Ameliorative effect of melatonin against gamma-irradiation-induced oxidative stress and tissue injury

El-Missiry, MA (El-Missiry, M. A.); Fayed, T. A. (Fayed, T. A.);
El-Sawy, MR (El-Sawy, M. R.); El-Sayed, AA (El-Sayed, A. A.)
[1] Mansoura Univ, Fac Sci, Dept Zool, Mansoura 35516, Egypt
E-mail Address: maelmissiry@yahoo.com

Abstract

While radiation hazards, due to free radical generation, present an enormous challenge for biological and medical safety, melatonin is a potent scavenger of a variety of free radicals. The aim of this study was to investigate the radioprotective effect of melatonin against oxidative stress and tissue injury induced by gamma radiation. Rats were subjected to two doses of 2 and 4Gy from cesium-137 source. Four days prior to irradiation, animals received melatonin daily (10mg/kg body weight i.p.). In the irradiated animals, the oxidative stress markers malondialdehyde (MDA) and protein carbonyl were significantly increased in the liver, while a marked decrease in hepatic contents of DNA, RNA, and glutathione (GSH) as well as activity of glutathione-S-transferase (GST) was demonstrated. In addition, catalase (CAT) activity was increased in the liver 5 days after irradiation. The levels of total lipids, cholesterol, triglyceride (TG), low-density lipoprotein (LDL), urea, and creatinine, as well as activities of aspartate aminotransferase (AST), alkaline phosphatase (ALP), and gamma-glutamyltransferase (GGT), were significantly increased in sera of the irradiated rats. This is coupled with decreased serum levels of high-density lipoprotein (HDL), total protein and albumin, and total globulins by irradiation. The administration of melatonin alone daily for 4 days caused significant decreases in MDA and protein carbonyl content and produced significant elevations of GSH content and GST activity in the liver. Moreover, significant decreases in total lipids, cholesterol, and TG without change in LDL or HDL levels in serum were demonstrated. Treatment with melatonin for 4 days before acute irradiation significantly abolished radiation-induced elevations in MDA and protein carbonyl levels in the liver and significantly maintained hepatic GSH content, GST, and CAT activities close to the control values. Preirradiation treatment with melatonin showed significantly higher hepatic DNA and RNA contents than irradiated rats. The levels of total lipids, cholesterol, TG, HDL, LDL, total proteins, albumin, total globulins, creatinine, and urea, as well as the activities of AST, ALT, and GGT in serum were significantly ameliorated when melatonin was injected before irradiation. In conclusion, the increase in oxidative stress markers and the concomitant change in antioxidant levels indicate the role of oxidative stress in radiation-induced tissue damage. Moreover, melatonin shows a radioprotective impact against ionizing-

radiation-induced oxidative stress and organ injury.

Keywords: Melatonin; radiation; radioprotection; antioxidants; oxidative stress; liver

Published In: ECOTOXICOLOGY AND ENVIRONMENTAL SAFETY **Volume:** 66 **Issue:** 2 **Pages:** 278-286 **DOI:** 10.1016/j.ecoenv.2006.03.008 **Published:** FEB 2007

References

1. Agrawal et al., 2001A. Agrawal, D. Chandra, R.K. Kale. Radiation induced oxidative stress. II. Studies in liver as a distant organ of tumor bearing mice.Mol. Cellul. Biochem., 224 (2001), pp. 9–17

2. Ahlers et al., 1997I. Ahlers, P. Solar, E. Ahlersova, M. Kassayova, B. Smajda. The influence of melatonin in metabolic changes in female rats induced by continuous irradiation and/or administration of 7, 12-dimethylbenz/a/anthracene Neoplasma, 44 (1997), pp. 253–257

3. Ahlersova et al., 1998E. Ahlersova, B. Pastorova, M. Kassayova, I. Ahlers, B. Smajda Reduced pineal melatonin biosynthesis in fractionally irradiated rats Physiol. Res., 47 (2) (1998), pp. 133–136

4. Allegra et al., 2003M. Allegra, R.J. Reiter, D.X. Tan, C. Gentile, L. Tesoriere, M.A. Livrea. The chemistry of melatonin's interaction with reactive species J. Pineal Res., 34 (2003), pp. 1–10

5. Badr et al., 1999F.M. Badr, O.H. El-Habit, M.M. Harraz .Radioprotective effect of melatonin assessed by measuring chromosomal damage in mitotic and meiotic cells. Mutat. Res., 444 (1999), pp. 367–372

