

Table 1 Suppl. The detailed information about genes involved in Cd, Zn and Cd/Zn interactions affected by high or low concentrations of calcium and potassium.

1) Genes regulated by Cd at high concentrations of Ca and K but not by Cd at low concentrations of Ca and K.

Gene location	Change	Gene name	Metabolism
TRIAE_CS42_4AL_TGACv1_289339_AA0969340	UP	beta-D-xylosidase 7	cell wall metabolism
TRIAE_CS42_4BS_TGACv1_328052_AA1081940	UP	beta-D-xylosidase 7	
TRIAE_CS42_2AL_TGACv1_096605_AA0320170	UP	endoglucanase 12	
TRIAE_CS42_7AS_TGACv1_569463_AA1816580	UP	endoglucanase 16	
TRIAE_CS42_1BL_TGACv1_030610_AA0095660	UP	endoglucanase 3	
TRIAE_CS42_6BL_TGACv1_501926_AA1621580	UP	endoglucanase 7	
TRIAE_CS42_7BS_TGACv1_594065_AA1955910	UP	endoglucanase 7	
TRIAE_CS42_4AL_TGACv1_288169_AA0939360	UP	sucrose:sucrose 1-fructosyltransferase	
TRIAE_CS42_4BL_TGACv1_320575_AA1043590	UP	xyloglucan 6-xylosyltransferase 1	
TRIAE_CS42_4AS_TGACv1_308016_AA1025240	UP	xyloglucan 6-xylosyltransferase 2	
TRIAE_CS42_7AS_TGACv1_570117_AA1830770	UP	xyloglucan endotransglycosylase/hydrolase protein 8	
TRIAE_CS42_3AS_TGACv1_211023_AA0683280	UP	xyloglucan endotransglycosylase/hydrolase protein 8	
TRIAE_CS42_6AL_TGACv1_471835_AA1514990	UP	UDP-glucuronate 4-epimerase 1	
TRIAE_CS42_6BL_TGACv1_499944_AA1595610	UP	UDP-glucuronate 4-epimerase 1	
TRIAE_CS42_4AL_TGACv1_288640_AA0954230	UP	cellulose synthase-like protein	
TRIAE_CS42_7BS_TGACv1_591846_AA1923450	UP	galacturonosyltransferase-like 9	
TRIAE_CS42_3B_TGACv1_222057_AA0756260	UP	glucuronosyltransferase	
TRIAE_CS42_1BL_TGACv1_030496_AA0092320	UP	pectinesterase/pectinesterase inhibitor 41	
TRIAE_CS42_5BL_TGACv1_406234_AA1342560	UP	vacuolar iron transporter 1.2	metal transporter
TRIAE_CS42_4AL_TGACv1_288808_AA0958530	UP	NRT1/PTR FAMILY 2.6	N transporter
TRIAE_CS42_6AL_TGACv1_471833_AA1514930	UP	NRT1/PTR FAMILY 7.2	

2) Genes regulated by Cd at low concentrations of Ca and K but not by Cd at high concentrations of Ca and K.

Gene location	Change	Gene name	Metabolism
TRIAE_CS42_5AL_TGACv1_376126_AA1232370	UP	cellulose synthase-like protein E6	sucrose
TRIAE_CS42_7AS_TGACv1_570274_AA1833190	UP	sucrose:sucrose 1-fructosyltransferase	metabolism
TRIAE_CS42_4BL_TGACv1_322243_AA1069920	UP	sugar transport protein 13	
TRIAE_CS42_3B_TGACv1_224181_AA0793560	UP	glucan endo-1,3-beta-glucosidase GI	
TRIAE_CS42_2BS_TGACv1_146482_AA0466090	UP	ABC transporter B family member 11	metal
TRIAE_CS42_5BL_TGACv1_405550_AA1330040	UP	ABC transporter G family member 48	transporter
TRIAE_CS42_7AL_TGACv1_560365_AA1802080	UP	copper transport protein ATX1	
TRIAE_CS42_4AL_TGACv1_290617_AA0987460	UP	NRT1/ PTR FAMILY 8.3	N transporter
TRIAE_CS42_4BS_TGACv1_328522_AA1089380	UP	NRT1/ PTR FAMILY 8.3	

3) Genes regulated by Zn at high concentrations of Ca and K but not by Zn at low concentrations of Ca and K.

