

TCP34, a nuclear-encoded response regulator-like TPR protein of higher plant chloroplasts

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Abstract: We describe the identification of a novel chloroplast protein, designated TCP34 (tetratricopeptide-containing chloroplast protein of 34 kDa) due to the presence of three tandemly arranged tetratricopeptide repeat (TPR) arrays. The presence of the genes encoding this protein only in the genomes of higher plants but not in photosynthetic cyanobacterial prokaryotes suggests that TCP34 evolved after the separation of the higher plant lineage. The *in vitro* translated precursor could be imported into intact spinach chloroplasts and the processed products showed stable association with thylakoid membranes. Using a specific polyclonal antiserum raised against TCP34, three protein variants were detected. Two forms, T¹ and T², were associated with the thylakoid membranes and one, S¹, was found released in the stroma. TCP34 protein was not present in etioplasts and appeared only in developing chloroplasts. The ratio of membrane-bound and soluble forms was maximal at the onset of photosynthesis. The high molecular mass thylakoid TCP34 variant was found in association with a transcriptionally active protein/DNA complex (TAC) from chloroplasts and recombinant TCP34 showed specific binding to *Spinacia oleracea* chloroplast DNA. Two TCP34 forms, T¹ and S¹, were found to be phosphorylated. An as yet unidentified phosphorelay signal may modulate its capability for plastid DNA binding through the phosphorylation state of the putative response regulator-like domain. Based on the structural properties and biochemical analyses, we discuss the putative regulatory function of TCP34 in plastid gene expression. © 2005 Elsevier Ltd. All rights reserved.

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References:

- Rochaix, J.D., Post-transcriptional steps in the expression of chloroplast genes (1992) *Annu. Rev. Cell. Biol.*, 8, pp. 1-28
- Rochaix, J.D., Post-transcriptional regulation of chloroplast gene expression in *Chlamydomonas reinhardtii* (1996) *Plant Mol. Biol.*, 32, pp. 327-342
- Mayfield, S.P., Christopher, B.Y., Cohen, A., Danon, A., Regulation of chloroplast gene expression (1995) *Annu. Rev. Physiol. Plant Mol. Biol.*, 46, pp. 147-166
- Sugita, M., Sugiura, M., Regulation of gene expression in chloroplasts of higher plants (1996) *Plant Mol. Biol.*, 32, pp. 315-326
- Goldschmidt-Clermont, M., Coordination of nuclear chloroplast expression in plant cells (1998) *Int. Rev. Cytol.*, 177, pp. 115-180
- Leon, P., Arroyo, A., MacKenzie, S., Nuclear control of plastid and mitochondrial development in higher plants (1998) *Annu.*