6. Balkan et al., 2004J. Balkan, G. Sener, U. Cevikbas, M. Keyer-Uysal, M. Uysal. Melatonin improved the disturbances in hepatic prooxidant and antioxidant balance and hepatotoxicity induced by a high cholesterol diet in C57BL/6J mice. Int. J. Vitamin Nutr. Res., 74 (5) (2004), pp. 349–354

7. Bandyopadhyay, 2001D. Bandyopadhyay, K. Biswas, M. Bhattcharyya, R.J. Reiter, K. Banerjee. Gastric toxicity and mucosal ulceration induced by oxygen-derived reactive species: protection by melatonin. Curr. Mol. Med., 1 (2001), pp. 501–513

8. Baynes, 1991J.W. Baynes. Role of oxidative stress in the development of

complication in diabetes. Diabetics, 40 (1991), pp. 405–412

9. Beutler, 1982E. Beutler. Red cell metabolism.E. Butler (Ed.), A Manual of Biochemical Methods, Grune and Stratton, New York (1982), p. 137

10. Bhatia and Manda, 2004A.L. Bhatia, K. Manda. Study on pre-treatment of melatonin against radiation-induced oxidative stress in mice. Environ. Toxicol. Pharmacol., 18 (2004), pp. 13–20

11. Biaglow et al., 2003J.E. Biaglow, I.S. Ayene, C.J. Koch, J. Donahue, T.D. Stamato, J.J. Mieyal, S.W. Tuttle. Radiation response of cells during altered protein thiol redox Radiat. Res., 159 (4) (2003), pp. 484–494

12. Bock et al., 1980P.P. Bock, R. Karmer, M. Paverka .A simple assay for catalase determination. Cell Biol. Monogr., 7,44-47 (1980)

13. Box and Maccubbin, 1997H.C. Box, A.E. Maccubbin. Lipid peroxidation and DNA damage. Nutrition, 13 (10) (1997), pp. 920–921

14. Breen and Murphy, 1995A.P. Breen, J.A. Murphy. Reactions of oxyradicals with DNA. Free Radical Biol. Med., 18 (1995), pp. 1033–1077

15. Brown et al., 1998K.E. Brown, M.T. Kinter, T.D. Oberley, M.L. Freeman, H.F. Frierson, L.A. Ridnour, Y. Tao, L.W. Oberley, D.R. Spitz. Enhanced -glutamyl transpeptidase expression and selective loss of Cu–Zn superoxide dismutase in hepatic iron overload. Free Radical Biol. Med., 24 (4) (1998), pp. 545–555

16. Burkhardt et al., 2001S. Burkhardt, R.J. Reiter, D.X. Tan, R. Hardeland, J. Cabrera, M. Karbownik. DNA oxidatively damaged by chromium (III) and H2O2 is protected by the antioxidants melatonin, N-acetyl-N-formyl-methoxykynuramine, resveratrol and uric acid. Int. J. Biochem. Cell Biol., 33 (2001), pp. 775–783

17. Burton, 1956K. Burton. A study of the conditions and mechanism of the diphenylamine reaction for the colorimetric estimation of deoxyribonucleic acid. Biochem. J., 62 (1956), p. 315

18. Cadet et al., 2004J. Cadet, S. Bellon, T. Douki, S. Frelon, D. Gasparutto, E. Muller, J.P. Pouget, J.L. Ravanat, A. Romieu, S. Sauvaigo. Radiation-induced DNA damage: formation, measurement, and biochemical features.J. Environ. Pathol. Toxicol. Oncol., 23 (1) (2004), pp. 33–43

19. Cuzzocrea and Reiter, 2001S. Cuzzocrea, R.J. ReiterPharmacological action of

melatonin in shock, inflammation and ischemia/reperfusion injury. Eur. J. Pharmacol., 426 (2001), pp. 1–10

20. Dean et al., 1997R.T. Dean, S. Fu, R. Stocker, M.J. Davies. Biochemistry and pathology of radical mediated protein oxidation. Biochem. J., 324 (1997), pp. 1–18

21. Djavaheri-Mergny et al., 2002M. Djavaheri-Mergny, M.J. Accaoui, D. Rouillard, J. Wietzerbin. Gamma-glutamyl transpeptidase activity mediates NF-kappaB activation through lipid peroxidation in human leukemia U937 cells. Mol. Cell Biochem., 232 (1–2) (2002), pp. 103–111

