Molecular mapping of genes conferring aluminum tolerance in rice (Oryza sativa L.)

Nguyen V.T., Burow M.D., Nguyen H.T., Le B.T., Le T.D., Paterson A.H.

Institute of Biotechnology, Hanoi, Viet Nam; Plant Genome Mapping Laboratory, Texas A and M University, College Station, TX 77843-2474, United States; Plant Molecular Genetics Laboratory, Texas Tech University, Lubbock, TX 79409-0001, United States; Department of Genetics, National University of Hanoi, Hanoi, Viet Nam; Applied Genetic Technology Center (AGTEC), Dept. Crop and Soil Science, University of Georgia, Athens, GA 30602, United States

Abstract: Crop productivity on acid soil is restricted by multiple abiotic stress factors. Aluminum (Al) tolerance seems to be a key to productivity on soil with a pH below 5.0, but other factors such as Mn toxicity and the deficiency of P, Ca and Mg also play a role. The development of Al-tolerant genotypes of rice is an urgent necessity for improving crop productivity in developing countries. Inhibition of root growth is a primary and early symptom of Al toxicity. The present study was conducted to identify genetic factors controlling the aluminum tolerance of rice. Several parameters related to Al tolerance, most importantly the relative root growth under Al stress versus non-stress conditions, were scored in 188 F_3 selfed families from a cross between an Al-tolerant Vietnamese local variety, Chiembau, and an Al-susceptible improved variety, Omon269-65. The two varieties are both Oryza sativa ssp. indica, but showed a relatively high level of DNA polymorphism, permitting the assembly of an RFLP map consisting of 164 loci spanning 1,715.8 cM, and covering most of the rice genome. A total of nine different genomic regions on eight chromosomes have been implicated in the genetic control of root and shoot growth under aluminum stress. By far the greatest effects on aluminum tolerance were associated with the region near WG110 on chromosome 1. This region does not seem to correspond to most of the genes that have been mapped for aluminum tolerance in other species, nor do they correspond closely to one another. Most results, both from physiological studies and from molecular mapping studies, tend to suggest that aluminum tolerance is a complex multi-genic trait. The identification of DNA markers (such as WG110) that are diagnostic for aluminum tolerance in particular gene pools provides an important starting point for transferring and pyramiding genes that may contribute to the sustainable improvement of crop productivity in aluminum-rich soils. The isolation of genes responsible for aluminum tolerance is likely to be necessary to gain a comprehensive understanding of this complex trait.

Author Keywords: Abiotic stress tolerance; Molecular-marker; Quantitative trait locus (QTL); Restriction fragment length polymorphism (RFLP); Rice

Index Keywords: aluminum; chromosomal localization; crop production; DNA polymorphism; genetic distance; genetic regulation; genotype; growth inhibition; manganese; metal tolerance; molecular mapping; pH; root growth; soil acidity; strain improvement; stress tolerance; Aluminum compounds; Chromosomes; DNA; Genes; Mapping; pH effects; Soils; Toxicity; Crop productivity; Plants (botany)

Year: 2001

Source title: Theoretical and Applied Genetics
Volume: 102
Issue: 7-Jun
Page : 1002-1010
Cited by: 43
Link: Scorpus Link
Molecular Sequence Numbers: PI416936

Correspondence Address: Paterson, A.H.; Applied Genetic Technology Center, Dept. Crop and Soil Science, University of Georgia, Athens, GA 30602, United States; email: paterson@uga.edu

ISSN: 405752
CODEN: THAGA
DOI: 10.1007/s001220000472
Language of Original Document: English
Abbreviated Source Title: Theoretical and Applied Genetics
Document Type: Article
Source: Scopus

Authors with affiliations:

1. Nguyen, V.T., Institute of Biotechnology, Hanoi, Viet Nam, Plant Genome Mapping Laboratory, Texas A and M University, College Station, TX 77843-2474, United States, Department of Genetics, National University of Hanoi, Hanoi, Viet Nam, Applied Genetic Technology Center (AGTEC), Dept. Crop and Soil Science, University of Georgia, Athens, GA 30602, United States
2. Burow, M.D., Plant Genome Mapping Laboratory, Texas A and M University, College Station, TX 77843-2474, United States, Applied Genetic Technology Center (AGTEC), Dept. Crop and Soil Science, University of Georgia, Athens, GA 30602, United States
3. Nguyen, H.T., Plant Molecular Genetics Laboratory, Texas Tech University, Lubbock, TX 79409-0001, United States
4. Le, B.T., Institute of Biotechnology, Hanoi, Viet Nam
5. Le, T.D., Department of Genetics, National University of Hanoi, Hanoi, Viet Nam
6. Paterson, A.H., Plant Genome Mapping Laboratory, Texas A and M University, College Station, TX 77843-2474, United States, Applied Genetic Technology Center (AGTEC), Dept. Crop and Soil Science, University of Georgia, Athens, GA 30602, United States

