Plant Drought Responses - Dicots

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Chart can be viewed on the internet at www.potatometabolicpathways.webs.com

Dehydrins are produced by plants in response to drought, ABA and low temperature. Examples include ERD10 and ERD14. [ERD = early response to dehydration]

ESCRPK2 phosphorylates SNRF1 in vitro

SCCRP2 → SNRF1

SNRF1 is induced in response to drought, ABA, salt stress, and cold

RCP1 / CTPase = a negative regulator of ABA-related drought responses

guanosine → GTP → cGMP → nucleoside diphosphate kinase

cGMP acts downstream of hydrogen peroxide and NO in the pathway to which ABA is involved in stomatal closure. cGMP is upstream of changes in cytoplasmic Ca

ASG37 / DeRAV2 controls stomata closure in response to water deficit stress

Other genes or proteins up-regulated by drought or involved in drought stress signaling but not yet included in pathways.

Protein ubiquitination

PROTEIN → (ATP) proteasome → peptides

E1 = ubiquitin activating enzyme (Arabidopsis has 2 E1 enzymes)
E2 = ubiquitin conjugating enzyme (Arabidopsis has at least 37 E2 enzymes)
E3 = ubiquitin ligase (Arabidopsis has more than 1000 E3 enzymes)

E3 ligases can be divided into single-subunit E3 ligases or multi-subunit E3 ligases

ABAP5 has E3 ubiquitin ligase activity in vitro. Overexpression of ABAP5 in Arabidopsis correlates with up-regulation of drought stress response gene expression

ASIp/DSK2 = UBC32. ubiquitin protein ligase is up-regulated in response to drought.

AIP2/ER3 is a Cys-a E3 ubiquitin ligase and is up-regulated by drought. Down-regulation of AIP2/ER3 has enhanced sensitivity to ABA in regulating stomatal aperture and drought response.

CaRma1H1 is a leaf paper drought-induced RING E3 ubiquitin ligase

ASIR3/RCD1 up-regulates increases drought tolerance in adult Arabidopsis and down-regulates drought tolerance in seedlings. Overexpression of ASIR3/RCD1 in E2 ubiquitin-conjugating enzyme (UBC9) and UBC9 interacts with ASIR3/RCD1

ILSP1/PUB1 also regulates auxin-responsive proteins, activation of Arabidopsis thaliana E1 -like (UBE1/Uba2)-type ligase, and proteins containing the plectolinin homology domain. Involved in regulation of cell death and defense responses in Arabidopsis and Potatoes.

Down-regulation of SCSPK2 in potato increased drought tolerance

Phosphatidylcholine-sensitive Ca-dependent protein kinase. Some of the detail shown here is from animal and yeast systems. Phosphatidylcholine-sensitive Ca-dependent protein kinase with drought responses (Ca-induced signalling). CDPKs, PK and PKC are related to each other in their structure and those have been proven to be involved. The full scheme is therefore included for reference at the moment.

PtdIns(3,5)P2 → PIP2B → PtdIns(4,5)P2 → PI-PLC → Ins(1,4,5)P3 + DAG

regulation of specific protein kinases ?

PtdIns(4,5)P2 → PI3K → PtdIns(3,4,5)P3

regulation of specific protein kinases ?

Ca2+ in the cytosol increases and acts as a second messenger in cells in response to drought

Ca2+ modulation ← IP3 complex

Ins(1,4,5)P3 → Ins(1,4)P2 → Ins(1)P → myo-inositol

Ins-PLC2 (2.7.8.3)

Ins(1,4,5)P3 → Ins(1,3,4)P3 → Ins(1,3,4,5)P4 → Ins(1,3,4,6)P4 → Ins(1,2,3,4,6)P5 → Ins(1,2,3,5,6)P5 → Ins(1,2,3,4,5,6)P6 (phytic acid)

Ca2+ modulation

Phosphoinositide cascade

In plants PtdIns(3)P is 10-20 fold higher than PtdIns(4,5)P2 (in animals the ratio is 1:1).