22. El-Missiry, 2000M.A. El-Missiry. Prophylactic effect of melatonin on lead-induced inhibition of haem biosynthesis and deterioration of antioxidant system in male rats. J. Biochem. Mol. Toxicol., 14 (2000), pp. 75–82

23. El-Missiry and Abdel Aziz, 2000M.A. El-Missiry, A. Abdel Aziz: Influence of melatonin on proliferation and antioxidant system in Ehrlich ascites carcinoma cells. Cancer Lett., 151 (2000), pp. 125–199

24. El-Missiry et al., 2004M.A. El-Missiry, A.I. Othman, M.A. Amer.l-Arginine ameliorates oxidative stress in alloxan-induced experimental diabetes mellitus J. Appl. Toxicol., 24 (2004), pp. 93–97

25. El-Sokkary et al., 2002G.H. El-Sokkary, H.M. Omar, A.F. Hassanein. Melatonin reduces oxidative damage and increases survival of mice infected with Schistosoma mansoni. Free Radical Biol. Med., 32 (2002), pp. 319–332

26. Esterbauer, 1996H. Esterbauer. Estimation of peroxidative damage: a critical review. Pathol. Biol. Paris, 44 (1996), pp. 25–28

27. Fang et al., 2002Y. Fang, S. Yang, G. Wu. Free radicals, antioxidants, and nutrition

28. Feurgard et al., 1999C. Feurgard, N. Boehler, J. Ferezou, C. Serougne, J. Aigueperse, P. Gourmelon, C. Lutton, D. Mathe. Ionizing radiation alters hepatic cholesterol metabolism and plasma lipoproteins in Syrian hamster.Int. J. Radiat. Biol., 75 (6) (1999), pp. 757–766

29. Habig et al., 1974W.H. Habig, M.J. Pabst, W.B. Jakoby Glutathione-S-transferase the first enzyme step in mercapturic acid formation. J. Biol. Chem., 1 (24) (1974), pp. 7139–7150

30. Halliwell, 1992B. Halliwell. Reactive oxygen species and the central nervous system. J. Neurochem., 59 (1992), p. 1609

31. Halliwell and Whiteman, 2004B. Halliwell, M. Whiteman. Measuring reactive species and oxidative damage in vivo and in cellculture: how should you do it and what do the results mean.Br. J. Pharmacol., 142 (2004), pp. 231–255

32. Jagetia et al., 2003G.C. Jagetia, G.K. Rajanikant, K. Shaival, M. Rao, S. Baliga. Alteration in the glutathione, glutathione peroxidase, superoxide dismutase and lipid peroxidation by ascorbic acid in the skin of mice exposed to fractionatedradiation. Clin. Chim. Acta, 332 (2003), pp. 111–121

33. Kamat et al., 2000J.P. Kamat, K.K. Boloor, T.P.A. Devasagayam, S.R. Venkatachalam. Antioxidant properties of Asparagus racemosus against damage induced by -radiation in rat liver mitochondria. J. Ethnopharmacol., 71 (2000), pp. 425–435

34. Karbownik and Reiter, 2000M. Karbownik, R.J. Reiter. Antioxidative effects of melatonin in protection against cellular damage caused by ionizingradiation. Proc. Soc. Exp. Biol. Med., 225 (2000), pp. 9–22

35. Kaya et al., 1999H. Kaya, N. Delibas, M. Serteser, E. Ulukaya, O. Ozkaya. The effect of melatonin on lipid peroxidation during radiotherapy in female rats. Strahlenther Onkol., 175 (1999), pp. 285–288

36. Kehrer and Lund, 1994J.P. Kehrer, L.G. Lund. Cellular reducing equivalents and oxidative stress

37. Kilanczyk and Bryszewska, 2003E. Kilanczyk, M. Bryszewska. The effect of melatonin on antioxidant enzymes in human diabetic skin fibroblasts. Cell. Mol. Biol. Lett., 8 (2) (2003), pp. 333–336

38. Kim and Lee, 2000J.K. Kim, C.J. Lee. Effect of exogenous melatonin on the ovarian follicles in irradiated mouse. Mutat. Res., 449 (2000), pp. 33–39

39. Koc et al., 2003aM. Koc, S. Taysi, M.E. Buyukokuroglu, N. Bakan. The effect of melatonin against oxidative damage during total-body irradiation in rats. Radiat. Res., 160 (2003), pp. 251–255