Gene location	Change	Gene name	Metabolism
TRIAE_CS42_3AS_TGACv1_211472_AA0690490	DOWN	galactinol--sucrose galactosyltransferase 2	cell wall
TRIAE_CS42_3B_TGACv1_220634_AA0712980	DOWN	galactinol--sucrose galactosyltransferase 2	metabolism
TRIAE_CS42_2AL_TGACv1_093126_AA0272730	UP	beta-fructofuranosidase	
TRIAE_CS42_2BS_TGACv1_148608_AA0494060	UP	mixed-linked glucan synthase 3	
TRIAE_CS42_2AL_TGACv1_094907_AA0304750	UP	alpha-mannosidase	
TRIAE_CS42_4BL_TGACv1_320384_AA1037370	UP	beta-d-xylosidase 7	
TRIAE_CS42_3AL_TGACv1_195110_AA0644920	UP	glucan endo-1,3-beta-glucosidase giii	
TRIAE_CS42_3AL_TGACv1_197519_AA0666560	UP	mannan synthase 11	
TRIAE_CS42_6DL_TGACv1_526670_AA1689480	UP	glyceraldehyde-3-phosphate dehydrogenase 2	
TRIAE_CS42_2AL_TGACv1_096532_AA0319750	UP	Casparian strip membrane protein 1	
TRIAE_CS42_2BL_TGACv1_132599_AA0438550	UP	Casparian strip membrane protein 1	
TRIAE_CS42_7BL_TGACv1_579238_AA1905690	UP	Casparian strip membrane protein 2	
TRIAE_CS42_1AL_TGACv1_000456_AA0012510	UP	expansin-B6	
TRIAE_CS42_7AL_TGACv1_556074_AA1754650	UP	zinc transporter ZTP29	metal
TRIAE_CS42_2BS_TGACv1_146136_AA0456350	UP	metal-nicotianamine transporter YSL6	transporter
TRIAE_CS42_3AL_TGACv1_193952_AA0623370	UP	ABC transporter B family member 8	
TRIAE_CS42_7DL_TGACv1_602942_AA1972460	UP	copper transport protein atx1	
TRIAE_CS42_6AS_TGACv1_485599_AA1548100	UP	nicotianamine synthase 1	metal chelator
TRIAE_CS42_4DL_TGACv1_344693_AA1148980	UP	nicotianamine synthase 2	
TRIAE_CS42_3AL_TGACv1_195593_AA0651660	UP	nicotianamine synthase 2	
TRIAE_CS42_3B_TGACv1_220857_AA0721520	UP	nicotianamine synthase 3	
TRIAE_CS42_6AL_TGACv1_472548_AA1523410	UP	nicotianamine synthase 9	
TRIAE_CS42_6BL_TGACv1_500437_AA1604610	UP	nicotianamine synthase 9	
TRIAE_CS42_2BS_TGACv1_146201_AA0458660	UP	nicotianamine synthase-like 5	
TRIAE_CS42_1AL_TGACv1_000513_AA0013700	UP	metallothionein-like protein 1b	
TRIAE_CS42_3B_TGACv1_221570_AA0744570	UP	NRT1/ PTR FAMILY 5.10	N transporter
TRIAE_CS42_6AL_TGACv1_471833_AA1514930	UP	NRT1/ PTR FAMILY 7.2	

4) Genes regulated by Zn at low concentrations of Ca and K but not by Zn at high concentrations of Ca and K.

