

INFLUENCE OF PROTEIN KINASE AND PHOSPHATASE INHIBITORS ON ADVENTITIOUS SHOOT REGENERATION IN EASTERN WHITE PINE (*PINUS STROBUS* L.)

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REFERENCES

- Ammirato P. V. (1983). Embryogenesis *In*: Evans D. A., Sharp W. R., Ammirato P. V., and Yamada Y. (Eds.). Handbook of Plant Cell Culture, Vol. I, MacMillan, New York: 82-123.
- Bradford M. M. (1976). A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Analytical Biochemistry*, 72: 248-254.
- Burritt D. J., Leung D. W. M. (1996). Organogenesis in cultured petiole explants of *Begonia erythrophylla*: the timing and specificity of the inductive stimuli. *Journal of Experimental Botany*, 47: 557-567.
- Cohen P. (1985). A role for protein phosphorylation in the hormonal control of enzyme activity. *European Journal of Biochemistry*, 151: 439-448.
- Delumeau O., Montrichard F., Laval-Martin D. L. (1998). NAD⁺ kinase activity, calmodulin levels during the growth of isolated cells from *Lycopersicon pimpinellifolium* and kinetic constants of the calmodulin-dependent NAD⁺ kinase. *Plant Science*, 138: 43-52.
- Flinn B. S., Webb D. T., Newcomb W. (1988). The role of cell clusters and promeristemoids in determination and competence for caulogenesis by *Pinus strobus* cotyledons *in vitro*. *Canadian Journal of Botany*, 66: 1556-1565.
- Garin E., Bernier-Cardou M., Isabel N., Klimaszewska K., Plourde A. (2000). Effect of sugars, amino acids, and culture technique on maturation of somatic embryos of *Pinus strobus* on medium with two gellan gum concentrations. *Plant Cell, Tissue and Organ Culture*, 62: 27-37.
- Gaspar T., Kevers C., Penel C., Greppin H., Reid D. M., Thorpe T.A. (1996). Plant hormones and plant growth regulators in plant tissue culture. *In Vitro Cellular Developmental Biology-Plant*, 32: 272-289.
- George M. W., Tripepi R. R. (1994). Cytokinins, donor plants and time in culture affect shoot regenerative capacity of American elm leaves. *Plant Cell, Tissue and Organ Culture*, 39: 27-36.
- Grover M., Sharma A. K., Dhingra A., Maheshwari S. C., Tyagi A. K. (1998). Regulation of plastid gene expression in rice involves calcium and protein phosphatases: kinases for signal transduction. *Plant Science*, 137: 185-190.
- Hoffman M. (1991). First protein kinase structure. *Science*, 253: 383.
- Hunter T. (1987). A thousand and one protein kinases. *Cell*, 50: 823-829.
- Hutchinson M. J., Murch S. J., Saxena P. K. (1996). Morphoregulatory role of TDZ: evidence of the involvement of endogenous auxin in TDZ-induced somatic embryogenesis of geranium (*Pelargonium x hortorum* Bailey). *Journal of Plant Physiology*, 149: 573-579.
- Kaul K. (1987). Plant regeneration from cotyledon-hypocotyl explants of *Pinus strobus* L. *Plant Cell Reports*, 6: 5-7.
- Kaul K. (1995). Somatic embryogenesis in eastern eastern white pine (*Pinus strobus* L.). Jain S.-M., Gupta P. K., and Newton R. J. (Eds.). *Somatic embryogenesis of woody plants*, Vol. 3, Gymnosperms, Kluwer Academic Publisher: 257-268.
- Klimaszewska K., Park Y. S., Overton C., Maceacheron I., Bonga J. M. (2001). Optimized somatic embryogenesis in *Pinus strobus* L. *In Vitro Cellular Developmental Biology-Plant*, 37: 392-399.
- Klimaszewska K., Bernier-Cardou M., Cyr D. R., Sutton B. C. S. (2000). Influence of gelling agents on culture medium gel strength, water availability, tissue water potential, and maturation response in embryogenic cultures of *Pinus strobus* L. *In Vitro Cellular Developmental Biology-Plant*, 36: 279-286.
- Laemmli U. K. (1970). Cleavage of structural proteins during the assembly of the head of bacteriophage T4. *Nature*, 227: 680-685.
- Laurie S., Nigel G. (2001). Halford The role of protein kinases in the regulation of plant growth and development. *Plant Growth Regulation*, 34: 253-265.

