Chapter 22
Drought and Salinity Tolerance in Transgenic Potato

Huaijun Si, Ning Zhang, and Di Wang

Abstract Drought and salinity are the most important environmental stress factors that limit agricultural production worldwide. Complex responses to drought and salinity stresses in plants are quantitative traits, thus involve cooperative functions of many genes and biochemical-molecular mechanisms. It is generally accepted that drought and salinity tolerance could be increased through transgenic approaches by incorporating genes involved in stress protection into plants that lack them. Potato is regarded as a moderately salt-sensitive and drought-sensitive crop. Transgenic potato plants with improved tolerance to drought and salinity stresses have been produced using various genes. This chapter presented the case study of enhanced drought and salinity tolerance of transgenic potato plants with a betaine aldehyde dehydrogenase (BADH) gene from spinach under the control of the constitutive expression promoter CaMV 35S and the stress-inducible expression promoter rd29A, respectively. The recent advance was summarized in improving drought and salinity tolerance through transgenic approaches in potato. The role of transgenic potato in sustainable production and its biosafety was also discussed. It is concluded that the transgenic approach is one of the powerful tools to improve potato crop for sustainable production and food supply in response to the coming increase of world population in the future.

22.1 Introduction

Abiotic stresses, such as drought, salinity, extreme temperatures, chemical toxicity and oxidative stresses, are serious threats to agriculture besides their deteriorative impact to the environment. Drought and salinity are the most important environmental stress

H. Si (✉) • N. Zhang • D. Wang
Gansu Provincial Key Laboratory of Aridland Crop Science; Gansu Key Laboratory of Crop Genetic and Germplasm Enhancement; College of Life Science and Technology, Gansu Agricultural University, Lanzhou 730070, People's Republic of China
e-mail: hjsi@gsau.edu.cn

Z. He et al. (eds.), *Sustainable Potato Production: Global Case Studies*,
DOI 10.1007/978-94-007-4104-1_22,

factors that limit food production worldwide, and may cause a serious salinization on more than 50% of all arable lands by the year 2050 (Wang et al. 2003). In China, almost half of the land is arid or semi-arid and the crop production is strongly affected by drought and salinity seasonally even if in the irrigated farm land.

Potato is regarded as a moderately salt-sensitive (Ahmad and Abdullah 1979), and drought-sensitive crop compared with other crops from the field experiments (Salter and Goode 1967; van Loon 1981). Drought always influences development and growth of stem, root and tuber (Ojala et al. 1990), and reduces number of tubers and yield in potato (Cavagnaro et al. 1971).

Complex reaction of plant in response to drought and salinity stresses is a quantitative character which genetic control includes the functions of many genes and biochemical-molecular mechanisms. These responses lead to a wide variety of biochemical and physiological changes such as the accumulation of various organic compounds of low-molecular weight, collectively known as compatible solutes or osmolytes, synthesis of late-embryogenesis-abundant (LEA) proteins, and activation of several detoxification enzymes (Bajaj et al. 1999).

Using transgenic approaches to enhance drought and salinity tolerance has been thoroughly reviewed lately in plants (Apse and Blumwald 2002; Rontein et al. 2002; Wang et al. 2003; Chen and Murata 2008; Kolodyazhnaya et al. 2009) and potato (Byun et al. 2007). It is generally accepted that drought and salinity tolerance could be increased through transgenic approaches by incorporating genes involved in stress protection into plants that lack them. Transgenic potato plants with improved tolerance to drought and salinity stress have been produced using various genes which have been summarized in Table 22.1 and briefly discussed below.

Trehalose is a non-reducing disaccharide of glucose. A plant that produces trehalose is often highly tolerant to desiccation stress. Goddijn et al. (1997) engineered trehalose biosynthesis in potato by introducing the *otsA* and *otsB* genes from *Escherichia coli*, which encode trehalose-6-phosphate synthase and trehalose-6-phosphate phosphatase, respectively. Jeong et al. (2001) introduced *GPD* gene for glyceraldehydes-3-phosphate dehydrogenase from the oyster mushroom (*Pleurotus sajor-caju*) into potato and obtained transgenic potato plants with enhanced salinity tolerance. Ambard-Bretteville et al. (2003) suppressed *FDH* gene encoding for formate dehydrogenase in transgenic potato plants which formate levels are increased. Thus, the suppression resulted in accumulation of praline in response to osmotic stress. Turhan (2005) developed transgenic potato plants with higher salinity tolerance by expressing *oxo* gene which enhanced synthesis of oxalate oxidase for catabolizing oxalic acid. The dehydration-responsive element (DRE) is essential for regulating dehydration-responsive gene expression (Yamaguchi-Shinozaki and Shinozaki 1994). The transformation of plants using regulatory genes is an attractive approach for producing dehydration-stress tolerant plants. The overexpression of *DREB1A* gene for DRE-binding protein from *Arabidopsis* in transgenic potato showed that the tolerance to salt-stress was increased in proportion to its copy number of the gene in tetrasomic tetraploid potato (Behnam et al. 2006). Oxidative stress is a major damaging factor for plants exposed to environmental stresses. Tang et al. (2006) obtained transgenic potato plants with increased tolerance to multiple environmental

Table 22.1 Genes overexpressed in transgenic potato plants for drought and salinity tolerance