Gene location		Gene name	Metabolism
TRIAE_CS42_7AS_TGACv1_569799_AA1824210	UP	alpha-glucosidase 2	cell wall
TRIAE_CS42_2DL_TGACv1_158029_AA0506490	UP	xyloglucan endotransglucosylase/hydrolase protein 13	metabolism
TRIAE_CS42_2AL_TGACv1_093664_AA0284830	UP	sugar transport protein 9	
TRIAE_CS42_4AL_TGACv1_291055_AA0991870	UP	xylanase inhibitor protein 1	
TRIAE_CS42_1BL_TGACv1_030377_AA0088490	UP	UDP-glucose 4-epimerase 1	
TRIAE_CS42_1AS_TGACv1_019540_AA0067810	UP	polygalacturonase inhibitor	
TRIAE_CS42_1BS_TGACv1_049504_AA0155280	UP	polygalacturonase inhibitor	
TRIAE_CS42_1BS_TGACv1_051077_AA0177630	UP	glucan 1,3-beta-glucosidase a	
TRIAE_CS42_5DL_TGACv1_434288_AA1433330	UP	beta-glucosidase	
TRIAE_CS42_5BL_TGACv1_405972_AA1338420	UP	beta-glucosidase	
TRIAE_CS42_5AL_TGACv1_374243_AA1194960	UP	beta-glucosidase	
TRIAE_CS42_1BL_TGACv1_030267_AA0084630	UP	pectinesterase/pectinesterase inhibitor 41	
TRIAE_CS42_1AL_TGACv1_001221_AA0027180	UP	chitinase 8	
TRIAE_CS42_7AL_TGACv1_557197_AA1777940	DOWN	xyloglucan endotransglucosylase/hydrolase protein 22	
TRIAE_CS42_7AL_TGACv1_557236_AA1778610	DOWN	xyloglucan endotransglucosylase/hydrolase protein 32	
TRIAE_CS42_6AS_TGACv1_485966_AA1554960	DOWN	glucomannan 4-beta-mannosyltransferase 1	
TRIAE_CS42_6BS_TGACv1_513375_AA1639370	DOWN	glucomannan 4-beta-mannosyltransferase 1	
TRIAE_CS42_1BL_TGACv1_031712_AA0119450	DOWN	glucose-1-phosphate adenylyltransferase large subunit	
TRIAE_CS42_7AS_TGACv1_569331_AA1813600	DOWN	endoglucanase 17	
TRIAE_CS42_5AL_TGACv1_376446_AA1237070	DOWN	endoglucanase 24	
TRIAE_CS42_2BL_TGACv1_130657_AA0415410	DOWN	endonuclease 4	
TRIAE_CS42_4AL_TGACv1_293009_AA1000000	DOWN	beta-glucosidase 8	
TRIAE_CS42_4BS_TGACv1_327950_AA1079550	DOWN	beta-glucosidase 8	
Novel08332	DOWN	callose synthase 3	
TRIAE_CS42_1BL_TGACv1_031037_AA0106440	DOWN	expansin-b4	
TRIAE_CS42_4BL_TGACv1_321043_AA1054210	DOWN	expansin-b4	
TRIAE_CS42_1AL_TGACv1_001658_AA0033700	DOWN	expansin-b4	
TRIAE_CS42_1AL_TGACv1_001900_AA0036430	UP	glutathione s-transferase gstu6	GSH
TRIAE_CS42_3B_TGACv1_221332_AA0737510	UP	glutathione s-transferase	metabolism
TRIAE_CS42_2AL_TGACv1_093058_AA0270800	DOWN	copper transport protein atx1	metal
TRIAE_CS42_6BS_TGACv1_513141_AA1631810	UP	copper-transporting atpase ran1	transporter
TRIAE_CS42_2BL_TGACv1_129973_AA0400750	UP	calcium-transporting atpase 8	
TRIAE_CS42_5BL_TGACv1_405494_AA1328630	UP	MATE efflux family protein 8	
TRIAE_CS42_2BL_TGACv1_132980_AA0440750	UP	vacuolar iron transporter homolog 5	
TRIAE_CS42_2BL_TGACv1_132980_AA0440730	UP	vacuolar iron transporter homolog 5	
TRIAE_CS42_2BL_TGACv1_132656_AA0438930	UP	vacuolar iron transporter homolog 5	

5) Genes regulated by Cd at low concentrations of Ca and K but not by Cd + Zn at low concentrations of Ca and K.

