

the fact that the activation of the defensive cascade did not occur until the plants came into contact with invaders.

In one clever approach, the *avr* gene from a pathogen is placed under a “pathogen-inducible promoter” and is then cloned into the crop plant genome. When the plant is invaded by any pathogen that would activate this promoter, the Avr protein will be produced, which will interact with its cognate R protein to activate the defense response. The difficulty in this approach is to find a proper promoter sequence, but this task may have become easier now thanks to modern array technology (see Chapter 4). In summary, great advances in our knowledge of molecular interaction pathways give us hope that a broad-range resistance to pathogenic microbes may be achieved with the transgenic approaches.

Stress-Tolerant Plants

Plants have to survive different kinds of stresses, such as cold weather, hot weather, and drought conditions. Salt (or drought) tolerance has attracted much attention because high salinity (much of it caused by years of irrigation) limits crop yield in 30% of cropland, exemplified by the Central Valley of California. The strategy used for this survival is extremely complex. First, plants produce a signaling molecule (abscisic acid; Figure 6.16) that activates a cascade of regulatory proteins, resulting in the expression of many effector proteins. Second, some of these proteins produce compatible osmolytes, such as quaternary amino compounds (e.g., glycine betaine; Figure 6.17) and sugars and sugar alcohols (e.g., ononitol; Figure 6.18), which maintain the high osmolarity in the cytosol without disturbing the structure of proteins. Finally, Na<sup>+</sup> ions are sequestered away from the cytosol into vacuoles by the use of the Na<sup>+</sup>/H<sup>+</sup> antiporter.

Because of this complexity of salt tolerance response, much of the work done so far utilized the simple approach to produce compatible osmolytes through the introduction of foreign genes. These studies have produced only limited success because the level of osmolyte overproduction was usually low (see the example of trehalose-producing transgenic rice discussed in Chapter 2) and the protection was only moderate. However, recently, transgenic carrots were created by introducing the gene coding for betaine aldehyde dehydrogenase (see Figure 6.17) into chloroplasts. Because of the strong amplification effects obtained by chloroplast cloning, the plants produced glycine betaine at a much higher level and could grow even in the presence of 400 mM NaCl. These are very promising results indeed, although it is still unclear whether we can achieve the ultimate tolerance without the participation of many other factors involved in the natural reaction of salt-resistant plants.

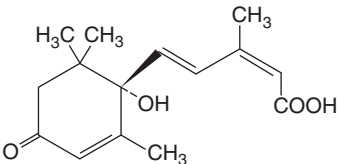


FIGURE 6.16

Absciscic acid. This plant signaling molecule is produced mainly when plants are stressed as a result of dehydration.

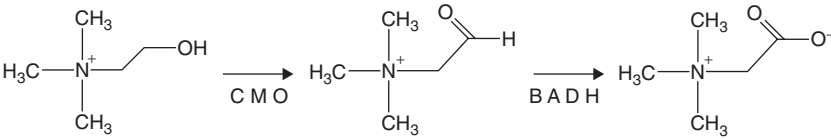


FIGURE 6.17

Biosynthesis of glycine betaine in plants. The synthesis starts from choline (left), which is converted by choline monooxygenase (CMO) into betaine aldehyde (center), which in turn is converted by betaine aldehyde dehydrogenase (BADH) into glycine betaine (right). *E. coli* uses a similar pathway, except that the first step is catalyzed by a conventional NAD<sup>+</sup>-linked dehydrogenase. *Arthrobacter*, a Gram-positive bacterium, converts choline in one step into glycine betaine by choline oxidase.