Gene	Gene product	Performance of transgenic plant	Reference
otsA	Trehalose-6-phosphate synthase	Trehalose accumulation	Goddijn et al. (1997)
otsB	Trehalose-6-phosphate phosphatase	Trehalose accumulation	Goddijn et al. (1997)
OLP	Osmotin-like protein	Salt resistance	Evers et al. (1999)
TPS1	Trehalose-6-phosphate synthase	Increased tolerance to drought	Yeo et al. (2000)
GPD	Glyceraldehydes-3-phosphate dehydrogenase	Improvement of salt tolerance	Jeong et al. (2001)
FDH	Formate dehydrogenase	Accumulate proline rapidly to resist drought	Ambard-Bretteville et al. (2003)
oxo	Oxalate oxidase	Higher salinity tolerance	Turhan (2005)
DREB1A	Dehydration-responsive element (DRE)-binding protein	Tolerance to salt stress	Celebi-Toprak et al. (2005)
DREB1A	Dehydration-responsive element (DRE)-binding protein	Highly tolerant to salinity	Behnam et al. (2006)
SOD and APX	Cu/Zn superoxide dismutase and ascorbate peroxidase	Multiple stresses including drought, salinity, oxidative stress and high temperature	Tang et al. (2006)
SST/FFT	Fructan	Proline accumulation	Knipp and Honermeier (2006)
StEREBP1	Ethylene responsive element binding protein 1	Tolerance to NaCl stress	Lee et al. (2007)
AtNDPK2	Nucleoside diphosphate kinase	Enhanced tolerance to salt	Tang et al. (2008)
codA	Choline oxidase	Enhanced tolerance to oxidative, salt, and drought stresses	Ahmad et al. (2008)
GLOase	L-gulono-c-lactone oxidase	Enhanced tolerance to various abiotic stresses like oxidative, salt and drought stresses	Hemavathi et al. (2010)
BADH	Betaine aldehyde dehydrogenase	Enhanced drought and salinity tolerance	Zhang et al. (2011)

stress due to the overexpressed both superoxide dismutase (SOD) and ascorbate peroxidase (APX) in chloroplasts. Glycine betaine (GB) is a common compatible solute in many different organisms including higher plants. Many plant species can accumulate GB in response to drought and salinity. Ahmad et al. (2008) and Zhang et al. (2011) showed that the transgenic potato plants were more tolerant to

drought and salinity stress because of overexpressing *codA* and betaine aldehyde dehydrogenase (BADH) genes for GB synthesis.

This chapter, based on our research, presented the case study of enhancing drought and salinity tolerance in transgenic potato plants expressing *BADH* gene from spinach. Roles of transgenic potato in sustainable crop production and its biosafety concerns were also addressed.

22.2 Enhancement of Drought and Salinity Tolerance in Transgenic Potato by Expressing *BADH* Gene

To ensure their own survival and prosperity of their offspring, plants have evolved a range of strategies to cope with various abiotic stresses. One common mechanism is the accumulations of compatible solutes including certain polyols, sugars, amino acids, betains and related compounds. Glycine betaine (GB) is one of the most important of osmolytes (Chen and Murata 2008). Many plant species accumulate betaine in response to drought and salinity, thus adapt arid and saline areas (Rhodes and Hanson 1993). In higher plants, GB is synthesized by conversion from choline to GB through a two-step oxidation via the intermadiate betaine aldehyde (Hanson and Scoff 1980). The relevant enzymes are choline monooxygenase (CMO) and betaine aldehyde dehydrogenase (BADH) (Sakamoto and Murata 2000). Transgenic plants of various species have been produced, which tolerance to drought and salinity has been enhanced because they have elevated levels of GB by expressing CMO or BADH transformed with the corresponding genes (Sakamoto and Murata 2000).

The fact that many important crops, such as rice, potato and tomato, are betaine-deficient has inevitably led to the proposal that it might be possible to increase drought and salinity tolerance by genetic engineering of GB synthesis (McCue and Hanson 1990). In this chapter, the spinach BADH gene was transformed into potato under the control of the constitutive expression promoter CaMV 35S and stress-inducible expression promoter rd29A respectively, and the resultant transgenic potato plants gained the ability resistant to drought and salinity stresses (Zhang et al. 2009, 2011).

22.2.1 Isolation of BADH Gene and Plasmid Construction

The 1,556 bp cDNA of *BADH* gene (GenBank accession AY156694) was isolated from spinach using reverse transcription-polymerase chain reaction (RT-PCR) method (Zhang et al. 2004). The sequence analysis showed that the *BADH* cDNA contains 1,494 bp open reading frame (ORF) encoding a protein of 497 amino acids. The nucleotide sequence of *BADH* cDNA shared 99.87% identity with *BADH* gene which was previously cloned from spinach (GenBank accession M31480) (Weretilnyk and Hanson 1990). The nucleotide sequence at position of 781–813 nt

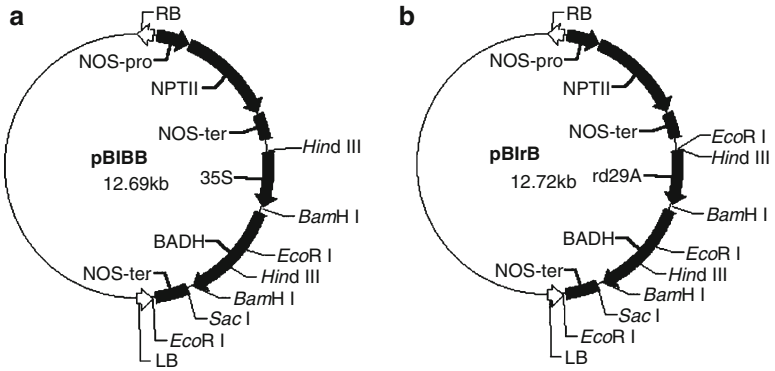

Fig. 22.1 Schematic diagram of the expression vectors pBIBB (**a**) and pBIrB (**b**). *RB* right border, *LB* left border, *NOS-pro* nopaline synthase promoter, *NOS-ter* nopaline synthase terminator, *NPTII* neomycin phosphotransferase II gene, *35 S* the constitutive expression promoter CaMV 35S, *rd29A* the stress-inducible expression promoter rd29A, *BADH* betaine aldehyde dehydrogenase gene. *Hind III, BamH I, EcoR I, Sac I* restriction endonuclease recognition sites

encodes the deca-peptide Val-Thr-Leu-Glu-Leu-Gly-Gly-Lys-Ser-Pro and at position of 992–994 nt encodes cysteine (Cys) related to the function of enzyme activity, and the deca-peptide and Cys are highly conserved among general dehydrogenase (Weretilnyk and Hanson 1989).

