

Disruption of the AtREV3 gene causes hypersensitivity to ultraviolet B light and ??-rays in Arabidopsis: Implication of the presence of a translesion synthesis mechanism in plants

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Abstract: To investigate UV light response mechanisms in higher plants, we isolated a UV light-sensitive mutant, rev3-1, in Arabidopsis. The root growth of rev3-1 was inhibited after UV-B irradiation under both light and dark conditions. We found that chromosome 1 of rev3-1 was broken at a minimum of three points, causing chromosome inversion and translocation. A gene disrupted by this rearrangement encoded the catalytic subunit of DNA polymerase ?? (AtREV3), which is thought to be involved in translesion synthesis. The rev3-1 seedlings also were sensitive to ??-rays and mitomycin C, which are known to inhibit DNA replication. Incorporation of bromodeoxyuridine after UV-B irradiation was less in rev3-1 than in the wild type. These results indicate that UV light-damaged DNA interrupted DNA replication in the rev3-1 mutant, leading to the inhibition of cell division and root elongation.

Index Keywords: Catalysis; DNA; Enzymes; Plants (botany); Ultraviolet radiation; Mutants; Cells; Amino Acid Sequence; Arabidopsis; Arabidopsis Proteins; Catalytic Domain; Chromosome Aberrations; Darkness; DNA Damage; DNA Repair; DNA-Directed DNA Polymerase; Gamma Rays; Light; Mitomycin; Molecular Sequence Data; Mutation; Phenotype; Plant Roots; Sequence Homology, Amino Acid; Ultraviolet Rays; Arabidopsis; Embryophyta

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References:

1. Ahmad, M., Jarillo, J.A., Klimczak, L.J., Landry, L.G., Peng, T., Last, R.L., Cashmore, A.R., An enzyme similar to animal type II photolyases mediates photoreactivation in Arabidopsis (1997) *Plant Cell*, 9, pp. 199-207
2. Asada, K., The water-water cycle in chloroplasts: Scavenging of active oxygens and dissipation of excess photons (1999) *Annu. Rev. Plant Physiol. Plant Mol. Biol.*, 50, pp. 601-639
3. Bell, C.J., Ecker, J.R., Assignment of 30 microsatellite loci to the linkage map of Arabidopsis (1994) *Genomics*, 19, pp. 137-144
4. Bemark, M., Khamlichi, A.A., Davies, S.L., Neuberger, M.S., Disruption of mouse polymerase ?? (Rev3) leads to embryonic lethality and impairs blastocyst development in vitro (2000) *Curr. Biol.*, 10, pp. 1213-1216
5. Britt, A.B., Molecular genetics of DNA repair in higher plants (1999) *Trends Plant Sci.*, 1, pp. 20-25
6. Britt, A.B., Chen, J.-J., Wykoff, D., Mitchell, D., A UV-sensitive mutant of Arabidopsis defective in the repair of pyrimidine-pyrimidinone(6-4) dimers (1993) *Science*, 261, pp. 1571-1574
7. Burgers, O.M.J., Eukaryotic DNA polymerases in DNA replication and DNA repair (1998) *Chromosoma*, 107, pp. 218-227
8. DiGiuseppe, J.A., Dresler, S.L., Bleomycin-induced DNA repair synthesis in permeable human fibroblasts: Mediation of long-patch and short-patch repair by distinct DNA polymerases (1989) *Biochemistry*, 28, pp. 9515-9520
9. Eeken, J.C.J., Romeijn, R.J., De Jong, A.W.M., Pastink, A., Lohman, P.H.M., Isolation and genetic characterisation of the Drosophila homologue of (SCE)REV3, encoding the catalytic subunit of DNA polymerase ?? (2001) *Mutat. Res.*, 485, pp. 237-253
10. Esposito, G., Godin, I., Klein, U., Yaspo, M.-L., Cumano, A., Rajewsky, K., Disruption of the Rev31-encoded catalytic subunit in mice of polymerase ?? results in early embryonic lethality (2000) *Curr. Biol.*, 10, pp. 1221-1224
11. Fil??e, J., Forterre, P., Sen-Lin, T., Laurent, J., Evolution of DNA polymerase families: Evidence for multiple gene exchange between cellular and viral proteins (2002) *J. Mol. Biol.*, 54, pp. 763-773
12. Friedberg, E.C., Siede, W., Cooper, A.J., Cellular responses to DNA damage in yeast (1991) *The Molecular and Cellular Biology of the Yeast Saccharomyces: Genome Dynamics, Protein Synthesis, and Engineering*, pp. 147-192. , J.R. Broach, J.R. Pringle, and E.W. Jones, eds (Cold Spring Harbor, NY: Cold Spring Harbor Laboratory Press)
13. Friedberg, E.C., Walker, G.C., Siede, W., (1995) *DNA Repair and Mutagenesis*, , Washington DC: American Society of Microbiology Press

