non-transgenic” or “non-genetically modified (non-GMO)”. In contrast, stable DNA introduction is referred to as "stable transformation" resulting in "stably transformed" cell or tissue and refers to the introduction and integration of one or more exogenous polynucleotides into the genome of a cell. The term "stable transformant" refers to a cell which has stably integrated one or more exogenous polynucleotides into the genomic or organellar DNA (chloroplast and/or mitochondria). Plants or parts thereof comprising cell stably transformed with exogenous DNA are typically referred to as “transgenic plants”, “transgenic plant cell” or, in the context of the present invention “transgenic seeds”.

The virus-based DNA construct of the present invention is capable of systemic, symptomless spread in the plant to which it was introduced. As used herein, the term “systemic, symptomless spread” refers to the ability of the virus-based vector to spread, for example, from the embryo cell to the developing leaf cells, without inducing the characteristic pathogenic symptoms of the virus. The DNA construct may be further transmitted to the offspring of the plant comprising the heterologous DNA. Without

wishing to be bound by any specific theory or mechanism of action, such transfer may result from the spreading of the virus-based DNA construct into the plant reproductive cells.

According to certain currently preferred embodiment, the DNA construct is based on the Geminivirus genetic components, as disclosed in International (PCT) Application Publication No. WO2007/141790 incorporated herein in its entirety by reference. The construct comprises the heterologous polynucleotide sequence flanked by a non-continuous nucleic acid sequences encoding a Geminivirus replicase.

According to other embodiments, the construct further comprises a polynucleotide sequence encoding a modified Geminivirus coat protein (CP). According to typical embodiments, the modified Geminivirus coat protein has the amino acid sequence set forth in SEQ ID NO:3. According to additional embodiments, the modified Geminivirus coat protein encoding polynucleotide comprises a mutation or deletion in nucleotides encoding the N-terminal 100 amino acids.

According to further typical embodiments the expression construct further comprises a polynucleotide sequence encoding a modified Geminivirus V2 protein. According to typical embodiments, the modified Geminivirus V2 protein has the amino acid sequence set forth in SEQ ID NO:4.

According to additional typical embodiments the expression construct further comprises a polynucleotide sequence encoding a modified Geminivirus C4 protein. According to typical embodiments, the modified Geminivirus C4 protein has the amino acid sequence set forth in SEQ ID NO:5. According to these embodiments, the modified Geminivirus C4 protein includes a mutation or deletion.

It is to be explicitly understood that other virus-based construct carrying long heterologous polynucleotides and capable of replicating and symptomless spread are also encompassed within the teachings of the present invention. As used herein, the term "long heterologous polynucleotides" refers to polynucleotides at least 1 kb long, typically at least 5 kb long more typically 6 kb long.

According to certain typical embodiments, the DNA construct is based on the tomato yellow leaf curl virus (TYLCV). Examples of such constructs are IL-60-BS (having the nucleic acid sequence set forth in SEQ ID NO:2) and pIR-GUS (having the nucleic acid sequence set forth in SEQ ID NO:8) as described in Figure 2.

The Geminivirus based construct used according to the teachings of the present invention are introduced into the seed embryo cells, and are not integrated into the genome of the cells. The plant grown from the seed comprising the heterologous DNA and the plant grown therefrom are thus referred to as non-genetically modified plant.

The agricultural use of genetically-modified plants is a matter of public debate and in many countries is unacceptable by law or regulation. The main considerations voiced against the use of transgenic plants are the fear of inappropriate selection of a transgenic lineage (due to masked deleterious positional effects), possible cross-fertilization with weeds and other crops, further genome alterations due to recombination (especially when copies of endogenous genes are added) and possible transduction of the foreign sequences to plant and soil microorganisms. Introduction of antibiotic-resistant genes to food and the environment is also a major concern.

Bio-safety and environmental aspects can only be concluded upon following actual, carefully controlled, field tests over time. Clearance to conduct such experiments depends on evaluation based on hard laboratory data. One advantage of the methods of the present invention arises from the finding that the TYCLV based constructs appear to be environmentally-friendly and ready for bio-safety-evaluation field tests. Geminiviruses are not seed-transmissible (Kashina et al. 2003. Phytoparasitica 31:188-199). The vector forms IL-60-BS and pIR are not insect-transmissible even when the plants were colonized with a large number of insect vectors. Thus, the TYCLV based constructs are highly suitable for plant transformation.

The presence of the heterologous DNA in the cell of a treated seed, whether expressed transiently or stably integrated, can be verified by employing any suitable method as is known to a person skilled in the art. Stable transformation of a cell may be detected by isolating genomic DNA and employing Southern blot hybridization with nucleic acid sequences which are capable of binding to one or more of the exogenous polynucleotides or employing polymerase chain reaction with appropriate primers to amplify exogenous polynucleotide sequences. Expression of the transformed DNA can be detected by for example, enzyme-linked immunosorbent assay (ELISA), which detects the presence of a polypeptide encoded by one or more of the exogenous polynucleotides or by detecting the activity of the protein encoded by the exogenous polynucleotide.