- Low R. K., Prakash A. P., Swarup S., Goh C. J., Kumar P. P. (2001). A differentially expressed bZIP gene is associated with adventitious shoot regeneration in leaf cultures of *Paulownia kawakamii*. *Plant Cell Reports*, 20: 696-700.
- Mcainsh M. R., Brownlee C., Hetherington A. M. (1997) Calcium ions as second messengers in guard cell signal transduction. *Physiologia Plantarum*, 100: 16-29.
- Mithila J., Hall J. C., Victor J. M. R., Saxena P. K. (2003). Thidiazuron induces shoot organogenesis at low concentrations and somatic embryogenesis at high concentrations on leaf and petiole explants of African violet (*Saintpaulia ionantha* Wendl.). *Plant Cell Reports*, 21: 408-414.
- Murch S. J., Victor J. M. R., Krishnaraj S., Saxena P. K. (1999). The role of proline in thidiazuron-induced somatic embryogenesis of peanut. *In Vitro Cellular Developmental Biology-Plant*, 35: 102-105.
- Murthy B. N. S., Murch S. J., Saxena P. K. (1995). Thidiazuron induced somatic embryogenesis in intact seedlings of peanut (*Arachis hypogaea* L.): endogenous growth regulator levels and significance of cotyledons. *Physiologia Plantarum*, 94: 268-276.
- Murthy B. N. S., Murch S. J., Saxena P. K. (1998). Thidiazuron: a potent regulator of *in vitro* plant morphogenesis. *In Vitro Cellular Developmental Biology-Plant*, 34: 267-275.
- Noël G. M., Tognetti J. A., Pontis H. G. (2001). Protein kinase and phosphatase activities are involved in fructan synthesis initiation mediated by sugars. *Planta*, 213: 640-646.
- Ohto M., Nakamura K. (1995). Sugar-induced increase of calcium-dependent protein kinases associated with the plasma membrane in leaf tissues of tobacco. *Plant Physiology*, 109: 973-981.
- Pan Z. G., Liu C. Z., Murch S. J., El-Demerdash M., Saxena P. K. (2003). Plant regeneration from mesophyll protoplasts of the Egyptian medicinal plants *Artemisia judaica* L. and *Echinops spinosissimus* Turra. *Plant Science*, 165: 681-687.
- Pontis H. G., Babio J. R., Salerno G. L. (1981). Reversible unidirectional inhibition of sucrose synthase by disulfides. *Proceedings of the National Academy of Sciences of USA*, 78: 6667-6669.
- Ramage C. M., Williams R. R. (2004). Cytokinin-induced abnormal shoot organogenesis is associated with elevated *Knotted1*-type homeobox gene expression in tobacco. *Plant Cell Reports*, 22: 919-924.
- Ramage C. M., Williams R. R. (2003). Mineral uptake in tobacco leaf discs during different developmental stages of shoot organogenesis. *Plant Cell Reports*, 21: 1047-1053.
- Schmülling T., Schafer S., Romanov G. (1997). Cytokinins as regulators of gene expression. *Physiologia Plantarum*, 100: 505-519.
- Schwarz O. J., Schlarbaum S. E., Beaty R. M. (1988). Plantlet regeneration from mature zygotic embryos of eastern white pine (*Pinus strobus* L.). *Plant Cell Reports*, 7: 174-177.
- Shih Y. W., Chou W. C., Lin Y. M., Huang D. D., Liu Z. H., Huang H. J. (2004). Changes in protein tyrosine phosphorylation during mannose and senescence induced cell death in rice. *Plant Growth Regulation*, 42: 271-282.
- Stone J. M., Walker J. C. (1995). Plant protein kinase families and signal transduction. *Plant Physiology*, 188: 451-457.
- Tang W. (2000). Peroxidase activity of desiccation-tolerant loblolly pine somatic embryos. *In Vitro Cellular Developmental Biology-Plant*, 36: 488-491.
- Tang W., Harris L. C., Outhavong V., Newton R. J. (2004). Antioxidants enhance *in vitro* plant regeneration by inhibiting the accumulation of peroxidase in Virginia pine (*Pinus virginiana* Mill.). *Plant Cell Reports*, 22: 871-877.
- Tang W., Newton R. J. (2003). Genetic transformation of conifers and its application in forest biotechnology. *Plant Cell Reports*, 22: 1-15.
- Torelli A., Borinato M., Soragni E., Bolpagni R., Bottura C., Branca C. (2004). The delay in hormonal treatment modulates the expression of *LESK1*, a gene encoding a putative serine-threonine kinase, marker of *in vitro* caulogenesis in tomato (*Lycopersicon esculentum* Mill.). *Plant Science*, 167: 607-620.
- Ullanat R., Jayabaskaran C. (2002). Distinct light-, cytokinin- and tissue-specific regulation of calcium dependent protein kinase gene expression in cucumber (*Cucumis sativus*). *Plant Science*, 162: 153-163.
- Webb D. T., Flinn B. S., Georgis W. (1988). Micropropagation of eastern white pine (*Pinus strobus* L.). *Canadian Journal of Forest Research*, 18: 1570-1580.
- Yamamoto S., Suzuki K., Shinshi H. (1999). Elicitor-responsive, ethylene-independent activation of GCC box-mediated transcription that is regulated by both protein phosphorylation and dephosphorylation in cultured tobacco cells. *Plant Journal*, 20: 571-579.
- Yancheva S. D., Golubowicz S., Fisher E., Lev-Yadun S., Flaishman M. A. (2003). Auxin type and timing of application determine the activation of the developmental program during *in vitro* organogenesis in apple. *Plant Science*, 165: 299-309.