14. Fujie, M., Kuroiwa, H., Suzuki, T., Kawano, S., Kuroiwa, T., Organelle DNA synthesis in the quiescent center of *Arabidopsis thaliana* (Col.) (1993) *J. Exp. Bot.*, 44, pp. 689-693
15. Gallego, F., Fleck, O., Li, A., Wyrzykowska, J., Tinland, B., AtRAD1, a plant homologue of human and yeast nucleotide excision repair endonucleases, is involved in dark repair of UV damages and recombination (2000) *Plant J.*, 21, pp. 507-518
16. Gibbs, P.E.M., McGregor, W.G., Maher, V.M., Nisson, P., A human homolog of the *Saccharomyces cerevisiae* REV3 gene which encodes the catalytic subunit of DNA polymerase ?? (1998) *Proc. Natl. Acad. Sci. USA*, 95, pp. 6876-6880
17. Gratzner, H.G., Monoclonal antibody to 5-bromo- and 5-indodeoxyuridine: A new reagent for detection of DNA replication (1982) *Science*, 218, pp. 474-475
18. Grossmann, K.F., Ward, A.M., Moses, R.E., *Saccharomyces cerevisiae* lacking Smn1, Rev3 or Rad51 have a normal S-phase but arrest permanently in G2 after cisplatin treatment (2000) *Mutat. Res.*, 461, pp. 1-13
19. Harborne, J.B., Williams, C.A., Advances in flavonoid research since 1992 (2000) *Phytochemistry*, 55, pp. 481-504
20. Haynes, R.H., Kunz, B.A., DNA repair and mutagenesis in yeast (1981) *The Molecular Biology of the Yeast Saccharomyces: Life Cycle and Inheritance*, pp. 371-414. , J.N. Strathern, E.W. Jones, and J.R. Broach, eds (Cold Spring Harbor, NY: Cold Spring Harbor Laboratory Press)
21. Hidema, J., Kang, S.-H., Kumagai, T., Changes in cyclobutyl pyrimidine dimer levels in rice (*Oryza sativa* L.) growing indoors and outdoors with or without supplemental UV-B radiation (1999) *J. Photochem. Photobiol.*, 52, pp. 1-3
22. Holbeck, S.L., Strathern, J.N., A role for REV3 in mutagenesis during double-strand break repair in *Saccharomyces cerevisiae* (1997) *Genetics*, 147, pp. 1017-1024
23. Jenkins, M.E., Harlow, G.R., Liu, Z., Shotwell, M.A., Ma, J., Mount, D.W., Radiation-sensitive mutant of *Arabidopsis thaliana* (1995) *Genetics*, 140, pp. 725-732
24. Jiang, C.Z., Yee, J., Mitchell, D.L., Britt, A.B., Photorepair mutants of *Arabidopsis* (1997) *Proc. Natl. Acad. Sci. USA*, 94, pp. 7441-7445
25. Johnson, R.E., Haracska, L., Prakash, S., Prakash, L., Role of DNA polymerase ? in the bypass of a (6-4) TT photoproduct (2001) *Mol. Cell. Biol.*, 21, pp. 3559-3563
26. Johnson, R.E., Prakash, S., Prakash, L., Efficient bypass of a thymine-thymine dimer by yeast DNA polymerase, pol ? (1999) *Science*, 283, pp. 1001-1004
27. Kimura, S., A novel DNA polymerase homologous to *Escherichia coli* DNA polymerase I from a higher plant, rice (*Oryza sativa* L.) (2002) *Nucleic Acids Res.*, 30, pp. 1585-1592
28. Konieczny, A., Ausubel, F.M., A procedure for mapping *Arabidopsis* mutations using co-dominant ecotype-specific PCR-based markers (1993) *Plant J.*, 4, pp. 403-410
29. Landry, L.G., Stapleton, A.E., Lim, J., Hoffman, P., Hays, J.B., Walbot, V., Last, R., An *Arabidopsis* photolyase mutant is hypersensitive to ultraviolet-B radiation (1997) *Proc. Natl. Acad. Sci. USA*, 94, pp. 328-332
30. Lawrence, C.W., Christensen, R., UV mutagenesis in radiation-sensitive strains of yeast (1976) *Genetics*, 82, pp. 207-232
31. Lawrence, C.W., Christensen, R.B., Ultraviolet-induced reversion of *cyc1* alleles in radiation-sensitive strains of yeast. III. *rev3* mutant strains (1979) *Genetics*, 92, pp. 397-408
32. Lawrence, C.W., Gibbs, P.E.M., Murante, R.S., Wang, X.-D., Li, Z., McManus, T.P., McGregor, W.G., Maher, V.M., Roles of DNA polymerase ?? and REV1 protein in eukaryotic mutagenesis and translesion replication (2000) *Cold Spring Harbor Symp. Quant. Biol.*, 65, pp. 61-69
33. Lawrence, C.W., O'Brien, T., Bond, J., UV-induced reversion of *his4* frameshift mutations in *rad6*, *rev1* and *rev3* mutants of yeast (1984) *Mol. Gen. Genet.*, 195, pp. 487-490
34. Lin, W., Wu, X., Wang, Z., A full-length cDNA of hREV3 is predicted to encode DNA polymerase ?? for damage-induced