Alternatively, the exogenous DNA can comprise a marker. A marker provides for the identification and/or selection of a cell, plant, and/or seed expressing the marker. A marker can encode a product, which when expressed at a sufficient level, confers resistance to a selective agent. Such markers and their corresponding selective agents include, but are not limited to, herbicide resistance genes and herbicides; antibiotic resistance genes and antibiotics; and other chemical resistance genes with their corresponding chemical agents. Bacterial drug resistance genes include, but are not limited to, neomycin phosphotransferase II (nptll) which confers resistance to kanamycin, paromycin, neomycin, and G418, and hygromycin phosphotransferase (hph) which confers resistance to hygromycin B. Resistance may also be conferred to herbicides from several groups, including amino acid synthesis inhibitors, photosynthesis inhibitors, lipid inhibitors, growth regulators, cell membrane disrupters, pigment inhibitors, seedling growth inhibitors, including but not limited to imidazolinones, sulfonylureas, triazolopyrimidines, glyphosate, sethoxydim, fenoxaprop, glufosinate, phosphinothricin, triazines, bromoxynil, and the like.

Additional type of marker is a marker the expression of which can be detected by following a biochemical reaction preferably producing color, upon providing of an appropriate substrate. Examples are the GUS (beta-glucuronidase) reporter system, luciderin-luciferase, green-fluorescent protein (GFP) system and the like.

According to certain embodiments, the DNA construct further comprises a regulatory element including, but not limited to, a promoter, an enhancer, and a termination signal.

Among the most commonly used promoters are the nopaline synthase (NOS) promoter (Ebert et al., 1987 Proc. Natl. Acad. Sci. U.S.A. 84:5745-5749), the octapine synthase (OCS) promoter, caulimovirus promoters such as the cauliflower mosaic virus (CaMV) 19S promoter (Lawton et al., 1987 Plant Mol Biol. 9:315-324), the CaMV 35S promoter (Odell et al., 1985 Nature 313:810-812), and the figwort mosaic virus 35S promoter, the light inducible promoter from the small subunit of rubisco, the Adh promoter (Walker et al., 1987 Proc. Natl. Acad. Sci. U.S.A. 84:6624-66280), the sucrose synthase promoter (Yang et al., 1990 Proc. Natl. Acad. Sci. U.S.A. 87:4144-4148), the R gene complex promoter (Chandler et al., 1989 Plant Cell 1:1175-1183), the chlorophyll a/b binding protein gene promoter, etc. Other commonly used promoters

are, the promoters for the potato tuber ADPGPP genes, the sucrose synthase promoter, the granule bound starch synthase promoter, the glutelin gene promoter, the maize waxy promoter, Brittle gene promoter, and Shrunken 2 promoter, the acid chitinase gene promoter, and the zein gene promoters (15 kD, 16 kD, 19 kD, 22 kD, and 27 kD; Perdersen et al. 1982 Cell 29:1015-1026). A plethora of promoters is described in International Patent Application Publication No. WO 00/18963.

The "3' non-coding sequences" refer to DNA 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. 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 I L. et al. (1989. Plant Cell 1:671-680).

The method of the present invention can be used for introducing any polynucleotide the presence and/or expression of which is of interest, including giving the plant desired property(ies) such as (a) resistance to biotic and a-biotic stress conditions, e.g., to insects, nematodes, diseases caused by viral, bacterial fungal and other pathogens pests, resistance to specific herbicide(s) (b) adaptation to hostile conditions such as salt tolerance, drought tolerance, cold and heat tolerance; (c) improved yield quality traits, including but not limited to pigmentation, firmness, type and content of ingredients including sugars, volatiles, oils, fatty acids and/or acids, size, growth rate, dwarf growth habit, time of emergence, time of fruit appearance and ripening; nutritional or commercial value; (d) improved production of edible yields, or of secondary metabolites, for the biopharmaceutical and cosmetic industries either in the form of a protein, secondary metabolites and (e) obtaining a desired growth habit, including determinate, semideterminate and indeterminate (e.g. for tomato), dwarf and normal (e.g. for corn) and plant vigor. The introduced DNA can also confer gene silencing such that the heterologous DNA is in the form of antisense, siRNA, dsRNA; or for producing raw materials for industries, including but not limited to fiber, wood, oils, resins, etc. as well as other plant traits governed by genetic factors, and/or interaction by genes and environment.