The 824 bp of rd29A promoter was amplified from *Arabidopsis thaliana* genome by the PCR technique (Zhang et al. 2005). Sequence analysis showed that the cloned fragment shared 99.39% identity with reported rd29A promoter (GenBank accession D13044) (Yamaguchi-Shinozaki and Shinozaki 1993) and contained several cis-acting elements including dehydration responsive element (DRE) and ascorbic acid (ABA) responsive element (ABRE) (Shinozaki and Yamaguchi-Shinozaki 1997). The result from transgenic potato plants showed that the expression of β-glucuronidase (GUS) gene under control of the rd29A promoter was induced by drought, salinity, low temperature and ABA (Zhang et al. 2005).

The plant expression vectors pBIBB and pBIrB were constructed by fusing *BADH* gene with the constitutive expression promoter CaMV 35S in plasmid pBI121 and the stress-inducible expression promoter rd29A in plasmid pBIrd (Fig. 22.1) (Si et al. 2007; Zhang et al. 2005). The expression vectors were then introduced into *Agrobacterium tumefaciens* strain LBA4404 by freeze-thaw method (Hofgen and Willmitzer 1988) and proved by the enzyme digestion and PCR amplification.

22.2.2 Potato Transformation and Molecular Analysis

Microtubers of potato cultivar Gannongshu 2 were used as the receptor for *Agrobacterium*-mediated transformation performed as described previously (Si et al. 2003). Green shoots were produced directly from surface of the transformed

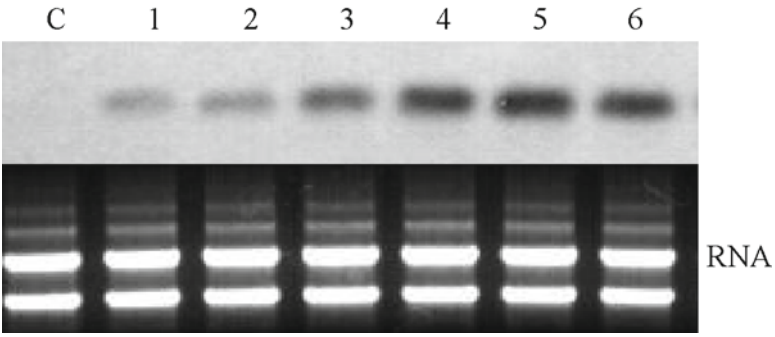

Fig. 22.2 Northern blotting analysis of *BADH* gene expression in the transgenic potato transformed with *BADH* gene under the control of the stress-inducible expression promoter rd29A. Plants were grown in vermiculite in 3 L pots in a greenhouse under natural light at 25 °C, and watered and fertilized weekly with a complete nutrient solution. When the plants reached 10 cm in height, they were treated with NaCl and polyethylene glycol (PEG, MW 6,000), respectively. NaCl treatment was begun at a concentration of 50 mM and increased stepwise by 50 mM every day until the final concentration, 500 mM, was reached. PEG treatment was conducted with 15% PEG solution once a day for 10 days. *Lane C* untransformed potato plant, *Lane 1 and 2* untreated transgenic potato plants, *Lane 3 and 4* transgenic potato plants subjected to NaCl and PEG treatments for 5 days, respectively, *Lane 5 and 6* transgenic potato plants 3 days after being subjected to NaCl and PEG treatments for 10 days, respectively. Each lane in electrophoresis contained the similar 30 μg RNA sample stained with ethidium bromide. This figure was reproduced from Zhang et al. (2011)

microtuber slices after 4 weeks cultured in MS medium (Murashige and Skoog 1962) containing 1 mg/L indole-3-acetic acid (IAA), 0.2 mg/L gibberellic acid (GA_3), 0.5 mg/L 6-benzyladenine (BAP) and 2 mg/L zeatin riboside (ZR) supplemented with 75 mg/L kanamycin and 400 mg/L carbenicillin. Roots were formed in about 10 days when green shoots transferred to MS medium supplemented with 50 mg/L kanamycin and 200 mg/L carbenicillin. The plantlets with well-developed roots were propagated for further molecular analysis. PCR and Southern blot analysis showed that *BADH* gene has been integrated into genome of potato (data not shown). Northern hybridization analysis demonstrated that expression of *BADH* gene was induced by drought and NaCl stress in the transgenic potato plants transformed with *BADH* gene driven by the promoter rd29A (Fig. 22.2), while was not induced in the transgenic plants driven by the promoter CaMV 35S as shown in Fig. 22.3 (Zhang et al. 2009; Zhang et al. 2011).