Gene location	Change	Gene name	Metabolism
TRIAE_CS42_2AL_TGACv1_093126_AA0272730	UP	beta-fructofuranosidase	cell wall metabolism
TRIAE_CS42_2BL_TGACv1_130262_AA0407610	UP	beta-fructofuranosidase	
TRIAE_CS42_7AS_TGACv1_569456_AA1816460	UP	bidirectional sugar transporter SWEET15	
TRIAE_CS42_5BL_TGACv1_407065_AA1353010	UP	sugar phosphate/phosphate translocator	
TRIAE_CS42_U_TGACv1_643566_AA2133030	UP	UDP-glucuronic acid decarboxylase 2	
TRIAE_CS42_2BL_TGACv1_131533_AA0428910	UP	chitinase 4	
TRIAE_CS42_5AL_TGACv1_376126_AA1232370	UP	cellulose synthase-like protein E6	
TRIAE_CS42_1BL_TGACv1_030616_AA0095830	UP	chitinase 2	
TRIAE_CS42_1BL_TGACv1_032922_AA0135460	UP	chitinase 2	
TRIAE_CS42_3B_TGACv1_224402_AA0796400	UP	expansin-A8	
TRIAE_CS42_1BL_TGACv1_032979_AA0135990	UP	expansin-B6	
TRIAE_CS42_6AS_TGACv1_485232_AA1541050	UP	wall-associated receptor kinase 4	
TRIAE_CS42_3B_TGACv1_224169_AA0793340	UP	WAT1-related protein	
TRIAE_CS42_3B_TGACv1_220741_AA0717780	UP	DIMBOA UDP-glucosyltransferase BX9	
TRIAE_CS42_3AL_TGACv1_195696_AA0652840	UP	DIMBOA UDP-glucosyltransferase BX9	
TRIAE_CS42_2BL_TGACv1_129819_AA0397180	UP	endoglucanase 12	
TRIAE_CS42_2BS_TGACv1_146084_AA0454940	UP	glucan endo-1,3-beta-glucosidase 3	
TRIAE_CS42_3B_TGACv1_224181_AA0793560	UP	glucan endo-1,3-beta-glucosidase GI	
TRIAE_CS42_2AS_TGACv1_113417_AA0355730	UP	6-phosphogluconolactonase 2	
TRIAE_CS42_2BS_TGACv1_146252_AA0460450	UP	6-phosphogluconolactonase 2	
TRIAE_CS42_3B_TGACv1_226636_AA0818250	UP	UDP-arabinopyranose mutase 1	
TRIAE_CS42_5AL_TGACv1_375282_AA1219100	UP	UDP-glucose 6-dehydrogenase 4	
TRIAE_CS42_5BL_TGACv1_404418_AA1299220	UP	UDP-glucose 6-dehydrogenase 4	
TRIAE_CS42_5BL_TGACv1_407717_AA1359070	UP	UDP-glycosyltransferase 74E1	
TRIAE_CS42_5BS_TGACv1_423573_AA1379790	UP	UDP-glycosyltransferase 74F2	
TRIAE_CS42_4BL_TGACv1_321953_AA1067130	UP	xyloglucan galactosyltransferase KATAMARI1	
TRIAE_CS42_3AS_TGACv1_211225_AA0686890	UP	xyloglucan glycosyltransferase 3	
TRIAE_CS42_5AL_TGACv1_376577_AA1238650	DOWN	pectin acetylesterase 3	
TRIAE_CS42_7BL_TGACv1_578713_AA1899080	DOWN	glucan endo-1,3-beta-glucosidase 13	
TRIAE_CS42_6AS_TGACv1_485988_AA1555330	UP	copper-transporting ATPase HMA5	metal transporter
TRIAE_CS42_2BL_TGACv1_131165_AA0423600	UP	ABC transporter C family member 9	
TRIAE_CS42_7AL_TGACv1_556075_AA1754700	UP	ABC transporter G family member 44	
TRIAE_CS42_7BL_TGACv1_580468_AA1914160	UP	ABC transporter G family member 44	
TRIAE_CS42_1BL_TGACv1_032124_AA0125710	UP	ABC transporter A family member 2	
TRIAE_CS42_1AL_TGACv1_003859_AA0051790	UP	ABC transporter A family member 2	
TRIAE_CS42_1BL_TGACv1_032124_AA0125720	UP	ABC transporter A family member 7	
TRIAE_CS42_1AL_TGACv1_001642_AA0033350	UP	ABC transporter A family member 8	
TRIAE_CS42_5AL_TGACv1_376264_AA1234660	UP	ABC transporter B family member 25	
TRIAE_CS42_7BS_TGACv1_592267_AA1934720	UP	ABC transporter G family member 48	
TRIAE_CS42_4AS_TGACv1_308827_AA1029610	UP	ABC transporter G family member 5	
TRIAE_CS42_7AS_TGACv1_570283_AA1833260	UP	zinc transporter 10	
TRIAE_CS42_7BL_TGACv1_577195_AA1868430	UP	zinc transporter 10	
TRIAE_CS42_1AL_TGACv1_000915_AA0021780	UP	zinc transporter 5	
TRIAE_CS42_1BL_TGACv1_030324_AA0086740	UP	zinc transporter 5	
TRIAE_CS42_7BL_TGACv1_577019_AA1862890	UP	potassium transporter 13	
TRIAE_CS42_6AL_TGACv1_471561_AA1510890	UP	potassium transporter 16	
TRIAE_CS42_4AL_TGACv1_290140_AA0982100	UP	Fe(2+) transport protein 1	
TRIAE_CS42_4BS_TGACv1_328611_AA1090980	UP	Fe(2+) transport protein 1	
TRIAE_CS42_7AL_TGACv1_557470_AA1781720	UP	admium/zinc-transporting ATPase HMA2	
TRIAE_CS42_2BS_TGACv1_147224_AA0480120	UP	nicotianamine synthase 9	metal chelator
Novel09899	UP	nitrate transporter	N metabolism
TRIAE_CS42_4AL_TGACv1_288748_AA0957150	UP	NRT1/ PTR FAMILY 2.11	