The expressed polynucleotide sequence can encode a molecule which would

protect the plant from abiotic stress factors such as drought, heat or chill. Examples include antifreeze polypeptides from *Myoxocephalus Scorpius* (WO 00/00512) or *M. octodecemspinosus*, the *Arabidopsis thaliana* transcription activator CBFl, glutamate dehydrogenases (WO 97/12983, WO 98/11240), calcium-dependent protein kinase genes (WO 98/26045), calcineurins (WO 99/05902), casein kinase from yeast (WO 02/052012), farnesyltransferases (WO 99/06580), ferritin (Deak M. et al. 1999. Nature Biotechnology 17:192-196), oxalate oxidase (WO 99/04013), DREBlA factor (Kasuga M. et al. 1999. Nature Biotech 17:276-286), genes of mannitol or trehalose synthesis such as trehalose-phosphate synthase or trehalose-phosphate phosphatase (WO 97/42326) or by inhibiting genes such as trehalase (WO 97/50561).

The expressed polynucleotide sequence could be a metabolic enzyme for use in the food-and-feed sector. Examples include phytases (GenBank Ace. No.: A 19451) and cellulases.

The expressed polynucleotide sequence can confer resistance to viruses, fungi, insects, nematodes and other pathogens and diseases, by directly attacking the pathogen, turning on the host defenses or by leading to an accumulation of certain metabolites or proteins. Examples include glucosinolates (defense against herbivores), chitinases or glucanases and other enzymes which destroy the cell wall of parasites, ribosome-inactivating proteins (RIPS) and other proteins of the plant resistance and stress reaction as are induced when plants are wounded or attacked by microbes, or chemically, by, for example, salicylic acid, jasmonic acid or ethylene, or lysozymes from non-plant sources such as, for example, T4-lysozyme or lysozyme from a variety of mammals, insecticidal proteins such as *Bacillus thuringiensis* endotoxin, α-amylase inhibitor or protease inhibitors (cowpea trypsin inhibitor), lectins such as wheatgerm agglutinin, siRNA, antisense RNA, RNAses or ribozymes. Further examples are nucleic acids which encode the *Trichoderma harzianum* chit42 endochitinase (GenBank Ace. No.: S78423) or the N-hydroxylating, multi-functional cytochrome P- 450 (CYP79) protein from *Sorghum bicolor* (GenBank Ace. No.: U32624), or functional equivalents thereof.

Resistance to pests such as, for example, the rice pest *Nilaparvata lugens* in rice plants can be achieved by expressing the snowdrop (*Galanthus nivalis*) lectin agglutinin (Rao et al. 1998. Plant J 15(4):469-77).

The expression of synthetic *cryIA(b)* and *cryIA(c)* genes, which encode

lepidoptera-specific *Bacillus thuringiensis* delta-endotoxins can bring about a resistance to insect pests in various plants (Goyal R K. et al. 2000. Crop Protection 19(5):307-312).

Additional genes which are suitable for pathogen defense comprise "polygalacturonase-inhibiting protein" (PGIP), thaumatine, invertase and antimicrobial peptides such as lactoferrin (Lee T J. et al. 2002. J Amer Soc Horticult Sci 127(2):158-164). The expressed polynucleotide sequence can bring about an accumulation of chemicals such as of tocopherols, tocotrienols or carotenoids. One example of such a polynucleotide is phytoene desaturase. Preferred are nucleic acids which encode the Narcissus pseudonarcissus phytoene desaturase (GenBank Ace. No.: X78815) or functional equivalents thereof. The expressed polynucleotide sequence can be used for production of nutraceuticals such as, for example, polyunsaturated fatty acids (arachidonic acid, eicosapentaenoic acid or docosahexaenoic acid) by fatty acid elongases and/or desaturases, or for production of proteins with improved nutritional value such as, for example, with a high content of essential amino acids (for example the high-methionine 2S albumin gene of the brazil nut). Preferred are polynucleotide sequences which encode the *Bertholletia excelsa* high-methionine 2S albumin (GenBank Ace. No.: AB044391), the *Physcomitrella patens* delta-6-acyl-lipid desaturase (GenBank Ace. No.: AJ222980), the *Mortierella alpina* delta-6-desaturase (Sakuradani et al. 1999. Gene 238:445-453), the *Caenorhabditis elegans* delta-5-desaturase (Michaelson et al. 1998, FEBS Letters 439:215-218), the *Caenorhabditis elegans* A5-fatty acid desaturase (des-5) (GenBank Ace. No.: AF078796), the *Mortierella alpina* delta-5 -desaturase (Michaelson et al. JBC 273: 19055-19059), the *Caenorhabditis elegans* delta-6-elongase (Beaudoin et al. 2000. PNAS 97:6421-6426), the *Physcomitrella patens* delta-6-elongase (Zank et al. 2000. Biochemical Society Transactions 28:654-657), or functional equivalents of these.