22.2.3 BADH Activities and Relative Electrical Conductivities of the Transgenic Plants

The analysis of BADH activity demonstrated that it could be detected in the transgenic potato plants transformed with *BADH* gene driven by the promoter CaMV 35S, but the enzyme activity could not be detected in the untransformed

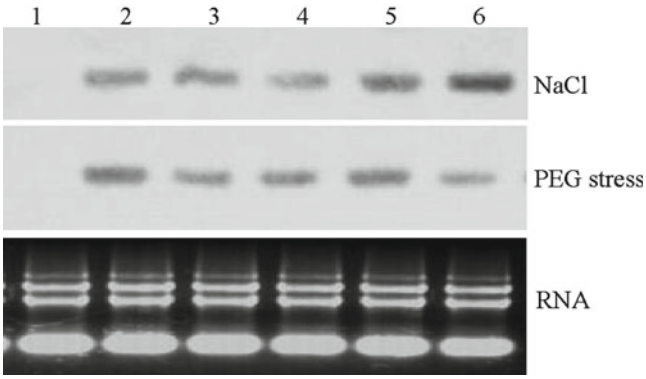

Fig. 22.3 Northern blotting analysis of transgenic potato plants transformed with *BADH* gene under the constitutive expression promoter CaMV 35S. Treatment was same as Fig. 22.2. *Lane 1* untransformed potato plant, *Lane 2–6* transgenic potato plants 3 days after being subjected to NaCl and PEG treatments for 10 days, respectively. Each lane in electrophoresis contained the similar 30 μg RNA sample stained with ethidium bromide. This figure was reproduced from Zhang et al. (2009)

control plants. The activity of BADH varied from 2.1 to 11.5 U among different transgenic individuals. The BADH activity and relative electrical conductivity on the transgenic potato leaves were highly negatively related ($y=-3.7738x+57.083$, $r=0.989^{**}$) (Zhang et al. 2009).

The activities of BADH in the transgenic potato plants transformed with *BADH* gene driven by the promoter rd29A were rather low when they were not stressed, but increased greatly 3 days after the treatment with NaCl and PEG had applied. The BADH activities varied between 10.8 and 11.7 U and varied a little among the different transgenic plant lines. The relative electrical conductivities among the transgenic plants were 17.4–19.6% under NaCl and PEG stress, much less than those among the control plants (45.6%). The low conductivities showed that the cell membranes of the transgenic plants were less injured than those of the control plants under NaCl and PEG stress. A significant negative linear relationship between the relative electrical conductivity (y) and BADH activity (x) was observed, which could be represented by a function of $y=-2.2083x+43.329$ ($r=0.9495$), revealing that BADH activity was positively related to protection of cell membrane permeability (Zhang et al. 2011).

22.2.4 Drought and Salinity Tolerance in Transgenic Potato Plants

The growth of the transgenic potato plants *in vitro* was normal and better than the untransformed plants under NaCl and PEG stresses. Plant height increased 0.41–1.0 cm and fresh weight per plant increased 10–35% for the transgenic potato plants transformed with *BADH* gene under the control of the promoter CaMV 35S

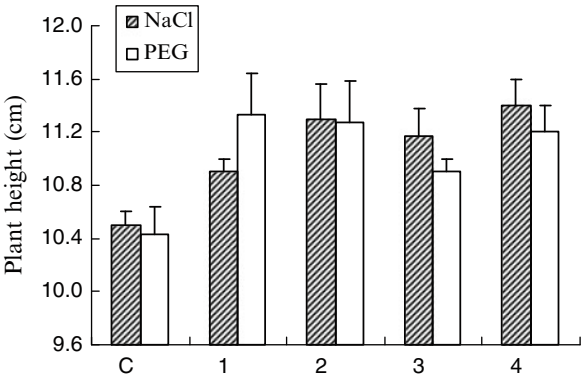

Fig. 22.4 Height of transgenic potato plants 3 days after 10 days of NaCl and PEG treatment had been completed, respectively. Plants were grown in vermiculite in 3 L pots in a greenhouse under natural light. Treatment was same as Fig. 22.2. The data are the mean ± standard error (*SE*) from three replicates. *C* nontransgenic potato plant, *1–4* transgenic potato plant lines. This figure was reproduced from Zhang et al. (2011)

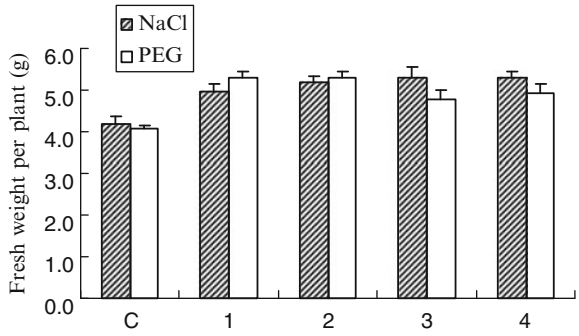

Fig. 22.5 Fresh weight per plant of transgenic potato plants 3 days after 10 days of NaCl and PEG treatment had been completed, respectively. Treatment was same as Fig. 22.2. Plants were grown in vermiculite in 3 L pots in a greenhouse under natural light. The data are the mean ± standard error (*SE*) from three replicates. *C* nontransgenic potato plant, *1–4* transgenic potato plant lines. This figure was reproduced from Zhang et al. (2011)

compared with the control potato plants (Zhang et al. 2009). For the transgenic potato plants with the promoter rd29A, plant height of the transgenic plants increased 0.4–0.9 cm and fresh weight per plant increased 17–29% compared with the control potato plants as shown in Fig. 22.4 and 22.5 (Zhang et al. 2011).

When exposed to various degree of NaCl stress (0%, 0.3% and 0.6%) for 2 months, the leaves of transgenic potato plant still stayed green, while the leaves of nontransgenic potato plant became yellow and wilting under 0.3% NaCl stress. A better growth performance was still observed in transgenic plants when they grew under the condition supplemented with 0.6% NaCl in comparison to nontransgenic control (Fig. 22.6), demonstrating that the transgenic plants with *BADH* gene acquired higher tolerance to NaCl stress than that of nontransgenic ones (Li et al. 2007).