Rev. Plant Physiol. Plant Mol. Biol., 49, pp. 453-480

- Rochaix, J.D., Kuchka, M., Mayfield, S., Schirmer-Rahire, M., Girard-Bascou, J., Bennoun, P., Nuclear and chloroplast mutations affect the synthesis or stability of the chloroplast psbC gene product in *Chlamydomonas reinhardtii* (1989) EMBO J., 8, pp. 1013-1021
- Danon, A., Mayfield, S.P., Light regulated translational activators: Identification of chloroplast gene specific mRNA binding proteins (1991) EMBO J., 10, pp. 3993-4001
- Barkan, A., Nuclear mutants of maize with defects in chloroplast polysome assembly have altered chloroplast RNA metabolism (1993) Plant Cell, 5, pp. 389-402
- Levy, H., Kindle, K.L., Stern, D.B., A nuclear mutation that affects the 3' processing of several mRNAs in *Chlamydomonas chloroplasts* (1997) Plant Cell, 9, pp. 825-836
- Boudreau, E., Nickelsen, J., Lemaire, S.D., Ossenbühl, F., Rochaix, J.-D., The Nac2 gene of *Chlamydomonas* encodes a TPR-like protein involved in psbD mRNA stability (2000) EMBO J., 19, pp. 3366-3376
- Vaistij, F.E., Boudreau, E., Lemaire, S.D., Goldschmidt-Clermont, M., Rochaix, J.-D., Characterization of Mbb1, a nucleus-encoded tetratricopeptide-like repeat protein required for expression of the chloroplast psb/psbT/psbH gene cluster in *Chlamydomonas reinhardtii* (2000) Proc. Natl Acad. Sci. USA, 97, pp. 14813-14818
- Goebel, M., Yanagida, M., The TPR snap helix: A novel protein repeat motif from mitosis to transcription (1991) Trends Biochem. Sci., 16, pp. 173-177
- Lamb, J.R., Tugendreich, S., Hieter, P., Tetratricopeptide repeat interactions: To TPR or not to TPR? (1995) Trends Biochem. Sci., 20, pp. 257-259
- Allen, J.F., Protein phosphorylation in regulation of photosynthesis (1992) Biochim. Biophys. Acta, 1098, pp. 275-335
- Parkinson, J.S., Kofoid, E.C., Communication modules in bacterial signaling proteins (1992) Annu. Rev. Genet., 26, pp. 71-112
- Allen, J.F., Control of gene expression by redox potential and the requirement for chloroplast and mitochondrial genomes (1993) J. Theor. Biol., 165, pp. 609-631
- Kakimoto, T., CKII, a histidine kinase homolog implicated in cytokinin signal transduction (1996) Science, 274, pp. 982-985
- Hua, J., Meyerowitz, E.M., Ethylene responses are negatively regulated by a receptor gene family in *Arabidopsis thaliana* (1998) Cell, 94, pp. 261-271
- Imamura, A., Hanaki, N., Umeda, H., Nakamura, A., Suzuki, T., Ueguchi, C., Mizuno, T., Response regulators implicated in His-to-Asp phosphotransfer signaling in *Arabidopsis* (1998) Proc. Natl Acad. Sci. USA, 95, pp. 2691-2696
- D'Agostino, I.B., Kieber, J.J., Phosphorelay signal transduction: The emerging family of plant response regulators (1999) Trends Plant Sci., 24, pp. 452-456
- Sakai, H., Aoyama, T., Bono, H., Oka, A., Two-component response regulators from *Arabidopsis thaliana* contain a putative DNA-binding motif (1998) Plant Cell Physiol., 39, pp. 1232-1239
- Urao, T., Yakubov, B., Yamaguchi-Shinozaki, K., Shinozaki, K., Stress-responsive expression of genes for two-component response regulator-like proteins in *Arabidopsis thaliana* (1998) FEBS Letters, 427, pp. 175-178
- Lohrmann, J., Buchholz, G., Keitel, C., Sweere, U., Kircher, S., Bäurle, I., Differential expression and nuclear localization of response regulator-like proteins from *Arabidopsis thaliana* (1999) Plant Biol., 1, pp. 495-505
- Sakai, H., Aoyama, T., Oka, A., *Arabidopsis* ARR1 and ARR2 response regulators operate as transcriptional activators (2000) Plant J., 24, pp. 703-711
- Jacobs, M.A., Connel, L., Cattolico, R.A., A conserved His-Asp signal response regulator-like gene in *Heterosigma akashiwo* chloroplasts (1999) Plant Mol. Biol., 41, pp. 645-655
- Lütke, H.A., Chow, K.C., Mickel, F.S., Moss, K.A., Kern, H.F., Scheele, G.A., Selection of AUG initiation codons differs in