References:

1. Alam, S.N., Cohen, M.B., Detection and analysis of QTLs for resistance to the brown planthopper, Nilaparvata lugens, in a doubled-haploid rice population (1998) Theor Appl Genet, 97, pp. 1370-1395
2. Aniol, A., Genetics of aluminum tolerance in wheat (Triticum aestivum L. Thell) (1990) Plant Soil, 123, pp. 223-227
3. Aniol, A., Gustafson, J.P., Chomosome location of genes controlling aluminum tolerance in wheat, rye, and tricale (1984) Can J Genet Cytol, 26, pp. 701-705
4. Armiger, H.W., Foy, C.D., Fleming, A.L., Caldwell, B.E., Differential tolerance of soybean varieties to an acid soil high in exchangeable aluminum (1968) Agron J, 59, pp. 415-418
5. Bianchi-Hall, C.M., Carter E.T., Jr., Rufty, T.W., Arellano, C., Boerma, H.R., Ashley, D.A., Heritability and resource allocation of aluminum tolerance derived from soybean PI 416937 (1998) Crop Sci, 38, pp. 513-522
6. Bushamuka, N.V., Zobel, R.W., Maize and soybean tap, basal, and lateral root responses to a stratified acid, aluminum toxic

soil (1998) Crop Sci, 38, pp. 416-421

7. Campbell, T.A., Jackson, P.R., Xia, Z.L., Effect of aluminum stress on alfalfa root proteins (1994) J Plant Nutr, 17, pp. 471-1994
8. Causse, M.A., Fulton, T.M., Cho, Y.G., Ahn, S.N., Chunwongse, J., Wu, K., Xiao, J., Tanksley, S.D., Saturated molecular map of the rice genome based on an interspecific backcross population (1994) Genetics, 138, pp. 1251-1274
9. Chittenden, L.M., Schertz, K.F., Lin, Y., Wing, R.A., Paterson, A.H., RFLP mapping of a cross between Sorghum bicolor and S. propinquum, suitable for high-density mapping, suggests ancestral duplication of Sorghum chromosomes (1994) Theor Appl Genet, 87, pp. 925-933
10. Delhaize, E., Ryan, P.R., Aluminum toxicity and tolerance in plants (1995) Plant Physiol, 107, pp. 315-321
11. Delhaize, E., Ryan, P.R., Randall, P.J., Aluminum tolerance in wheat (Triticum aestivum L.). Aluminum stimulated excretion of malic acid from root apices (1993) Plant Physiol, 103, pp. 695-702
12. (1991) The Production yearbook, , FAO, Rome, Italy
13. Fageria, N.Y., Wright, R.J., Baligar, V.C., Rice cultivar response to aluminum in nutrient solution (1988) Commun Soil Sci Plant Anal, 19, pp. 1133-1142
14. Foy, C.D., Effect of aluminum on plant growth (1974), pp. 601-642. , Carson EW (ed) The plant root and its environment. University Press of Virginia, Charlottesville, VirginiaFoy, C.D., Effect of nutrient deficiencies and toxicities in plants: Acid soil toxicity (1982) Manuscript for handbook of nutrition and food, , CRC Press, Boca Raton, Florida
15. Foy, C.D., (1982) Effects of soil acidity on plants, , Invited contribution to an EPA "Acidic Deposition Critical Assessment Document" prepared under a cooperative agreement between EPA and North Carolina State University, Raleigh, North Carolina (available from author)
16. Foy, C.D., The physiology of plant adaptation to mineral stress (1983) Iowa State J Res, 57, pp. 355-391
17. Foy, C.D., Chaney, R.L., White, M.C., The physiology of metal toxicity in plants (1978) Annu Rev Plant Physiol, 29, pp. 511-566
18. Gallego, F.J., Benito, C., Genetic control of aluminum tolerance in rye (Secale cereale L.) (1997) Theor Appl Genet, 95, pp. 393-399
19. Gallego, F.J., Calles, B., Benito, C., Molecular markers linked to the aluminium tolerance gene Alt1 in rye (1998) Theor Appl Genet, 97, pp. 1104-1109
20. Gassmann, W., Schrocder, J.I., Inward-rectifying K+ channels in root hairs of wheat. A mechanism for aluminum- sensitive low affinity K+ uptake (1994) Plant Physiol, 105, pp. 1399-1408
21. Howeler, R.H., Cadavid, L.F., Screening of rice cultivars for tolerance to Al-toxicity in nutrient solutions as compared with a field screening method (1976) Agronomy J, 68, pp. 551-555
22. Huang, J.W., Pellet, D.M., Papernik, L.A., Kochian, L.V., Aluminum interactions with voltage-dependent calcium transport in plasma membrane vesicles isolated from roots of aluminum-sensitive and tolerant wheat cultivars (1993) Plant Physiol, 102, pp. 85-93
23. Johnson, J.P., Carver, B.F., Baligar, V.C., Expression of aluminum tolerance transferred from Atlas 66 to hard winter wheat (1997) Crop Sci, 37, pp. 103-108
24. Khatiwada, S.P., Senadhira, D., Carpena, A.L., Zeigler, R.S., Fernandez, P.G., Variability and genetics of tolerance for aluminum toxicity in rice (Oryza sativa L.) (1996) Theor Appl Genet, 93, pp. 738-744
25. Kochian, L.V., Cellular mechanisms of aluminum toxicity and resistance in plants (1995) Annu Rev Plant Physiol Plant Mol Biol, 46, pp. 237-260
26. Kosambi, D.D., The estimation of map distances from recombination values (1994) Ann Eugen, 12, pp. 172-175