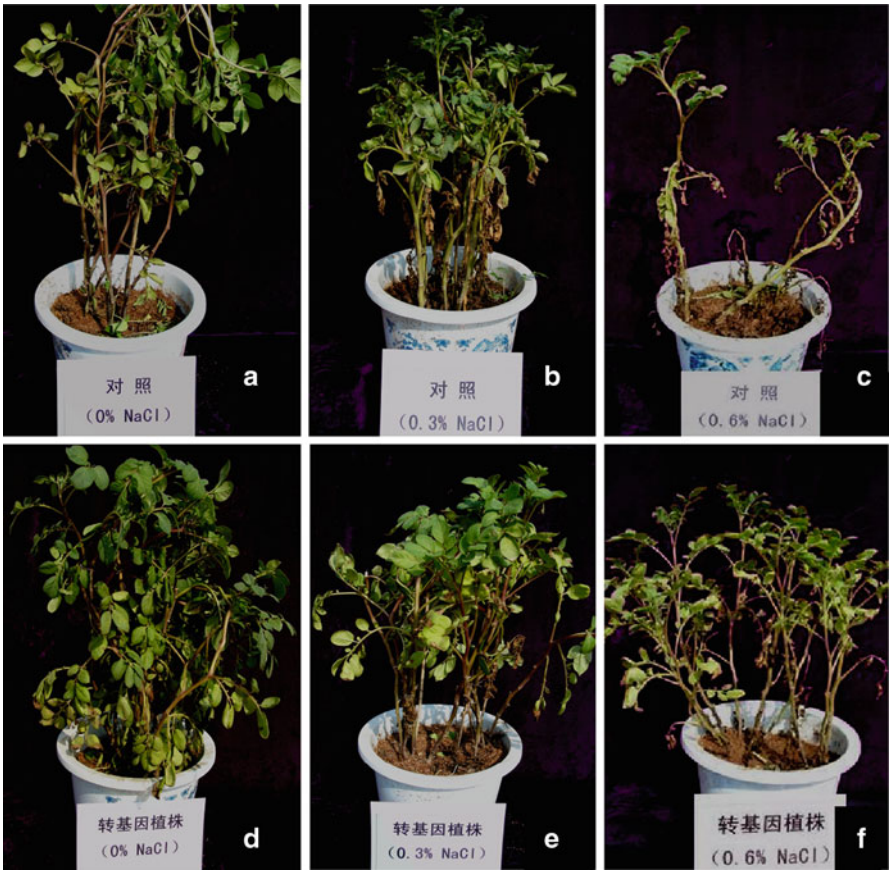

Fig. 22.6 Comparison on growth of the transgenic potato plants transformed with *BADH* gene and nontransgenic potato plants under stress of NaCl concentration of 0%, 0.3% and 0.6% for 2 months respectively. (**a–c)** nontransgenic potato plants under stress of NaCl concentration of 0%, 0.3% and 0.6% respectively, (**d–f)** transgenic potato plant line GN-4 under stress of NaCl concentration of 0%, 0.3% and 0.6% respectively. This figure was reproduced from Li et al. (2007)

The result suggested that the *BADH* gene can be used to improve the drought and salinity tolerance of important crops that are betaine-deficient through genetic engineering.

22.3 Role of Transgenic Potato in Sustainable Potato Production

With increasing population, higher demand for economic development and rapid urbanization, the global potentials for food will continue to grow; furthermore, climate change is leading to production uncertainties. Against this backcloth, a range

of transgenic crops, that are herbicide-tolerant, insect-resistant, drought and other forms of stress-tolerant, or higher yielding, have been developed, and a few are now being grown in many parts of the world. The area of transgenic crops grown globally has increased from 2 to 134 million hectares in 2009 since wide-scale planting started in 1996 (Park et al. 2011). The principal transgenic crops are soya bean, maize, cotton and canola, which are modified for agronomic input traits such as herbicide tolerance and/or insect resistance (*Bacillus thuringiensis*-Bt). Recent work has focused on the use of biotechnology to produce abiotic stress-tolerant and nutritionally enhanced food and feed with a range of new events being predicted by 2015 (Newell-McGloughlin 2008).

Potato is an easy-to-grow plant and can provide more nutritious food faster and on less land than any other food crop, and in almost any habitat. A shift towards the use of potato in convenience foods, such as potato chips and French fries, has been recorded in developed nations, but in developing economies the majority of the potato crop is still used for direct consumption. Today, potatoes are grown worldwide and more than a billion people consume them on a daily basis. To support this demand, a lot of varieties have been developed (Mullins et al. 2006).

It generally requires 10–15 years to develop a single potato cultivar through traditional breeding (Byun et al. 2007). It also relies on utilizing existing genetic stocks, whose quantities are limited (Bajaj et al. 1999). In addition, the cultivated species *Solanum tuberosum* is autotetraploid which has a highly complicated quantitative inheritance pattern, and is difficult to hybridize sexually with the related relative wild species *Solanum*. The most obvious advantage of using transgenic approaches for crop improvement is that genes from any organism can be utilized, whereas in conventional breeding the gene pool is restricted to closely related plant species. Thus, a large variety of genes are available for transfer into plants to confer a specific desirable effect (Bajaj et al. 1999).

Park et al. (2011) deemed that transgenic crops are a potential 'tool' giving options for ongoing sustainable development if the growing world population is to be adequately fed, both in terms of quantity and quality, without further compromising the environmental services that the planet provides, and elucidated the considerable contribution of transgenic crops in relation to the three traditional pillars of sustainability, i.e. economically, environmentally and socially (Park et al. 2011 and references therein).