Gene location	Change	Gene name	Metabolism
TRIAE_CS42_3B_TGACv1_222945_AA0773750	UP	NRT1/ PTR FAMILY 5.10	
TRIAE_CS42_3AL_TGACv1_194627_AA0636990	UP	NRT1/ PTR FAMILY 5.10	
TRIAE_CS42_1BL_TGACv1_031160_AA0108950	UP	NRT1/ PTR FAMILY 5.2	
TRIAE_CS42_1BL_TGACv1_031703_AA0119250	UP	NRT1/ PTR FAMILY 8.3	
TRIAE_CS42_4BS_TGACv1_328522_AA1089380	UP	NRT1/ PTR FAMILY 8.3	
TRIAE_CS42_6AL_TGACv1_473845_AA1533160	UP	ammonium transporter 1 member 2	
TRIAE_CS42_6BL_TGACv1_501472_AA1617880	UP	ammonium transporter 1 member 2	
TRIAE_CS42_3AL_TGACv1_194468_AA0633610	UP	ammonium transporter 2 member 3	
TRIAE_CS42_3B_TGACv1_222607_AA0767670	UP	ammonium transporter 2 member 3	

6) Genes regulated by Cd at high concentrations of Ca and K but not by Cd + Zn at high concentrations of Ca and K.