The expressed polynucleotide sequence can be used for production of high-quality proteins and enzymes for industrial purposes (for example enzymes, such as lipases) or as pharmaceuticals (such as, for example, antibodies, blood clotting factors, interferons, lymphokins, colony stimulation factor, plasminogen activators, hormones or vaccines, as described, for example, by Hood E E. et al. (1999. Curr Opin Biotechnol 10(4):382-60 and Ma J K. et al. (1999. Curr Top Microbiol Immunol 236:275-92). For example, it has been possible to produce recombinant avidin from chicken albumen and

bacterial P-glucuronidase (GUS) on a large scale in transgenic maize plants (Hood et al. 1999. Adv Exp Med Biol 464: 127-47; Review).

The expressed polynucleotide sequence can be also used for obtaining an increased storability in cells which normally comprise fewer storage proteins or storage lipids, with the purpose of increasing the yield of these substances for example acetyl-CoA carboxylase. Preferred polynucleotide sequences are those which encode the Medicago sativa acetyl-CoA carboxylase (accase) (GenBank Ace. No.: L25042), or functional equivalents thereof.

Additional examples of expressible polynucleotides include Hepatitis B surface antigen (Kumar GBS et al. 2005. PLANTA 222 (3):484-493), herbicide resistance (Duke, S O. 2005. Pest Management Science 61(21):1-218), interferon (Edelbaum, O. et al.1992. J. Interferon Res. 12:449-453), T7-RNA polymerase (Zeitoune et al. 1997. Plant Science 141:59-65).

Further examples of polynucleotide sequence which can be expressed in the transformed plants of the present invention are mentioned for example in Dunwell J M. 2000. J Exp Bot. 51:487-96.

The heterologous DNA transformed into the plant cell according to the teachings of the present invention can also be employed for the reduction (suppression) of transcription and/or translation of target genes. Thus, the DNA construct can comprises heterologous DNA the expression of which brings about PTGS (post transcriptional gene silencing) or TGS (transcriptional silencing) effects and thus a reduction of the expression of endogenous genes. Such reduction can be achieved for example by expression of an antisense RNA or of a double-stranded RNA, each of which has homology with the endogenous target gene to be suppressed. Also, the expression of a suitable sense RNA can cause a reduction in the expression of endogenous genes, by means of what is known as co-suppression (EP Application Publication No. 0465572). Particularly preferred is the expression of a double-stranded small interfering RNA (siRNA) for reducing the gene expression of a target gene via RNA interference (RNAi). Methods for inhibiting individual target genes using RNA with double-stranded structure, where the target gene and the region of the RNA duplex have at least partial identity are known to a person skilled in the art.

The following provide examples for applications where reduction of gene

expression can be obtained by transforming plant seed with an appropriate heterologous DNA according to teachings of the present invention.

Delayed fruit maturation or a modified maturation phenotype (prolonged maturation, later senescence) can be achieved for example by reducing the gene expression of genes selected from the group consisting of polygalacturonases, pectin esterases, β-1,4)glucanases (cellulases), β-galactanases (β-galactosidases), or genes of ethylene biosynthesis, such as 1-aminocyclopropane-1-carboxylate synthase, adenosylmethionine hydrolase (SAMase), aminocyclopropane-1-carb-oxylate deaminase, aminocyclopropane-1-carboxylate oxidase, genes of carotenoid biosynthesis such as, for example, genes of pre-phytoene biosynthesis or phytoene biosynthesis, for example phytoene desaturases, and O-methyltransferases, acyl carrier protein (ACP), elongation factor, auxin-induced gene, cysteine(thiol) proteinases, starch phosphorylases, pyruvate decarboxylases, chalcone reductases, protein kinases, auxin-related gene, sucrose transporters, meristem pattern gene. Further advantageous genes are described for example in International (PCT) Applications Publication Nos. WO 91/16440, WO 91/05865, WO 91/16426, WO 92/17596, WO 93/07275 or WO 92/04456. particularly preferred is the reduction of the expression of polygalacturonase for the prevention of cell degradation and mushiness of plants and fruits, for example tomatoes. Nucleic acid sequences such as that of the tomato polygalacturonase gene (GenBank Acc. No.: x14074) or its homologs can preferably used for this purpose.

The reduction of the gene expression of genes encoding storage proteins has numerous advantages, such as, for example, the reduction of the allergenic potential or modification regarding composition or quantity of other metabolites, such as, for example, oil or starch content.

Resistance to plant pathogens such as arachnids, fungi, insects, nematodes, protozoans, viruses, bacteria and diseases can be achieved by reducing the gene expression of genes which are essential for the growth, survival, certain developmental stages (for example pupation) or the multiplication of a specific pathogen. Such a reduction can bring about a complete inhibition of the abovementioned steps, or else a delay of same. They can take the form of plant genes which for example make possible the penetration of the pathogen, but may also be homologous pathogen genes. The transformed and expressed heterologous nucleic acid sequence (for example the double-

stranded RNA) is directed against genes of the pathogen, such that the pathogen life cycle is interrupted.