22.4 Biosafety of Transgenic Potato

Despite the growth and use of transgenic crops in many areas of the world, some governments, organizations and individuals still hesitate to acknowledge that transgenic crops provide economic and environmental benefits that are unobtainable in a timely manner via non-transgenic advances in plant breeding. Hall and Moran (2006) described some of the organizations that believe that there are unacceptable

risks associated with the release of transgenic crops. Conner et al. (2003) and Nap et al. (2003) summarized the current status of environmental release of genetically modified (GM) crops around the globe. They provided an overview of the approaches used for regulating GM crop release into the environment and presented a detailed description of risk assessments and how they are performed, followed by a discussion of the perceived risks associated with the release of GM crops. Craig et al. (2008) summarized general features of risk assessments of GM crops, which provided an introduction to some of the main considerations made in the compilation and evaluation of risk assessments.

In order to alleviate some of the public concerns over the deployment of GM crops in agriculture, Conner and colleagues developed a novel transformation vector (intragenic vector) system (Conner et al. 2007; Barrell et al. 2010). Intragenic vector system is a gene transfer system composed of only DNA that originates from that host plant species (or related species to which it can be hybridised). Gene transfer using intragenic vectors will facilitate the well-defined genetic improvement of plants with all transferred DNA originating from within the gene pool already available to plant breeders. In this manner, genes can be introgressed into elite cultivars without the incorporation of any foreign DNA. The resulting plants are non-transgenic, although they are derived using the tools of molecular biology and plant transformation. With gene transfer using intragenic vectors, there is no longer a clear biological distinction between traditional plant breeding approaches and development of GM crops (Conner et al. 2007). This opens up the possibility of using an intragenic vector system to create non-transgenic GM crops.

Many nontheological ethical objections to genetic engineering are associated with interfering with nature or natural evolution or the natural order of life. The intragenic vector system will help alleviate some of the ethical issues associated with transferring DNA across wide taxonomic boundaries, and will provide a socially acceptable and responsible way forward for the development of GM crops (Barrell et al. 2010).

For potato crop, genetic modification using intragenic vectors can therefore provide a valuable breeding tool. There are several groups improving potato traits, such as disease resistance, abiotic stress tolerance, pigmentation and processing quality, using intragenic/cisgenic approaches (Barrell et al. 2010). The intragenic vector system offers opportunities to accelerate the efficiency and extent of further potato improvement. Ongoing improvements can be expected in characteristics such as resistant to pests, diseases, herbicides, and environmental stress, as well as quality traits such as improved post-harvest storage, flavor, nutrition, shape and colour. Genetic manipulation of these characteristics will allow breeders to respond much more quickly to the market need for new and improved potato cultivars. The anticipated result is higher quality, blemish-free tubers with reduced chemical residues as demanded by the processors and consumers (Conner 2004).

The adoption rate of GM potato in agriculture will be become higher along with higher satisfaction of growers and benefits for the whole production chain result from best characters of GM potato. GM potato will be proved to be a promising

solution for sustainable potato production, which could serve as one of powerful tools in combating famine and malnutrition in developing countries with increasing of world population in the future.

22.5 Conclusion

In the twenty-first century, food security has potential crisis in the world. Potato crop is grown worldwide and plays very important role in food security in developing countries. Since potato crop is introduced to China in the seventeenth century, it is steadily spread throughout the country. In order to overcome drought climate and backward production conditions in north China, the potato makes a greater contribution to solve food problem since it can be grown to yield relatively better production while other food crops is not in the arid and semi-arid areas.

Improvement of cultivated potato by traditional breeding method is slow and unpredictable due to its tetraploid genetics and the quantitative nature of inheritance. Genetic engineering provides a faster and more reliable means for potato crop improvement and these techniques are especially applicable to development of resistance to abiotic and biotic stresses such as drought, salt, cold, and pathogens (Byun et al. 2007).

In the chapter, the transgenic potato plants that are resistant to drought and salinity stresses are developed by transforming into potato with *BADH* gene from spinach. However, the transgenic potato plants have yet to be grown commercially since they must be performed assessment on field performance and biosafety. For practical applications, the useful stress-tolerant transgenic potato plants must give higher yield under stress and field conditions compared with the control plants. There is still much more work ahead in assessment of the transgenic potato plants under field performance.

Food insecurity is one of the most important social issues faced today. Strategies to address food insecurity must aim to increase agricultural productivity in order to tackle poverty, and must provide long-term improvements in crop yields to keep up with demands as the world's population grows. Genetically enhanced plants provide one route to sustainable higher yields, either by increasing the intrinsic yield capability of the crop or by protecting them from biotic and abiotic constraints (Christou and Twyman 2004). In conclusion, genetic engineering has the potential to help increase production and productivity in agriculture. While there is no easy solution to improve potato crop for sustainable production and food supply, transgenic approach is an alternative way to meet the aim and contribute to safe food supply.

Acknowledgments We would like to thank Junlian Zhang, Dongkui Li, Yikai Wen, Liang Li, Tao Yang, Honghui Du, Bailin Liu, and Chunfeng Zhang for performing valuable work on the research. This work was supported in part by the National High-Technology (863) Program of China (2006AA100107 and 2009AA10Z103), Research Fund for the Doctoral Program of Higher Education of China (20050733003), and the Research Grant from Agri-biotechnology and Development Program of Gansu Province of China (GNSW-2006-01).