Change	Gene name	Metabolism
DOWN	beta-glucosidase 16	cell wall metabolism
UP	endoglucanase 16	
UP	endoglucanase 3	
UP	endoglucanase 7	
UP	xyloglucan endotransglycosylase/hydrolase protein 8	
UP	chitinase 2	
UP	chitinase 2	
UP	chitinase 4	
UP	beta-amylase 1, chloroplastic	
UP	vacuolar iron transporter 1.2	metal transporter
UP	ABC transporter B family member 19	
UP	ABC transporter B family member 19	
UP	ammonium transporter 2 member 3	
UP	glucan endo-1,3-beta-glucosidase 13	
UP	bidirectional sugar transporter SWEET13	
UP	chitinase 8	
UP	sucrose transport protein SUT1	
UP	sucrose transport protein SUT1	
UP	sugar carrier protein C	
UP	UDP-glucose 4-epimerase 1	N metabolism
UP	xyloglucan endotransglucosylase/hydrolase protein 13	
UP	xyloglucan endotransglucosylase/hydrolase protein 30	
UP	glucan 1,3-beta-glucosidase A	
UP	glucan 1,3-beta-glucosidase A	
UP	beta-glucosidase BoGH3B	
UP	bidirectional sugar transporter SWEET14	
DOWN	endonuclease 4	
DOWN	callose synthase 3	
DOWN	cellulose synthase A catalytic subunit 1	
DOWN	UDP-D-apiiose/UDP-D-xylose synthase	metal transporter
DOWN	UTP--glucose-1-phosphate uridylyltransferase	
DOWN	xyloglucan endotransglucosylase/hydrolase protein 32	
DOWN	beta-glucosidase BoGH3B	
DOWN	expansin-B4	
DOWN	expansin-B4	
UP	copper-transporting ATPase HMA5	
UP	plasma membrane ATPase	
UP	calcium-transporting ATPase 8	
UP	MATE efflux family protein 7	
UP	vacuolar iron transporter homolog 5	metal chelation
UP	vacuolar iron transporter homolog 5	
UP	vacuolar iron transporter homolog 5	
UP	vacuolar iron transporter homolog 5	
UP	vacuolar iron transporter homolog 5	
DOWN	copper transport protein ATX1	
UP	metallothionein-like protein 1	
UP	nicotianamine synthase 2	
DOWN	malate dehydrogenase	N metabolism
UP	NRT1/ PTR FAMILY 6.2	
UP	high-affinity nitrate transporter-activating protein 2.1	
UP	high-affinity nitrate transporter-activating protein 2.1	
DOWN	NRT1/ PTR FAMILY 6.3	

7) Genes regulated by Zn at low concentrations of Ca and K but not by Cd + Zn at low concentrations of Ca and K.

Change	Gene name	Metabolism
DOWN	galactinol--sucrose galactosyltransferase 2	cell wall metabolism
UP	glucan endo-1,3-beta-glucosidase GIII	
UP	UDP-glucose 6-dehydrogenase 4	
UP	UDP-glucose 6-dehydrogenase 4	
UP	UDP-glucose 6-dehydrogenase 4	
UP	NRT1/ PTR FAMILY 2.6	N metabolism
UP	NRT1/ PTR FAMILY 6.2	
UP	ABC transporter B family member 8	metal transporter
UP	metal-nicotianamine transporter YSL6	
UP	vacuolar iron transporter homolog 5	
UP	nicotianamine synthase 1	metal chelation
UP	nicotianamine synthase 1	
UP	nicotianamine synthase 1	
UP	nicotianamine synthase 1	
UP	nicotianamine synthase 2	
UP	nicotianamine synthase 2	
UP	nicotianamine synthase 2	
UP	nicotianamine synthase 2	
UP	nicotianamine synthase 2	
UP	nicotianamine synthase 2	
UP	nicotianamine synthase 2	
UP	nicotianamine synthase 3	
UP	nicotianamine synthase 4	
UP	nicotianamine synthase 6	
UP	nicotianamine synthase 9	
UP	nicotianamine synthase 9	
UP	nicotianamine synthase-like 5 protein	
UP	NRT1/ PTR FAMILY 5.10	N metabolism
UP	NRT1/ PTR FAMILY 7.3	