40. Koc et al., 2003bM. Koc, S. Taysi, M.E. Buyukokuroglu, N. Bakan. Melatonin protects rat liver against irradiation-induced oxidative injury.J. Radiat. Res., 44 (2003), pp. 211–215

41. Le Maire et al., 1990M. Le Maire, L. Thauvette, B. De foresta, A. Viel, G. Beauregard, M. Poitier. Effect of ionizing radiation on proteins: evidence of nonrandom fragmentation and caution in the use of the method for determination of molecular mass. Bichem. J., 267 (1990), pp. 431–439

42. Lee et al., 2002D.H. Lee, M.H. Ha, J.R. Kim, M. Gross, D.R. Jacobs-Glutamyltransferase, alcohol, and blood pressure: a four year follow-up study. Ann. Epidemiol., 12 (2002), pp. 90–96

43. Lee et al., 2004aD.H. Lee, R. Blomhoff, D. Jacobs Jr.Is serum gamma glutamyltransferase a marker of oxidative stress? Free Radical Res., 38 (6) (2004), pp. 535–539

44. Lee et al., 2004bD.H. Lee, M. Gross, D.R. Jacobs: The association of serum carotenoids and tocopherols with gamma glutamyltransferase: the CARDIA study. Clin. Chem., 50 (2004), pp. 582–588

45. Levine et al., 1990R.L. Levine, D. Garland, C.N. Oliver, A. Amici, I. Climent, A.G. Lenz, B.W. Ahn, S. Shaltiel, E.R. Stadtman. Determination of carbonyl content in oxidatively modified proteins. Methods Enzymol., 186 (1990), pp. 464–478

46. Lewin, 1976S. Lewin. Vitamin C: Its Molecular Biology and Medical Potential. Academic Press, New York (1976)

47. Mary et al., 2002N.K. Mary, B.S. Shylesh, B.H. Babu, J. Padikkala. Antioxidant and hypolipidaemic activity of a herbal formulation—liposem. Indian J. Exp. Biol., 40 (8) (2002), pp. 901–906

48. Meneghini, 1997R. Meneghini. Iron homeostasis, oxidative stress, and DNA damage. Free Radical Biol. Med., 23 (5) (1997), pp. 783–792

49. Menendez-Pelaez and Reiter, 1993A. Menendez-Pelaez, R.J. Reiter. Distribution of melatonin in mammalian tissues: the relative importance of nuclear versus cytosolic localization.J. Pineal Res., 15 (2) (1993), pp. 59–69

50. Mohan et al., 1995N. Mohan, K. Sadeghi, R.J. Reiter, M.L. Meltz. The neurohormn melatonin inhibits cytokine, mitogen and ionizing radiation induced NF-kappa B. Biochem. Mol. Biol. Int., 27 (1995), pp. 1063–1070

51. Muller-Wieland, 1994D. Muller-Wieland, B. Behnke, K. Koopmann, W. Krone. Melatonin inhibits LDL receptor activity and cholesterol synthesis in freshly isolated human mononuclear leukocytes. Biochem. Biophys. Res. Commun., 203

(1) (1994), pp. 416–421

52. Ohkawa et al., 1979H. Ohkawa, N. Ohishi, K. Yagi. Assay for lipid peroxides in animal tissues by thiobarbituric acid reaction. Anal. Biochem., 95 (1979), pp. 351–358

53. Okatani et al., 2003Y. Okatani, A. Wakatsuki, R.J. Reiter, H. Enzan, Y. Miyahara. Protective effect of melatonin against mitochondrial injury induced by ischemia and reperfusion of rat liver. Eur. J. Pharmacol., 469 (2003), pp. 145–147

54. Onody et al., 2003A. Onody, C. Csonka, Z. Giricz, P. Ferdinandy. Hyperlipidemia induced by a cholesterol-rich diet leads to enhanced peroxynitrite formation in rat hearts. Cardiovasc. Res., 58 (3) (2003), pp. 663–670

55. Othman et al., 2001A.I. Othman, M.A. El-Missiry, M.A. Amer. The protective action of melatonin on indomethacin-induced gastric and testicular oxidative stress in rats. Redox Rep., 6 (2001), pp. 173–177

56. Othman et al., 2004A.I. Othman, S. Al-Sharawy, M.A. El-Missiry. Role of melatonin in ameliorating lead induced haematotoxicity. Pharmacol. Res., 50 (2004), pp. 301–307