References

Ahmad R, Abdullah Z (1979) Salinity induced changes in the growth and chemical composition of potato. Pak J Bot 11:103–112

Ahmad R, Kim MD, Back KH, Kim HS, Lee HS, Kwon SY, Murata N, Chung WI, Kwak SS (2008) Stress-induced expression of choline oxidase in potato plant chloroplasts confers enhanced tolerance to oxidative, salt, and drought stresses. Plant Cell Rep 27:687–698

Ambard-Bretteville F, Sorin C, Rébeillé F, Hourton-Cabassa C, des Francs-Small CC (2003) Repression of formate dehydrogenase in *Solanum tuberosum* increases steady-state levels of formate and accelerates the accumulation of praline in response to osmotic stress. Plant Mol Biol 52:1153–1168

Apse MP, Blumwald E (2002) Engineering salt tolerance in plants. Curr Opin Biotech 13:146–150

Bajaj S, Targolli J, Liu LF, Ho THD, Wu R (1999) Transgenic approaches to increase dehydration-stress tolerance in plants. Mol Breed 5:493–503

Barrell PJ, Jacobs JME, Baldwin SJ, Conner AJ (2010) Intragenic vectors for plant transformation within gene pools. CAB reviews: perspectives in agriculture, veterinary science, nutrition and natural resources 5, No. 010. doi: 10.1079/PAVSNNR20105010. http://www.cabi.org/cabreviews

Behnam B, Kikuchi A, Celebi-Toprak F, Yamanaka S, Kasuga M, Yamaguchi-Shinozaki K, Watanabe KN (2006) The *Arabidopsis DREB1A* gene driven by the stress-inducible rd29A promoter increases salt-stress tolerance in proportion to its copy number in tetrasomic tetraploid potato (*Solanum tuberosum*). Plant Biotechnol 23:169–177

Byun MO, Kwon HB, Park SC (2007) Recent advances in genetic engineering of potato crops for drought and saline stress tolerance. In: Jenks MA, Hasegawa PM, Jain SM (eds) Advances in molecular breeding toward drought and salt tolerant crops. Springer, Dordrecht, pp 713–737

Cavagnaro JB, De Lis BR, Tizio RM (1971) Drought hardening of the potato plant as an after-effect of soil drought conditions at planting. Potato Res 14:181–192

Celebi-Toprak F, Behnam B, Serrano G, Kasuga M, Yamaguchi-Shinozaki K, Naka H, Watanabe AJ, Yamanaka S, Watanabe KN (2005) Tolerance to salt stress of the transgenic tetrasomic tetraploid potato, *Solanum tuberosum* cv. Desiree appears to be induced by the *DREB1A* gene and rd29A promoter of *Arabidopsis thaliana*. Breeding Sci 55:311–319

Chen THH, Murata N (2008) Glycinebetaine: an effective protectant against abiotic stress in plants. Trends Plant Sci 13:499–505

Christou P, Twyman RM (2004) The potential of genetically enhanced plants to address food insecurity. Nutr Res Rev 17:23–42

Conner AJ (2004) Global environmental and food safety issues of GM potatoes. Abstracts of the proceedings of the fifth world potato congress, Kunming, China, p 11

Conner AJ, Barrell PJ, Baldwin SJ, Lokerse AS, Cooper PA, Erasmuson AK, Nap JP, Jacobs JME (2007) Intragenic vectors for gene transfer without foreign DNA. Euphytica 154:341–353

Conner AJ, Glare TR, Nap JP (2003) The release of genetically modified crops into the environment. II. Overview of ecological risk assessment. Plant J 33:19–46

Craig W, Tepfer M, Degrassi G, Ripandelli D (2008) An overview of general features of risk assessments of genetically modified crops. Euphytica 164:853–880

Evers D, Overney S, Simon P, Greppin H, Hausman JF (1999) Salt tolerance of *Solanum tuberosum* L. overexpressing an heterologous osmotin-like protein. Biol Plantarum 42:105–112

Goddijn O, Verwoerd T, Voogd E, Krutwagen R, Graaf P, Poels J, Dun K, Ponstein A, Damm B, Pen J (1997) Inhibition of trehalase activity enhances trehalose accumulation in transgenic plants. Plant Physiol 113:181–190

Hall C, Moran D (2006) Investigating GM risk perceptions: a survey of anti-GM and environmental campaign group members. J Rural Stud 22:29–37

Hanson AD, Scoff NA (1980) Betaine synthesis from radioactive precursor in attached water stressed barley leaves. Plant Physiol 66:342–348

Hemavathi UCP, Akula N, Young KE, Chun SC, Kim DH, Park SW (2010) Enhanced ascorbic acid accumulation in transgenic potato confers tolerance to various abiotic stresses. Biotechnol Lett 32:321–330

Hofgen R, Willmitzer L (1988) Storage of competent cells for *Agrobacterium* transformation. Nucleic Acid Res 16:9877

Jeong MJ, Park SC, Byun MO (2001) Improvement of salt tolerance in transgenic potato plants by glyceraldehydes-3-phosphate dehydrogenase gene transfer. Mol Cells 12:185–189

Knipp G, Honermeier B (2006) Effect of water stress on proline accumulation of genetically modified potatoes (*Solanum tuberosum* L.) generating fructans. J Plant Physiol 163:392–397

Kolodyazhnaya YS, Kutsokon NK, Levenko BA, Syutikova OS, Rakhmetov DB, Kochetov AV (2009) Transgenic plants tolerant to abiotic stresses. Cytol Genet 43:132–149

Lee HE, Shin D, Park SR, Han SE, Jeong MJ, Kwon TR, Lee SK, Park SC, Yi BY, Kwon HB, Byun MO (2007) Ethylene responsive element binding protein 1 (StEREBP1) from *Solanum tuberosum* increases tolerances to abiotic stress in transgenic potato plants. Biochem Biophys Res Commun 353:863–868