Virus resistance can be achieved for example by reducing the expression of a viral coat protein, a viral replicase, a viral protease and the like. A large number of plant viruses and suitable target genes are known to the skilled artisan.

Reduction of undesired, allergenic or toxic plant constituents such as, for example, glucosinolates or patatin. Suitable target genes are described (in WO 97/16559, *inter alia*). The target genes which are preferred for reduction of allergenic proteins are described for example by Tada Y et al. (1996) FEBS Lett 391(3):341-345 or Nakamura R (1996) Biosci Biotechnol Biochem 60(8):1215-1221.

Delayed signs of senescence. Suitable target genes are, *inter alia*, cinnamoyl-CoA:NADPH reductases or cinnamoyl-alcohol dehydrogenases. Further target genes are described (in WO 95/07993, *inter alia*).

Increase of the methionine content by reducing threonine biosynthesis, for example by reducing the expression of threonine synthase (Zeh M et al. 2001.Plant Physiol 127(3): 92-802).

A plant seed is a complete self-contained reproductive unit generally consisting of a zygotic embryo resulting from sexual fertilization or through asexual seed reproduction (apomixis), storage reserves of nutrients in structures referred to as cotyledons, endosperm or megagametophytes, and a protective seed coat encompassing the storage reserves and embryo. In nature, maturation of plant seeds is usually accompanied by gradual loss of water over a period of time to levels between 5-35% moisture content. Once these low moisture levels are achieved, plant seeds can be stored for extended periods.

Germination of sexual zygotic and apomictic plant seeds is generally triggered by one or more environmental cues such as the presence of water, oxygen, optimal temperature or cold/hot treatment, and exposure to light and its duration. Seeds germinate by means of a series of events which commence with the uptake of water (imbibition) by a quiescent dry seed and then subsequently proceed through various biophysical, biochemical and physiological events which ultimately result in the elongation of the embryo along its axis and development of the offspring.

The continuous process of seed germination may be divided into three phases. Phase one is referred to as imbibition and is characterized by a rapid initial intake of water into the seed. Other significant events occurring in phase one are the initiation of repair of damage nuclear and mitochondrial DNA, which may have occurred during seed desiccation and/or the maturation process, and subsequent commencement of protein synthesis facilitated by existing mRNA.

Phase two is characterized by a significant reduction in the rate of water uptake (i.e., imbibition has been completed). This is accompanied by activation or *de novo* synthesis of enzymes that specialize in hydrolyzing the complex storage reserves of carbohydrates, proteins, and lipids in the embryo and the cotyledons or megagametophytes. The hydrolysis of these complex storage reserves provides the substrates required for the respiration and growth of the seed embryos.

Phase three is characterized by a second rapid increase in the rate of water uptake. Water absorbed during phase three is used primarily for the initiation of meristematic cell division at the root and shoot apices of the embryo, and for uptake into the cells along the embryonal axis. Water taken up by the axial cells of the embryo applies turgor pressure which results in axial cell elongation. The net effect is that the embryo elongates to the point of emergence through the seed coat. Protrusion of a shoot or root radicle through the seed coat signifies the completion of germination and the onset of seedling growth and development.

The speed and success for germination of seeds varies considerably depending on various factors such as the residual influence of environmental conditions in which the seed developed and maturated, the amount of storage reserve compounds synthesized during the seed maturation process, the duration of storage, the quality of the storage environment (e.g., temperature and humidity) and the environmental conditions prevailing during the germination processes. From a commercial perspective, it is desirable to reduce the risk of germination failure and to ensure that seeds emerge and germinate rapidly and uniformly.

The commercial need for optimum seed germination performance has led to the development of processes known in the art for zygotic seeds as "seed priming". This term may be defined as the limited uptake of water that is sufficient to initiate the early events of germination, but not sufficient to permit radicle protrusion, preferably

followed by drying. Several principle techniques are used commercially to accomplish seed priming. Regardless of the particular method used, the fundamental principles of seed priming are that: (1) the preliminary stages of germination are activated specifically and exclusively through controlling the availability of water to the seeds, and (2) the germination processes initiated through an external priming process are subsequently arrested by a desiccation or partial desiccation step.

Unexpectedly, the present invention now shows that including a virus-based DNA construct in the seed priming medium results in the uptake of the DNA by the seed such that the DNA enters the seed cells. Without wishing to be bound by any specific theory or mechanism of action, this phenomenon may be attributed to viral elements enabling the introduction of the heterologous DNA into the seeds cells.

Any method for seeds priming as is known to a person skilled in the art can be used according to the teachings of the present invention. Priming can be performed under a variety of temperatures and aeration (e.g., stirring, agitation, bubbling, etc.) using any of the techniques for controlled water uptake: priming with solutions (inorganic, e.g., salts/nutrients, or organic, e.g., PEG) or with solid particulate systems or by controlled hydration with water as described, for example, in Taylor, A G. et al1998. Seed Science Technology 8:245-256).