PtdIns (phosphatidylinositol) 3-phosphate 5-kinase) is induced in Arabidopsis by salt, wilting, and abscisic acid.

Inositol-1,4,5-trisphosphate 5-phosphatase 11 is induced in Arabidopsis in response to drought

PtdIns(3)P → PtdIns(3,5)P2

PtdIns(3,5)P2 → PtdIns(5)P

PtdIns(5)P → PtdIns(4,5)P2

PtdIns(4)P → PtdIns(4,5)P2

PtdIns(3,4)P2 → PtdIns(3,4,5)P3

PtdIns(3,4,5)P3 → PtdIns(3,4)P2

PtdIns(3,4)P2 → PtdIns(4)P

PtdIns(4)P → PtdIns

PtdIns → myo-inositol

"high energy" phosphate bond in inositol polyphosphates

diphosphoinositol pentakisphosphate (5-PP-Ins(1,2,3,4,6)P5)

diphosphoinositol tetrakisphosphate (5-PP-Ins(1,3,4,6)P4)

Ins(1,3,4,5,6)P5 → Ins(1,2,3,4,5,6)P6 (phytic acid)

Ins(1,2,3,4,5,6)P6 → Ins(1,2,3,4,5)P5

Ins(1,2,3,4,5)P5 → Ins(1,2,3,4)P4

Ins(1,2,3,4)P4 → Ins(1,2,3)P3

Ins(1,2,3)P3 → Ins(1,2)P2

Ins(1,2)P2 → Ins(2)P

Ins(2)P → myo-inositol

myo-inositol may exist in different isomers (myo-inositol, chiro-, scyllo-, neo-, epi-, DPI = glucosyl phosphatidylinositol)

Increased levels of inositol in potato in response to drought

myo-inositol 2-phosphate synthase (MIPS) (upregulated in response to drought)

myo-inositol 1-phosphate synthase (MIPS) (upregulated in response to drought)

In Arabidopsis ASP11 is a regulator of myo-inositol monophosphatase involving TRP and SnRK1

TRP is considered as a SnRK1 regulatory molecule

trehalose 6-phosphate synthase (TPS)

trehalose 6-phosphate

trehalose

trehalose-6-phosphate phosphatase (TPP)

UDP-glucose + fructose 6-phosphate → UDP + sucrose 6-phosphate

sucrose-phosphate synthase gene SPS1F upregulated by drought in Arabidopsis

sucrose-phosphate synthase

sucrose 6-phosphate

sucrose

sucrose-phosphate phosphatase

sucrose synthase

UDP-glucose

glycogen synthase kinase

glycogen synthase

glycogen

starch

starch phosphorylase

starch synthase

starch branching enzyme

starch debranching enzyme

sucrose synthase gene SUS1 and SUS3 upregulated by drought in Arabidopsis

sucrose synthase

fructose

sucrose

NDP + sucrose → NDP-glucose + fructose

Increase in galactinol and raffinose in drought resistant potatoes (Legay et al. (2011). Also, Taji et al (2002) found that drought and salt stress induced galactinol synthase (galactinol synthase) and raffinose synthase (raffinose synthase) in Arabidopsis. Raffinose synthase (raffinose synthase) is a key enzyme for raffinose family oligosaccharides (RFO) synthesis from sucrose. Raffinose family oligosaccharides (RFO) are transported from source to sink tissues and function as osmoprotectants and as reactive oxygen species (ROS) scavengers during abiotic stress (Nishizawa et al. 2008). Raffinose family oligosaccharides (RFO) are also known to protect membranes and proteins from damage caused by dehydration (Nishizawa et al. 2008). Raffinose family oligosaccharides (RFO) are synthesized in the cytosol from sucrose and myo-inositol (Nishizawa et al. 2008).