plant and animals (1987) *EMBO J.*, 6, pp. 43-48

- Sikorski, R.S., Boguski, N.S., Goebel, M., Hieter, P., A repeating amino acid motif in CDC23 defines a family of proteins and a new relationship among genes required for mitosis and RNA synthesis (1990) *Cell*, 60, pp. 307-317
- Hurst, H.C., Transcription factors 1: BZip proteins (1994) *Protein Profile*, 1, pp. 123-168
- Posas, F., Casamayor, A., Morral, N., Arino, J., Molecular cloning and analysis of a yeast protein phosphatase with an unusual amino-terminal region (1992) *J. Biol. Chem.*, 267, pp. 11734-11740
- Volz, K., Structural conservation in the CheY superfamily (1993) *Biochemistry*, 32, pp. 11741-11753
- Kyte, J., Doolittle, R.F., A simple method for displaying the hydrophobic character of a protein (1982) *J. Mol. Biol.*, 23, pp. 337-348
- Von Heijne, G., Steppuhn, J., Herrmann, R.G., Domain structure of mitochondrial and chloroplast targeting peptides (1989) *Eur. J. Biochem.*, 180, pp. 535-545
- Schmitz, G., Schmidt, M., Feierabend, J., Comparison of the expression of a plastidic chaperonin 60 in different plant tissues and under photosynthetic and non-photosynthetic conditions (1996) *Planta*, 200, pp. 326-336
- Itou, H., Tanaka, I., The OmpR-family of proteins: Insights into the tertiary structure and functions of the two-component regulator proteins (2001) *J. Biochem.*, 129, pp. 343-350
- Suck, R., Zeltz, P., Falk, J., Acker, J., Kössel, H., Krupinska, K., Transcriptionally active chromosomes (TACs) of barley chloroplasts contain the α -subunit of plastome-encoded RNA polymerase (1996) *Curr. Genet.*, 30, pp. 515-521
- Krause, K., Krupinska, K., Molecular and functional properties of highly purified transcriptionally active chromosomes from spinach chloroplasts (2000) *Physiol. Plantarum*, 109, pp. 188-195
- Peltier, J.B., Ytterberg, A.J., Sun, Q., Van Wijk, K.J., New functions of the thylakoid membrane proteome of *Arabidopsis thaliana* revealed by a simple, fast, and versatile fractionation strategy (2004) *J. Biol. Chem.*, 279, pp. 49367-49383
- Haze, K., Yoshida, H., Yanagi, H., Yura, T., Mori, K., Mammalian transcription factor ATF6 is synthesized as a transmembrane protein and activated by proteolysis to endoplasmic reticulum stress (1999) *Mol. Biol. Cell*, 10, pp. 3787-3799
- Rudner, D.Z., Fawcett, P., Losick, R., A family of membrane-embedded metalloproteases involved in regulated proteolysis of membrane-associated transcription factors (1999) *Proc. Natl Acad. Sci. USA*, 96, pp. 14765-14770
- Brown, M.S., Ye, J., Rawson, R.B., Goldstein, J.L., Regulated intramembrane proteolysis: A control mechanism conserved from bacteria to humans (2000) *Cell*, 100, pp. 391-398
- Sokolenko, A., Pojidaeva, E., Zinchenko, V., Panichkin, V., Glaser, V.M., Herrmann, R.G., Shestakov, S.V., The gene complement for proteolysis in the cyanobacterium *Synechocystis* sp PCC 6803 and *Arabidopsis thaliana* chloroplasts (review) (2002) *Curr. Genet.*, 41, pp. 291-310
- Koonin, E.V., Makarova, K.S., Rogozin, I.B., Davidovic, L., Letelier, M.-C., Pellegrini, L., The rhomboids: A nearly ubiquitous family of intramembrane serine proteases that probably evolved by multiple ancient horizontal gene transfers (2003) *Genome Biol.*, 4, p. 19
- Herrmann, R.G., Westhoff, P., Link, G., Biogenesis of plastids in higher plants (1992) *Plant Gene Research. Cell Organelles*, pp. 276-332. , R.G. Herrmann Springer Vienna
- Small, I.D., Peeters, N., The PPR motif - A TPR-related motif prevalent in plant organellar proteins (2000) *Trends Biochem. Sci.*, 25, pp. 46-47
- Herrmann, R.G., Possingham, J.V., Plastid DNA-the plastome (1980) *Results Probl. Cell Differ.*, 10, pp. 45-96
- Kuroiwa, T., The replication, differentiation, an inheritance of plastids with emphasis on the concept of organelle nuclei (1991) *Int. Rev. Cytol.*, 128, pp. 1-62
- Herrmann, R.G., Kowallik, K.V., Multiple amounts of DNA related to the size of chloroplasts. II. Comparison of electron-