A priming matrix is characterized by its effective osmotic potential. An effective osmotic potential typically lowers the water potential available for seed imbibitions allowing or causing a limited amount of water to move into the seed to a level sufficient for initial steps of germination without actual protrusion of the radical, i.e., to prime the seed. Seeds germination occurs only when water available to the seed reaches a potential sufficient for physiological development, which varies between plant species. Typically this value falls between 0 and -2 mPa. Many priming matrices that provide an appropriate osmotic potential are being used, including water, water with one or more solutes, solid matrices, and the like. For example, the priming matrix may comprise an aerated solution of osmotic material, of organic nature such as polyethylene glycol (PEG) (see U.S. Patent No. 5,119,598), glycerol, mannitol, or inorganic salt (or combination of salts) such as potassium phosphate, potassium nitrate, and the like. Alternatively, seeds may be primed using a solid matrix. A solid matrix material should have a high water holding capacity to allow seeds to imbibe. In this method, the priming

matrix can comprise an absorbent medium such as clay, vermiculite, perlite, saw dust, corn cobs, and/or peat to absorb water and then transfer it to the seed (e.g., U.S. Patent No. 4,912,874). The extent of hydration is controlled by altering the water content of the medium and the medium/seed ratio. Methods are also known to imbibe seeds in a slurry of PEG 6000 and vermiculite, or other matrices (e.g., U.S. Patent No. 5,628,144). In still other methods, priming employs a semi-permeable membrane that mediates the transfer of water from a solution characterized by a given osmotic pressure to the seed (e.g., U.S. Patent No. 5,873,197). In other methods, ultrasonic energy can be used to assist in the priming process (e.g., U.S. Patent No. 6,453,609). Optionally a variety of additives, chemicals, and/or compounds can be included in the priming matrix, including surfactants, selective agents, fungicides, agents to modify osmotic potential, osmotic protectants, agents to aid drying or protect the seed during drying, agents to enhance seed processing, agents to extend storage shelf-life, agents to enhance coating and/or perfusion, agents to enhance germination of the seed, and the like. Fungicides can be included in the priming matrix, for example, thiram, captan, metalaxyl, pentachloronitrobenzene, fenaminosulf, bactericides or other preservatives. In addition, various growth regulators or hormones, such as gibberellins or gibberellic acid, cytokinins, inhibitors of abscissic acid, 2-(3,4-dichlorophenoxy) triethylamine (DCPTA), potassium nitrate, and ethaphon can also be present in the priming matrix. Other optional agents include glycerol, polyethylene glycol, mannitol, DMSO, Triton X-100, Tween-20, NP-40, ionic compounds, non-ionic compounds, surfactants, detergents, and the like. A time sufficient to produce a primed seed allows pre-germinative metabolic processes to take place within the seed up to any level including that immediately preceding radicle-emergence. The time to produce a primed seed is dependent on the specific seed variety, its state or condition, and the water potential of the priming matrix. While typical water amounts and media water potentials for given seed types are already generally known for some seeds, it is frequently best to test a small sample of a new seed over a readily determined range of osmotic potentials and temperatures to determine what conditions of temperature, water potential, and time provide appropriate imbibing of the seed and resultant pre-germination events. The temperature at which the priming methods are carried out may vary with the seeds to be treated, but typically is between 18°C to 30°C. The primed seeds may be retained in the priming matrix through germination as denoted by radical emergence. Seed produced by

this method may be further dried (e.g., as in U.S. Patent No. 4,905,411).

Methods to determine if a seed has been primed are known in the art. For example, optimization of priming treatments can be performed by carrying out germination assays. (See, for example, Jeller H. et al. 2003. Braz J Biol 63:61-68). In addition, molecular markers of germination and/or priming are known. See, for example, Job et al. 2000. Seed Biology: Advances and Applications, Eds. Black et al., CABI International, Wallingford, UK, pp. 449-459; De Castro R D. et al. 2000. Plant Physiol 122:327-336; Bradford et al. 2000. Seed Biology: Advances and Applications, Eds. Black et al., CABI International, Wallingford, UK pp. 221-251; and Gallardo K. et al. 2001 Plant Physiol 126:835-848.