27. Lander, E.S., Botstein, D., Mapping Mendelian factor underlying quantitative traits using RFLP linkage maps (1989) Genetics, 121, pp. 185-199
28. Lander, E.S., Green, P., Abrahamson, J., Barlow, A., Daly, M.J., Lincoln, S.E., Newburg, L., MAPMAKER: An interactive computer package for constructing primary genetic linkage maps of experimental and natural populations (1987) Genomics, 1, pp. 174-181
29. Larsen, P.B., Tai, C.Y., Kochian, L.V., Howell, S.H., Arabidopsis mutants with increased sensitivity to aluminum (1996) Plant Physiol, 110, pp. 743-751
30. Li, Z., Pinson, S.R.M., Stansel, J.W., Park, W.D., Identification of quantitative trait loci (QTLs) for heading date and plant height in cultivated rice (Oryza sativa L.) (1995) Theor Appl Genet, 91, pp. 374-381
31. Lima, M., Furlani, P.R., Miranda, J.B., Divergent selection for aluminum tolerance in a maize (Zea mays L.) population (1992) Maydica, 37, pp. 123-132
32. Lincoln, S.E., Daly, M.J., Lander, E.S., Mapping genes controlling quantitative traits with MAPMAKER/QTL 1.1 (1992) White-head Institute Tech Rep, 2nd edn., , Cambridge, Massachusetts
33. Luo, M.C., Dvorak, J., Molecular mapping of an aluminum toerance locus on chromosome 4D of Chinese Spring Wheat (1996) Euphytica, 91, pp. 31-35
34. Magnavaca, R., Gardiner, C.O., Clark, R.B., Inheritance of aluminum tolerance in maize (1987), pp. 201-212. , Gabelman HW, Loughman BC (eds) Genetic aspects of plant mineral nutrition. Nijhoff, Dordrecht, The NetherlandsMassot, N., Poschenrieder, C., Barcelo, J., Differential response of three bean (Phaseolus vulgaris) cultivars to aluminum (1992) Acta Bot Neerl, 41, pp. 293-298
35. Matsumoto, H., Biochemical mechanism of the toxicity of aluminum and the sequestration of aluminium in the plant cell (1991), pp. 825-838. , Wright RJ, Baligar VC, Murrmenn RP (eds) Plant-soil interaction at low pH. Kluwer Academic, Dordrecht, The NetherlandsMcCouch, S.R., Tanksley, S.D., Development and use of restriction fragment length polymorphism in rice breeding and genetics (1991), pp. 83-107. , Khush GS, Toenniessen GH (eds) Rice Biotechnology, CAB Int. Wallingford, UKMoon, D.H., Ottoboni, L.M.M., Souza, A.P., Sibov, S.T., Gaspar, M., Arruda, P., Somaclonal-variation-induced aluminum-sensitive mutant from an aluminum-inbred maize tolerant line (1997) Plant Cell Rep, 16, pp. 686-691
36. Morimura, S., Taakahashi, E., Matsumoto, H., Association of aluminum with nucleic and inhibition of cell division in onion (Allium opa) roots (1978) Z Pflanzenernahr Bodenk, 88, pp. 395-401
37. Naidoo, G., Steward, J.Mc.D., Lewis, R.J., Accumulation sites of Al in smapbean and cotton roots (1978) Agron J, 70, pp. 489-492
38. Pan, W.L., Hopkin, A.G., Jackson, W.A., Aluminum inhibition of shoot lateral branches of Glycine max and reversal by exogenous cytokinin (1989) Plant Soil, 120, pp. 1-9
39. Paterson, A.H., Lander, E.S., Hewitt, J.D., Peterson, S., Lincoln, S.E., Tanksley, S.D., Resolution of quantitative traits into Mendelian factors by using a complete linkage map of restriction fragment length polymorphisms (1988) Nature, 335, pp. 721-726
40. Rangel, Z., Role of calcium in aluminum toxicity (1992) New Phytol, 121, pp. 499-513
41. Rengel, Z., Disturbance of cell Ca2+ homeostasis as a primary trigger of the Al toxicity syndrome (1992) Plant Cell Environ, 15, pp. 931-938
42. Rhue, R.D., Grogan, C.O., Stockmeyer, E.W., Everett, H.L., Genetic control of aluminum tolerance in corn (1978) Crop Sci, 18, pp. 1063-1067
43. Riede, C.R., Anderson, J.A., Linkage of RFLP markers to an aluminum tolerance gene in wheat (1996) Crop Sci, 36, pp.

