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Козеко Л.Е. «РОЛЬ ШАПЕРОНОВ HSP90 В УСТОЙЧИВОСТИ И ПЛАСТИЧНОСТИ …» http://cytgen.com/articles/5320056s.pdf

Table. Client proteins of HSP90 chaperones in plants

Client proteins of HSP90	Process	Phenotypic changes after gene knockdown	Species	Dependence on HSP90	References
Transcriptional heat shock factors, HSF					
HsfA1	Main regulators of *HSP* expression	Changes in the basic and induced TR*; no effect on morphology	Plants	Binds HSP90/HSP70 complex under n.c.	[27, 28]
AtHsfA1d	Regulator of *HSP* expression (C/I)	Reduced TR with simultaneous knockdown of 2 or 3 HsfA1, in the latter case – multiple phenotype disorders	*A. thaliana*	Binds AtHSP90-2 under n.c.	[17, 29]
AtHsfA2	Intensifier of *HSP* expression (I)	Reduced duration of induced TR; no effect on plant morphology; inhibited growth of callus	*A. thaliana*	Depends on AtHSP90-1 and cochaperones ROF1/FKBP62 ROF2/FKBP65	[30-33]
HsfA2	Component of heat shock granules	—	Plants	Release from granules depends on HSP90 and is inhibited by GDA	[34]
AtHsfA7a	Regulation of *HSP* expression (I)	Poor induction of TR; no effect on morphology	*A. thaliana*	Binds AtHSP90-2 under n.c.	[17]
HsfB	Synergic co-activator of HsfA1/ repressor of *HSP* expression (C/I)	No effect on morphology	Plants	Associated with HSP90/HSP70 complex under n.c.	[27, 28]
AtHsfB1	Idem	—	*A. thaliana*	Binds AtHSP90-2 under n.c.	[17]
Other HSP90-dependent proteins					
HTD1,	Negative	Reduced	*A.*	Binds	[35]

component of ubiquitin ligases CRL4	regulation of TR	thermoresistance	*thaliana*	AtHSP90-1	
BIN2 kinase	BR-signaling in plants	Delayed growth and development, disrupted architecture of hypocotyl xylem	*A. thaliana*	Nuclear / cytosolic localization and activity depends on AtHSP90-1 and AtHSP90-3	[36, 37]
BES1, transcription factor	BR-signaling in plants	Dwarfness, leaves with long leafstalks and narrow epinastic plates, change in hypocotyl length, response to red light and darkness, GDA	*A. thaliana*	Negative control of BR biosynthesis by heterocomplex of HSP90-BES1	[37-39]
SCF E3, ubiquitin ligase complex	Proteolysis of cell cycle proteins	—	*A. thaliana*	Complex assembly is regulated by HSP90 and cochaperone SGT1	[40]
TIR1, F-box-protein, co-receptor of auxin, subunit of ubiquitin ligase SCF E3	Proteolysis of proteins Aux/IAA ensures the transduction of auxin signal; regulation of growth processes	Loss of sensitivity to auxin, smaller number of lateral roots, change in growth response to increased temperature	*A. thaliana*	Stabilization of TIR1 in the nucleus depends on HSP90–SGT1	[41-43]
COI1, F-box-protein, receptor of jasmonic acid, subunit of ubiquitin ligase SCF E3	Signaling of jasmonic acid	Loss of sensitivity to jasmonic acid	*A. thaliana*	Maintenance of stable SGT1b–HSP70–HSP90 complex	[44]
ZTL, F-box-protein, photoreceptor of blue light, subunit of ubiquitin ligase SCF	Proteolysis of proteins of circadian rhythm	Prolonged circadian period	*A. thaliana*	Ripening and stabilization depend on cytosolic HSP90	[40]
FKF1, flavin-dependent F-box-protein	Flowering regulation	Late flowering	*A. thaliana*	Stabilization depends on AtHSP90-3	[45]
RISC, RNA-protein complex	RNA-interference	—	Tobacco protoplasts	Complex assembly and functioning	[46, 47]