57. Petersen and Doorn, 2004D.R. Petersen, J.A. Doorn. Reactions of 4-hydroxynonenal with proteins and cellular targets. Free Radical Biol. Med., 37 (7) (2004), pp. 937–945

58. Reiter, 1993R. Reiter. Interactions of the pineal hormone melatonin with oxygen-centered free radicals: a brief review. Braz. J. Med. Biol. Res., 26 (1993), pp. 1141–1155

59. Reiter, 2003R.J. Reiter. Melatonin: clinical relevance. Best Pract. Res. Clin. Endocr. Metab., 17 (2) (2003), p. 273285

60. Reiter et al., 2000aR.J. Reiter, J.R. Calvo, M. Karbownik, W. Qi, D.X. Tan. Melatonin and its relation to the immune system and inflammation. Ann. NY Acad. Sci., 917 (2000), pp. 376–386

61. Reiter et al., 2000bR.J. Reiter, D.X. Tan, C. Osuna, E. Gitto. Actions of melatonin in the reduction of oxidative stress: a review. J. Biomed. Sci., 7 (2000), pp. 444–458

62. Reiter et al., 2001R.J. Reiter, D.X. Tan, L.C. Manchester, W. Qi. Biochemical reactivity of melatonin with reactive oxygen and nitrogen species. A review of

the evidence. Cell Biochem. Biophys., 34 (2001), pp. 237–256

63. Reiter et al., 2004R.J. Reiter, D.X. Tan, E. Gitto, R.M. Sainz, J.C. Mayo, J. Leon, L.C. Manchester, Vijayalaxm, E. Kilic, U. Kilic. Pharmacological utility of melatonin in reducing oxidative cellular and molecular damage. Pol. J. Pharmacol., 56 (2) (2004), pp. 159–170

64. Rodriguez et al., 2004C. Rodriguez, J.C. Mayo, R.M. Sainz, I. Antolin, F. Herrera, V. Martin, R.J. Reiter. Regulation of antioxidant enzymes: a significant role of melatonin. J. Pineal Res., 36 (2004), pp. 1–9

65. Rodriguez-Reynoso et al., 2004S. Rodriguez-Reynoso, C. Leal, E. Portilla-de Buen, J.C. Castillo, F. Ramos-Solano. Melatonin ameliorates renal ischemia/reperfusion injury. J. Surg. Res., 116 (2) (2004), pp. 242–247

66. Samanta et al., 2004N. Samanta, K. Kannan, M. Bala, H.C. Goel. Radioprotective mechanism of Podophyllum hexandrum during spermatogenesis. Mol. Cell Biochem., 267 (1–2) (2004), pp. 167–176

67. Schnell et al., 2001J.W. Schnell, R.A. Anderson, J.E. Stegner, S.P. Schindler, R.B. Weinberg. Effects of a high polyunsaturated fat diet and vitamin E supplementation on high-density lipoprotein oxidation in humans. Atherosclerosis, 159 (2001), pp. 459–466

68. Scott et al., 1989M.D. Scott, S.R. Meshnick, J.W. Eaton. Superoxide dismutase amplifies organismal sensitivity to ionizing radiation. J. Biol. Chem., 264 (1989), pp. 2498–2510

69. Sener et al., 2003G. Sener, N. Jahovic, O. Tosun, B.M. Atasoy, B. Yegen. Melatonin meliorates ionizing radiation-induced oxidative organ damage in rats. Life Sci., 74 (2003), pp. 563–572

70. Sener et al., 2004G. Sener, K. Paskaloglu, H. Toklu, C. Kapucu, G. Ayanoglu-Dulger, A. Kacmaz, A. Sakarcan. Melatonin ameliorates chronic renal failure-induced oxidative organ damage in rats.J. Pineal Res., 36 (4) (2004), pp. 232–241

71. Sridharan and Shyamaladevi, 2002S. Sridharan, C.S. Shyamaladevi. Protective effect of N-acetylcysteine against gamma ray induced damages in rats—biochemical evaluations. Indian J. Exp. Biol., 40 (2) (2002), pp. 181–186

72. Stadtman and Berlett, 1997E.R. Stadtman, B.S. Berlett. Reactive oxygen mediated protein oxidation in aging and disease. Chem. Res. Toxicol., 10 (1997), pp. 485–490