After priming, the seeds may be allowed to germinate, or the primed seeds can be dried. The appropriate conditions (temperature, relative humidity, and time) for the drying process will vary depending on the seed and can be determined empirically (see, for example, Jeller et al. 2003. *ibid*). Drying primed seed includes a superficial drying of the seed or, alternatively, drying the seed back to its original water content. The dried seeds can be immediately germinated or can be stored under appropriate conditions. Germination conditions for various seeds are known. One factor in determining appropriate germination conditions is the threshold germination temperature range, which is the range of temperatures for a species within which seeds of that species will germinate at a predetermined moisture level and with adequate oxygen. Another factor is the threshold germination moisture range, which is the range of moisture for a species within which seeds of the species will germinate at a given temperature and with adequate oxygen. Threshold germination temperature range and/or threshold germination moisture range values are known for various seeds, as are methods to empirically determine these conditions for any given seed and variety.

The method of the invention greatly reduces the time required for introduction of heterologous gene(s) into the plant cells, generation, selection and propagation of the plants of interest. The potential for somaclonal variation caused by tissue de-differentiation in culture is nullified. When Geminivirus-based construct is used, the plants contain foreign DNA, as every tissue infected with benign microorganisms does, and yet the treated plants are not genomically modified. The method of the invention can cut drastically the time and cost of breeding, since it facilitates the expression of

gene(s) of interest in any desired plant variety, thus adding needed traits such as resistance/tolerance to biotic/a-biotic stress conditions, improving yield and quality for any given environment and market and the like, as long as genes controlling the desired trait are known. Similarly, the heterologous DNA introduced according to teachings of the present invention can result in silencing of certain process(s) when so required (e.g., development of green back in tomato fruit is desired in Italy but is unacceptable in the USA).

The following examples are presented in order to more fully illustrate some embodiments of the invention. They should, in no way be construed, however, as limiting the broad scope of the invention. One skilled in the art can readily devise many variations and modifications of the principles disclosed herein without departing from the scope of the invention.

EXAMPLES

Example 1: Priming using a priming medium without foreign DNA

Tomato seed priming in the presence of polyethylene glycol (PEG) was carried out as previously described (Khan, A A. 1992. In: Horticultural Reviews, Vol. 14, ed. J. Janick. New York: John Wiley, pp. 131-181; Taylor G. et al. 1998. Seed Science Technology 8:245-256), with some modifications.

Batches of 50 tomato seeds were imbibed in a solution composed of 0.1M $Ca(NO3)_2$; 0.1M MES (4-morpholineetahnsulfonic acid); 15mM $MgCl_2$ and 25% (solution T2) or 20% (solution T3) of PEG 8000. The osmotic pressure of solutions T2 and T3 was -1.25 mPa and -1.2 mPa respectively. Untreated dry seeds of the same cultivar, same seed lot were used as control. Treatment was carried out under constant temperature of 20°C with a 12 hour light regimen daily, and stirred gently for 4 or 6 days to obtain proper aeration. Seeds were then placed on 3M filter paper supplemented with 3ml sterile water and germination rates were recorded daily. The data demonstrate (Figure 1) a significant increase in germination uniformity of primed seed in comparison with control (successful priming).

Example 2: introducing IL-60 constructs into seeds by using priming medium

Tomato seeds were primed with a priming solution containing 25% PEG and

germinated as described in Example 1 above in the presence of 20, 40 and 60 μg of each of the IL-60-BS (SEQ ID NO:2) and pIR-GUS (SEQ ID NO:8) DNA constructs. The constructs are illustrated in Figure 2A and 2B, respectively. Constructs are also described in International (PCT) Patent Application Publication No. WO 2007/141790, incorporated herein by reference. Untreated dry seeds and seeds primed at the same conditions but without the DNA construct served as control.

Six days after germination the seedlings were transplanted into pots containing 10 liters soil and placed in a greenhouse at 25°C. Twenty one days after planting, DNA was extracted from true leaves (the third true leaf or above) and subjected to PCR with the following primers for GUS assay:

Forward primer: ATTGATCAGCGTTGGTGGGA (SEQ ID NO:6) and reverse primer: TGCGGTCGCGAGTGAAGATC (SEQ ID NO:7) designed to amplify the entire *gus* gene present within the pIR-GUS DNA construct. Positive PCR reaction confirmed the presence of a GUS DNA sequence in the true leaves. These results show that the DNA constructs of the IL-60 based vectors were introduced to the seed cell(s) using the above priming procedure. The introduced DNA replicated, spread and was expressed throughout the plant system. An example of the results of such assay is shown in Figure 3.

Example 3: Expression of the foreign genes

The DNA constructs of the IL-60 family as detailed in Example 2 above (IL-60-BS in combination with pIR-GUS) facilitated the expression of the foreign *gus* gene present within the pIR-GUS DNA construct and introduced via priming.

Tomato leaves from the plant obtained as described in Example 2 above were stained for beta-glucuronidase (GUS) according to Jefferson R A. et al. (1987. EMBO J 6: 3901-3907).

Blue color staining of the leaf tissue clearly denotes the expression of the GUS protein (Figure 4A-B).

Example 4: expression of specific DNA from IL-60 vectors under modified priming conditions.