mutagenesis in humans (1999) *Mutat. Res.*, 433, pp. 89-98

35. Liu, Z., Hall, J.D., Mount, D.W., Arabidopsis UVH3 gene is a homolog of the *Saccharomyces cerevisiae* RAD2 and human XPG DNA repair genes (2001) *Plant J.*, 26, pp. 329-338
36. Liu, Z., Hossain, G.S., Islas-Osuna, M.A., Mitchell, D.L., Mount, D.W., Repair of UV damage in plants by nucleotide excision repair: Arabidopsis UVH1 DNA repair gene is a homolog of *Saccharomyces cerevisiae* Rad1 (2000) *Plant J.*, 21, pp. 519-528
37. Matsuda, T., Bebenek, K., Masutani, C., Hanaoka, F., Kunkel, T.A., Low fidelity DNA synthesis by human DNA polymerase- ϵ (2000) *Nature*, 404, pp. 1011-1013
38. McDonald, J.P., Levine, A.S., Woodgate, R., The *Saccharomyces cerevisiae* RAD30 gene, a homologue of *Escherichia coli* dinB and umuC, is DNA damage inducible and functions in a novel error-free postreplication repair mechanism (1997) *Genetics*, 147, pp. 1557-1568
39. Morrison, A., Christensen, R.B., Alley, J., Beck, A.K., Bernstine, E.G., Lemontt, J.F., Lawrence, C.W., REV3, a *Saccharomyces cerevisiae* gene whose function is required for induced mutagenesis, is predicted to encode a nonessential DNA polymerase (1989) *J. Bacteriol.*, 171, pp. 5659-5667
40. Nagata, Y., Min, T.K., Nakano, T., Asami, T., Yoshida, S., Treatment of dark-grown *Arabidopsis thaliana* with a brassinosteroid-biosynthesis inhibitor, brassinazole, induces some characteristics of light-grown plants (2000) *Planta*, 211, pp. 781-790
41. Nakajima, S., Sugiyama, M., Iwai, S., Hitomi, K., Otsoshi, E., Kim, S.-T., Jiang, C.-Z., Yamamoto, K., Cloning and characterization of a gene (UVR3) required for photorepair of 6-4 photoproducts in *Arabidopsis thaliana* (1998) *Nucleic Acids Res.*, 26, pp. 638-644
42. Nelson, J.R., Lawrence, C.W., Hinkle, D.C., Thymine-thymine dimer bypass by yeast DNA polymerase η (1996) *Science*, 272, pp. 1646-1649
43. Nelson, J.R., Lawrence, C.W., Hinkle, D.C., Deoxycytidyl transferase activity of yeast REV1 protein (1996) *Nature*, 382, pp. 729-731
44. Prakash, S., Prakash, L., Translesion DNA synthesis in eukaryotes: A one- or two-polymerase affair (2002) *Genes Dev.*, 16, pp. 1872-1883
45. Quah, S.-K., Von Borstel, R.C., Hastings, P.J., The origin of spontaneous mutation in *Saccharomyces cerevisiae* (1980) *Genetics*, 96, pp. 819-839
46. Ries, G., Heller, W., Puchta, H., Sandermann, H., Seidlitz, H.K., Hohn, B., Elevated UV-B radiation reduces genome stability in plants (2000) *Nature*, 406, pp. 98-101
47. Reuven, N.B., Arad, G., Maor-Shoshani, A., Livneh, Z., The mutagenesis protein UmuC is a DNA polymerase activated by UmuD ψ , RecA, and SSB and is specialized for translesion replication (1999) *J. Biol. Chem.*, 274, pp. 31763-31766
48. Rozema, J., Van De Staaij, J., Björn, L.O., Caldwell, M., UV-B as an environmental factor in plant life: Stress and regulation (1997) *Tree*, 12, pp. 22-28
49. Sakai, W., Ishi, C., Inoue, H., The upr-1 gene encodes a catalytic subunit of the DNA polymerase η which is involved in damage-induced mutagenesis in *Neurospora crassa* (2002) *Mol. Genet. Genomics*, 267, pp. 401-408
50. Shikazono, N., Tanaka, A., Watanabe, H., Tano, S., Rearrangements of the DNA in carbon ion-induced mutants of *Arabidopsis thaliana* (2001) *Genetics*, 157, pp. 379-387
51. Singhal, R.K., Hinkle, D.C., Lawrence, C.W., The REV3 gene of *Saccharomyces cerevisiae* is transcriptionally regulated more like a repair gene than one encoding a DNA polymerase (1992) *Mol. Gen. Genet.*, 236, pp. 17-24
52. Srivastava, V., Miller, S., Busbee, D., Immunofluorescent evaluation of DNA repair synthesis using interactive laser