				depend on HSP90	
AGO1, component of RISC complex	Idem	Elliptical, enlarged first leaves of the rosette, delayed initiation and growth of the following leaves, fewer rosette and more stalk leaves, irregular location of flowers on the flower stalk	*A. thaliana*	Regulated by cytosolic and HSP90 with cochaperone SQN	[46, 48]
GRF2, GRF10, family 14-3-3	Modulation of protein interactions and the activity of enzymes	—	*A. thaliana*	Binds with AtHSP90-2	[49, 50]
Toc64, component of translocon of external membrane of chloroplasts	Post-translational import of protein into chloroplasts	—	*A. thaliana*	Binds with cytosolic HSP90	[51]
Tic40, component of translocon of the inner membrane of chloroplasts	Idem	Chlorosis, disrupted development of chloroplasts, delayed growth (similarly to *Athsp90-5*)	*A. thaliana*	Binds with AtHSP90-5 (HSP90C)	[52, 53]
Tic110, component of translocon of the inner membrane of chloropasts	Idem	Delayed growth of the seed bud at the stage of globule	*A. thaliana*	Binds with AtHSP90-5 (HSP90C)	[52, 53]
VIPP1/PTAC4	Biogenesis of membranes of plastid thylakoids	Chlorosis, upsetting the biogenesis of thylakoids	*A. thaliana*, *Chlamidomonas*	AtHSP90-5 (HSP90C) binds and assists in disassembling VIPP1 during membranogenesis	[54, 55]
CLV1/CLV2/CLV3, complex of transmembrane receptor-like proteins with kinase activity in CLV1	Determining the meristem status of cells, transition to differentiation	Disorganization of stalk, floral and root meristems, bundle-shaped divergence of the stalk, increased number of flower organs, short	*A. thaliana*	Folding and activation of the complex require AtHSP90-7 (GRP94, SHD)	[56]

		roots, upset elongation of pollen tubes			
SYP22, SYP31, SYP32, SYP41, SYP42, SYP43, SYP111, SYP121, SYP132, receptors SNARE	Fusion of transport vesicules with cellular membrane or organellas	—	*A. thaliana*	Bind with AtHSP90-7 (GRP94, SHD)	[57]
F22K18.70, calcineurin-like metal-dependent phosphoesterase	Processing of mRNA, phosphorylation of proteins	—	*A. thaliana*	Binds with AtHSP90-7 (GRP94, SHD)	[58]
SMT2, sterol methyltransferase	Biosynthesis of sterol	Defects of vascular bundles of cotyledons, floral organs, smaller sizes of the organism	*A. thaliana*	Binds AtHSP90-7 (GRP94, SHD)	[58, 59]
PRXR1, peroxidase	Antioxidant activity; biosynthesis of coumarin and phenylpropanoid	—	*A. thaliana*	Binds with AtHSP90-7 (GRP94, SHD)	[58]
F6I7.12, pectate lyase	Pectin cleavage	—	*A. thaliana*	Binds with AtHSP90-7 (GRP94, SHD)	[58]
T27E13.12, UDP-glycosyltransferase	Synthesis and decomposition of polysaccharides	—	*A. thaliana*	Binds with AtHSP90-7 (GRP94, SHD)	[58]
ATACX1, peroxisome acyl-CoA oxidase 1	Catabolism of fatty acids	Disturbed biosynthesis of jasmonic acid when injured, shorter roots	*A. thaliana*	Binds with AtHSP90-7 (GRP94, SHD)	[58]
NLR-proteins (NBS-LRR-proteins), R-proteins					
RPM1	Activation of hypersensitivity reaction to *Pseudomonas syringae*	Decreased resistance to pathogen	*A. thaliana*	Stability and specificity of functioning depends on cytosolic HSP90	[60]
NDR1, protein with glycosyl-phosphatidylinositol-anchor	Component of RPM1-signaling (see above)	—	*A. thaliana*	Depends on cytosolic HSP90	[60]
RPS2	Activation of hypersensitivit	Decreased resistance to	*A. thaliana*	Activation depends on	[61]

	y reaction to *Pseudomonas syringae*	pathogen		AtHSP90-1	
Pto	Resistance to *Pseudomonas syringae*	Decreased resistance to pathogen	*Nicotiana benthamiana*	Depends on HSP90	[62]
Rx	Resistance to potato virus X	Decreased resistance to pathogen	*Nicotiana benthamiana*, transgen on Rx	Depends on HSP90	[62]
N	Resistance to tobacco mosaic virus	Decreased resistance to pathogen	*Nicotiana benthamiana*, transgen on N	Depends on HSP90	[62, 63]
MLA1, MLA6	Activation of hypersensitivity reaction to *Blumeria graminis* f sp *hordei*	Decreased resistance to pathogen	*Hordeum vulgare*	Depends on HSP90	[64]
RPP	Activation of hypersensitivity reaction to *Peronospora parasitica*	Decreased resistance to pathogen	*A. thaliana*	Competency to accepting signal depends on HSP90 with cochaperones	[65]
OsCERK1, chitin receptor, and OsRac1, vegetative GTPase of Rho-type	Chitin-initiated immune response	Decreased resistance to pathogen fungi	*Oryza sativa*	Formation of a complex, transporting from ER to plasmalemma and maintenance of competency depends on HSP90 and cochaperone Hop	[66]

*Abbreviations: BR – brassinosteroids, GDA – geldanamycin, I – inducible, C – constitutive, n.c. – normal conditions, TR – thermoresistance