73. Sun et al., 1998J. Sun, Y. Chen, M. Li, Z. Ge. Role of antioxidant enzymes on ionizing radiation resistance. Free Radical Biol. Med., 24 (1998), pp. 586–593

74. Tan et al., 1993D.X. Tan, L.D. Chen, B. Poeggeler, L.C. Manchester, R.J. Reiter. Melatonin: a potent endogenous hydroxyl radical scavenger. Endocr. J., 1 (1993), pp. 57–60

75. Tan et al., 2000aD.X. Tan, L.C. Manchester, R.J. Reiter, B.F. Plummer, J. Linson, S.T. Weintraub, W. Qi. Melatonin directly scavenges hydrogen peroxide: a potentially new metabolic pathway of melatonin biotransformation. Free Radical Biol. Med., 29 (2000), pp. 1177–1185

76. Tan et al., 2000bD.X. Tan, L.C. Manchester, R.J. Reiter, W.B. Qi, M. Karbowink, J.R. Calvo. Significance of melatonin in antioxidiative defense system: reactions and products. Biol. Signals Recept., 9 (2000), pp. 137–140

77. Tan et al., 2001D.X. Tan, L.C. Manchester, S. Burkardt, R.M. Sainz, J.C. Mayo, R. Kohen, E. Shohami, Y.S. Huo, R. Hardeland, R.J. Reiter .N-acetyl-N-formyl-5-methoxyknuramine, a biogenic amine and melatonin metabolite, functions as a potent antioxidant. FASEB J., 15 (2001), pp. 2294–2296

78. Taysi et al., 2003S. Taysi, M. Koc, M.E. Buyukokuroglu, K. Altinkaynak, Y.N. Sahin. Melatonin reduces lipid peroxidation and nitric oxide during irradiation-induced oxidative injury in the rat liver. J. Pineal Res., 34 (2003), pp. 173–177

79. Tesoriere et al., 1999L. Tesoriere, D. D'Arpa, S. Conti, V. Giaccone, A.M. Pintaudi, M.A. Livrea. Melatonin protects human red blood cells from oxidative haemolysis: new insights into the radical-scavenging activity. J. Pineal Res., 27 (1999), pp. 95–105

80. Thoresen et al., 1983S.S. Thoresen, J.R. Clayton, Q.F. Dortch, S.L. Ahmed. A rapid technique for the determination of RNA and DNA in marine phytoplankton. J. Plankton Res., 5 (1983), pp. 253–261

81. Tomas-Zapico and Coto-Montes, 2005C. Tomas-Zapico, A. Coto-Montes. A proposed mechanism to explain the stimulatiory effect of melatonin on antioxidative enzymes. J. Pineal Res., 39 (2005), pp. 99–104

82. Undeger et al., 2004U. Undeger, B. Giray, A.F. Zorlu, K. Oge, N. Bacaran. Protective effects of melatonin on the ionizing radiation induced DNA damage in the rat brain. Exp. Toxicol. Pathol., 55 (5) (2004), pp. 379–384

83. Urata et al., 1999Y. Urata, S. Honma, S. Goto, S. Todoroki, T. Iida, S. Cho, K. Honma, T. Kondo.Melatonin induces gamma-glutamylcysteine synthetase mediated by activator protein-1 in human vascular endothelial cells. Free Radical Biol. Med., 27 (1999), pp. 838–847

84. Vijayalaxmi et al., 2004Vijayalaxmi, R.J. Reiter, D.X. Tan, T.S. Herman, C.R. Thomas. Melatonin as a radioprotective agent: a review. Int. J. Radiat. Oncol. Biol. Phys., 59 (2004), pp. 639–653

85. Ward, 1988J.F. Ward. DNA damage produced by ionizing radiation in mammalian cells: identities, mechanisms of formation, and reparability. Prog. Nucl. Acid Res. Mol. Biol., 35 (1988), pp. 95–125

86. Weiss et al., 2003J.F. Weiss, R. Michael, M.R. Landauer. Protection against ionizing radiation by antioxidant nutrients and phytochemicals. Toxicology, 189 (2003), pp. 1–20

87. Zwirska-Korczala et al., 2003K. Zwirska-Korczala, J. Jochem, B. Rybus-Kalinowska, R. Polaniak, E. Birkner. Assessment of blood superoxide dismutase, glutathione peroxidase activity and malondialdehyde concentration as oxidation status parameters in obese women. Pol. Arch. Med. Wewn., 110 (1) (2003), pp. 725–731