cytometry (1993) Cytometry, 14, pp. 144-153

53. Tanaka, A., Sakamoto, A., Ishigaki, Y., Nikaido, O., Sun, G., Hase, Y., Shikazono, N., Watanabe, H., An ultraviolet-B-resistant mutant with enhanced DNA repair in Arabidopsis (2002) Plant Physiol., 129, pp. 64-71
54. Tanaka, A., Shikazono, N., Yokota, Y., Watanabe, H., Tano, S., Effects of heavy ions on the germination and survival of Arabidopsis thaliana (1997) Int. J. Radiat. Biol., 72, pp. 121-127
55. Tang, M., Pham, P., Shen, X., Taylor, J.-S., O'Donnell, M., Woodgate, R., Goodman, M.F., Roles of E. coli DNA polymerase IV and V in lesion-targeted and untargeted SOS mutagenesis (2000) Nature, 404, pp. 1014-1018
56. Tang, M., Shen, X., Frank, E.G., O'Donnell, M., Woodgate, R., Goodman, M.F., UmuD²C is an error-prone DNA polymerase, Escherichia coli pol V (1999) Proc. Natl. Acad. Sci. USA, 96, pp. 8919-8924
57. Thompson, J.D., Gibson, T.J., Plewniak, F., Jeanmougin, F., Higgins, D.G., The CLUSTAL_X windows interface: Flexible strategies for multiple sequence alignment aided by quality analysis tools (1997) Nucleic Acids Res., 25, pp. 4876-4882
58. Van Sloun, P.P.H., Romeijn, R.J., Eeken, J.C.J., Molecular cloning, expression and chromosomal localisation of the mouse Rev31 gene, encoding the catalytic subunit of polymerase ?? (1999) Mutat. Res., 433, pp. 109-116
59. Wagner, J., Gruz, P., Kim, S.-R., Yamada, M., Matsui, K., Fuchs, R.P.P., Nohmi, T., The dinB gene encodes a novel E. coli DNA polymerase, DNA pol IV, involved in mutagenesis (1999) Mol. Cell, 4, pp. 281-286
60. Wittschieben, J., Shivji, M.K.K., Lalani, E., Jacobs, M.A., Marini, F., Gearhart, P.J., Rosewell, I., Wood, R.D., Disruption of developmentally regulated Rev31 gene causes embryonic lethality (2000) Curr. Biol., 10, pp. 1217-1220
61. Xu, H., Swoboda, I., Bhalla, P.L., Sijbers, A.M., Zhao, C., Ong, E.-K., Hoeijmakers, J.H.J., Singh, M.B., Plant homologue of human excision repair gene ERCC1 points to conservation of DNA repair mechanisms (1998) Plant J., 13, pp. 823-829