Li DK, Wand D, Zhang JL, Si HJ, Liu N (2007) Determination of salt-tolerance of the second asexual multiplication generation of transgenic potato (*Solanum tuberosum* L.) with *BADH* gene. Plant Physiol Commun 43:873–875

McCue KF, Hanson AD (1990) Drought and salt tolerance: towards understanding and application. Trends Biotechnol 8:358–362

Mullins E, Milbourne D, Petti C, Doyle-Prestwich BM, Meade C (2006) Potato in the age of biotechnology. Trends Plant Sci 11:254–260

Murashige T, Skoog F (1962) A revised medium for rapid growth and bioassays with tobacco tissues cultures. Physiol Planta 15:473–479

Nap JP, Metz PLJ, Escaler M, Conner AJ (2003) The release of genetically modified crops into the environment. Part I. Overview of current status and regulations. Plant J 33:1–18

Newell-McGloughlin M (2008) Nutritionally improved agricultural crops. Plant Physiol 147:939–953

Ojala JC, Stark JC, Kleinkopf GE (1990) Influence of irrigation and nitrogen management on potato yield and quality. Am J Potato Res 67:29–43

Park JR, McFarlane I, Phipps RH, Ceddia G (2011) The role of transgenic crops in sustainable development. Plant Biotechnol J 9:2–21

Rhodes D, Hanson AD (1993) Quaternary ammonium and tertiary sulfonium compounds in higher plants. Annu Rev Plant Physiol Plant Mol Biol 44:357–384

Rontein D, Basset G, Hanson AD (2002) Metabolic engineering of osmoprotectant accumulation in plants. Metab Eng 4:49–56

Sakamoto A, Murata N (2000) Genetic engineering of glycinebetaine synthesis in plants: current status and implications for enhancement of stress tolerance. J Exp Bot 51:81–88

Salter PJ, Goode JE (1967) Crop responses to water at different stages of growth. Res Rev Commonwealth Bureau Hortic, East Malling 2:93–97

Shinozaki K, Yamaguchi-Shinozaki K (1997) Gene expression and signal transduction in water-stress response. Plant Physiol 115:327–334

Si HJ, Xie CH, Liu J (2003) An efficient protocol for *Agrobacterium*-mediated transformation of microtuber and the introduction of an antisense class I patatin gene into potato. Acta Agron Sin 29:801–805

Si HJ, Zhang N, Wang D (2007) Enhancement of drought and salt resistances in tobacco by transformation of betaine aldehyde dehydrogenase gene. Acta Agron Sin 33:1335–1339

Tang L, Kim MD, Yang KS, Kwon SY, Kim SH, Kim JS, Yun DJ, Kwak S, Lee HS (2008) Enhanced tolerance of transgenic potato plants overexpressing nucleoside diphosphate kinase 2 against multiple environmental stresses. Transgenic Res 17:705–715

Tang L, Kwon SY, Kim SH, Kim JS, Choi JS, Cho KY, Sung CK, Kwak SS, Lee HS (2006) Enhanced tolerance of transgenic potato plants expressing both superoxide dismutase and ascorbate peroxidase in chloroplasts against oxidative stress and high temperature. Plant Cell Rep 25:1380–1386

Turhan H (2005) Salinity response of transgenic potato genotypes expressing the oxalate oxidase gene. Turk J Agric For 29:187–195

van Loon CD (1981) The effect of water stress on potato growth, development, and yield. Am J Potato Res 58:51–69

Wang WX, Vinocur B, Altman A (2003) Plant responses to drought, salinity and extreme temperatures: towards genetic engineering for stress tolerance. Planta 218:1–14

Weretilnyk EA, Hanson AD (1989) Betaine aldehyde dehydrogenase from spinach leaves: purification, *in vitro* translation of the mRNA and regulation by salinity. Arch Biochem Biophys 271:55–63

Weretilnyk EA, Hanson AD (1990) Molecular cloning of a plant betaine aldehyde dehydrogenase, an enzyme implicated in adaptation to salinity and drought. Proc Natl Acad Sci USA 87:2745–2749

Yamaguchi-Shinozaki K, Shinozaki K (1993) Characterization of the expression of a desiccation-responsive *rd29A* gene of *Arabidopsis thaliana* and analysis of its promoter in transgenic plants. Mol Gen Genet 236:331–340

Yamaguchi-Shinozaki K, Shinozaki K (1994) A novel *cis*-acting element in an *Arabidopsis* gene is involved in responsiveness to drought, low-temperature, or high-salt stress. Plant Cell 6:251–264

Yeo ET, Kwon HB, Han SE, Lee JT, Ryu JC, Byu MO (2000) Genetic engineering of drought resistant potato plants by introduction of the trehalose-6-phosphate synthase (TPS1) gene from *Saccharomyces cerevisiae*. Mol Cell 10:263–268

Zhang N, Si HJ, Li L, Yang T, Zhang CF, Wang D (2009) Drought and salinity tolerance in transgenic potato expressing the betaine aldehyde dehydrogenase gene. Acta Agron Sin 35:1146–1150

Zhang N, Si HJ, Wang D (2005) Cloning of *rd29A* gene promoter from *Arabidopsis thaliana* and its application in stress-resistance transgenic potato. Acta Agron Sin 31:159–164

Zhang N, Si HJ, Wen G, Du HH, Liu BL, Wang D (2011) Enhanced drought and salinity tolerance in transgenic potato plants with a *BADH* gene from spinach. Plant Biotechnol Rep 5:71–77

Zhang N, Wang D, Si HJ (2004) Isolation and expression of betaine aldehyde dehydrogenase gene from spinach. J Agric Biotech 12:612–613