- microscopic and autoradiographic data (1970) *Protoplasma*, 69, pp. 365-372
- Sato, N., Albrieux, C., Joyard, J., Douce, R., Kuroiwa, T., Detection and characterisation of a plastid envelope DNA-binding protein which may anchor plastid nucleoids (1993) *EMBO J.*, 12, pp. 555-561
 - Nakano, T., Murakami, S., Shoji, T., Yoshida, S., Yamada, Y., Sato, F., A novel protein with DNA binding activity from tobacco chloroplast nucleoids (1997) *Plant Cell*, 9, pp. 1673-1682
 - Sato, N., Ohshima, K., Watanabe, A., Ohta, N., Nishiyama, Y., Joyard, J., Douce, R., Molecular characterization of the PEND protein, a novel bZip protein in the envelope membrane that is the site of nucleoid replication in developing plastids (1998) *Plant Cell*, 10, pp. 859-872
 - Sato, N., Ohta, N., DNA-binding specificity and dimerization of the DNA-binding domain of the PEND protein in the chloroplast envelope membrane (2001) *Nucl. Acids Res.*, 29, pp. 2244-2250
 - Jeong, S.Y., Rose, A., Meier, I., MFP1 is a thylakoid-associated, nucleoid-binding protein with a coiled-coil structure (2003) *Nucl. Acids Res.*, 31, pp. 5175-5185
 - Pfannschmidt, T., Nilsson, A., Allen, J.F., Photosynthetic control of chloroplast gene expression (1999) *Nature*, 397, pp. 625-628
 - Mizuno, T., Kaneko, T., Tabata, S., Compilation of all genes encoding bacterial two-component signal transducers in the genome of the cyanobacterium *Synechocystis* sp PCC 6803 (1996) *DNA Res.*, 3, pp. 407-414
 - Yeh, K.C., Lagarias, J.C., Eukaryotic phytochromes: Light-regulated serine/threonine protein kinase with histidine ancestry (1998) *Proc. Natl Acad. Sci. USA*, 95, pp. 13976-13981
 - Chang, C., Stewart, R.C., The two-component system: Regulation of diverse signaling pathways in prokaryotes and eukaryotes (1998) *Plant Physiol.*, 117, pp. 723-731
 - Sassone-Cori, P., Ransone, L.J., Lamph, W.W., Verma, I.M., Direct interaction between Fos and Jun nuclear oncoproteins: Role of the 'leucine zipper' domain (1988) *Nature*, 336, pp. 692-695
 - Yamamoto, K.K., Gonzalez, G.A., Briggs III, W.H., Montminy, M.R., Phosphorylation-induced binding and transcriptional efficacy of nuclear factor CREB (1988) *Nature*, 334, pp. 494-499
 - Hunter, T., Karin, M., The regulation of transcription by phosphorylation (1992) *Cell*, 70, pp. 375-387
 - Hunter, T., Protein kinases: The Yin and Yang of protein phosphorylation and signaling (1995) *Cell*, 80, pp. 225-236
 - Wellmer, F., Schäfer, E., Harter, K., The DNA binding properties of the parsley bZIP transcription factor CPRF4a are regulated by light (2001) *J. Biol. Chem.*, 276, pp. 6274-6279
 - Sambrook, J., Fritsch, E.F., Maniatis, T., (1989) *Molecular Cloning: A Laboratory Manual*, 2nd edit. Cold Spring Harbor Laboratory Press Cold Spring Harbor, NY
 - Laemmli, U., Cleavage of structural proteins during the assembly of the head of bacteriophage T4 (1970) *Nature*, 227, pp. 680-685
 - Towbin, H., Staehelin, T., Gordon, J., Electrophoretic transfer of proteins from polyacrylamide gels to nitrocellulose sheets: Procedure and some applications (1979) *Proc. Natl Acad. Sci. USA*, 76, pp. 4350-4354
 - Clausmeyer, S., Klösigen, R.B., Herrmann, R.G., Protein import into chloroplasts. the hydrophilic luminal proteins exhibit unexpected import and sorting specificities inspite of structurally conserved transit peptides (1993) *J. Biol. Chem.*, 268, pp. 13869-13876
 - Eichacker, L.A., Müller, B., Helfrich, M., Stabilization of the chlorophyll binding apoproteins, P700, CP47, CP43, D2, and D1, by synthesis of Zn-pheophytin a in intact etioplasts from barley (1996) *FEBS Letters*, 395, pp. 251-256
 - Baginsky, S., Tiller, K., Link, G., Transcription factor phosphorylation by a protein kinase associated with chloroplast RNA polymerase from mustard (*Sinapis alba*) (1997) *Plant Mol. Biol.*, 34, pp. 181-189

- De Vitry, C., Diner, B.A., Popot, J.L., Photosystem II particles from *Chlamydomonas reinhardtii*. Purification, molecular weight, small subunit composition, and protein phosphorylation (1991) *J. Biol. Chem.*, 266, pp. 16614-16621
- Polycarpou-Schwarz, M., Papavassiliou, A.G., Distinguishing specific from nonspecific complexes on southwestern blots by rapid DMS protection assays (1993) *Nucl. Acids Res.*, 21, pp. 2531-2532
- Becker, W., Kentrup, H., Klumpp, S., Schultz, J.E., Joost, H.G., Molecular cloning of a protein serine/threonine phosphatase containing a putative regulatory tetratricopeptide repeat domain (1994) *J. Biol. Chem.*, 269, pp. 22586-22592
- Chen, J., Parsons, S., Brautigan, D.L., Tyrosine phosphorylation of protein phosphatase 2A in response to growth stimulation and v-src transformation of the fibroblasts (1994) *J. Biol. Chem.*, 269, pp. 7957-7962

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