905-909

44. Ryan, P., Shadd, J.E., Kochian, L.V., Aluminum toxicity in root: Correlation among ionic current, ion fluxes, and root elongation in aluminum-sensitive and aluminum-tolerant wheat cultivars (1992) Plant Physiol, 99, pp. 1193-1200
45. Ryan, P., Di Tomaso, J., Kochian, L.V., Aluminum toxicity in roots: An investigation of spatial sensitivity and role of the root cap (1993) J Exp Bot, 44, pp. 437-446
46. Sanchez, P.A., Salinas, J.G., Low-input technology for managing oxisols and ultisols in tropical America (1981) Adv Agron, 34, pp. 279-406
47. (1987) SAS/STAT guide for personal computer, version 6, , SAS Institute, Cary, Norh Carolina
48. Sivaguru, M., Paliwal, K., Differential aluminum tolerance on some tropical rice cultivars. I. Growth performance (1993) J Plant Nutr, 16, pp. 1705-1716
49. Sivaguru, M., James, M.R., Anbudurai, P.R., Balakumar, T., Characterization of differential aluminum tolerance among rice genotypes cutivated in South India (1992) J Plant Nutr, 15, pp. 233-246
50. De Sousa, C.N.A., Classification of Brazilian wheat cultivars for aluminum toxicity in acid soils (1998) Plant Breed, 117, pp. 217-221
51. Taylor, G.J., The physiology of aluminum phytotoxicity (1988), 24, pp. 123-163. , Sigel H (ed) Metal ions in biogical systems. Aluminum and its role in Biology. Marcel Dekker, New YorkTaylor, G.J., Current views of the aluminum stress response: The physiological basis of tolerance (1991) Curr Top Plant Biochem Physiol, 10, pp. 57-93
52. Urrea-Gomez, R., Ceballos, H., Pandey, S., Antonio, F.C., Filho, B., Leon, L.A., A greenhouse screening technique for acid soil tolerance in maize (1996) Agron J, 88, pp. 806-812
53. Wallace, S.U., Anderson, I.C., Aluminum toxicity and DNA synthesis in wheat roots (1984) Agron J, 76, pp. 5-8
54. Wu, P., Zhao, B., Yan, J., Luo, A., Wu, Y., Senadihra, D., Genetic control of seedling tolerance to aluminum toxicity in rice (1997) Euphytica, 97, pp. 289-293
55. Yoshida, S., Forno, D.A., Cock, J.A., Gomez, K.A., (1976) Laboratory manual for physiological studies of rice, 3rd edn., , International Rice Research Institute. Los Banos, The Phillippines
56. Zhao, X.J., Sucoff, E., Stadelmann, E.J., Al3+ and Ca2+ alteration of membrane permeability of Quercus rubra root cortex cells (1987) Plant Physiol, 83, pp. 159-162