Priming was conducted as in example 2 with the basic priming solution containing 5% PEG and the addition of 75% dimethylsulfoxide (DMSO) as to obtain final osmotic potential of -0.131 mPa (1.296 Atm., according to Christopher et. al Macromolecules 2003. 36:6888-6893). In this modified priming solution, the IR-GUS DNA was introduced and replicated as indicated by GUS expression as described in Examples 2 and 3 above.

The foregoing description of the specific embodiments will so fully reveal the general nature of the invention that others can, by applying current knowledge, readily modify and/or adapt for various applications such specific embodiments without undue experimentation and without departing from the generic concept, and, therefore, such adaptations and modifications should and are intended to be comprehended within the meaning and range of equivalents of the disclosed embodiments. It is to be understood that the phraseology or terminology employed herein is for the purpose of description and not of limitation. The means, materials, and steps for carrying out various disclosed functions may take a variety of alternative forms without departing from the invention.

CLAIMS

1. A method for introducing heterologous DNA into at least one cell of a plant seed embryo comprising contacting a plant seed with a priming medium containing a virus-based DNA construct comprising the heterologous DNA under conditions enabling priming, thereby obtaining the seed embryo comprising the heterologous DNA.

2. The method of claims 1, further comprising the step of providing suitable conditions for subsequent seed germination and growth so as to obtain a plant or part thereof comprising the heterologous DNA.

3. The method of claim 1, wherein the virus-based DNA construct comprises viral genes or parts thereof enabling replication and symptomless spreading of the construct into adjacent plant cells.

4. The method of claim 3, wherein the DNA construct is a Geminivirus based construct.

5. The method of claim 4, wherein the DNA construct comprises the heterologous DNA flanked by a non-contiguous nucleic acid sequences encoding Geminivirus replicase or replicase-associated proteins.

6. The method of claim 5, wherein the DNA construct further comprises a polynucleotide sequence encoding a modified Geminivirus coat protein (CP).

7. The method of claim 6, wherein the modified Geminivirus coat protein comprises a mutation or deletion in nucleotides encoding an N-terminal 100 amino acids.

8. The method of claim 5, wherein the DNA construct further comprises a polynucleotide sequence encoding a modified Geminivirus V2 protein.

9. The method of claim 8, wherein the DNA construct further comprises a polynucleotide sequence encoding a modified Geminivirus C4 protein.

10. The method of claim 5, wherein the DNA construct further comprises a bacterial polynucleotide sequence.

11. The method of any one of claims 4-10, wherein the Geminivirus is Tomato Yellow Leaf Curl Virus (TYLCV).

12. The method of claim 11, wherein the DNA construct is a Geminivirus-based construct selected from the group consisting of IL-60 having the nucleic acids sequence set forth on SEQ OD NO:1 and IL-60-BS having the nucleic acids sequence set forth in SEQ ID NO:2.

13. The method of claim 1, wherein the DNA construct is an expression construct thereby the heterologous DNA is expressed within the plant cell.

14. The method of claim 13, wherein the DNA construct further comprises at least one regulatory element selected from the group consisting of an enhancer, a promoter, and a transcription termination sequence.

15. The method of any one of claims 1-2, wherein the DNA construct further comprises a marker for identifying the seed and plants comprising the heterologous DNA.

16. The method of claim 1, wherein the heterologous DNA encodes a product selected from the group consisting of a peptide, a polypeptide, a protein and an RNA molecule.

17. The method of claim 16, wherein the peptide, polypeptide or protein are useful in the cosmetic or pharmaceutical industry.

18. The method of claim 16, wherein the RNA molecule is an inhibitory RNA selected from the group consisting of antisense RNA, dsRNA and siRNA.

19. The method of claim 16, wherein the encoded product confers a desirable agronomic trait selected from the group consisting of resistance to biotic or abiotic stress, increased yield, increased yield quality and preferred growth pattern.

20. The method of claim 1, wherein the heterologous DNA is transiently expressed in the at least one cell of the seed embryo and cells derived therefrom.

21. The method of claim 1, wherein the heterologous DNA is incorporated into the genome of the at least one cell of the seed embryo and cells derived therefrom.

22. The method of claim 1, wherein the priming medium have a water potential enabling seed imbibitions but not radicle emergence.

23. The method of claim 22, wherein the priming medium is an aqueous solution.

24. The method of claim 22, wherein the priming medium is a solid matrix.

25. A seed produced by the method of claim 1, wherein the seed comprises a virus-based DNA construct comprising heterologous DNA.

26. A plant or part thereof grown from the seed according to claim 25, wherein the plant or part thereof comprises the virus-based DNA construct comprising heterologous DNA.

27. The method of claim 1, wherein the seed is of a monocot origin.

28. The method of claim 1, wherein the seed is of a dicot origin.

29. The method of claim 1, wherein the seed is of cone-bearing origin.