

zest to the overarching essence of providing a quick and easy solution to the problem of pest infestation in third world countries. There is need for further investigations to identify the other garlic juice constituents (apart from alliin) with toxic effects on *S. zeamais*, and to elucidate the precise mechanisms by which they exert their insecticidal effects.

Acknowledgements

The research leading to this publication was supported by the facility at and funding from Michael Okpara University of Agriculture, Umudike, Nigeria, the RWTH Aachen University, Germany, and the European Community's 7th Framework Programme [FP7/2007-2013] under grant agreement No. 215009. The HPLC work was done in the lab of Prof. Alan J. Slusarenko at the RWTH Aachen University. The assistance of Dr. Chukwunonso Ejike in facilitating the collaboration which resulted in this paper gratefully acknowledged.

References

- Abbott W.S. 1925. A method of computing the effectiveness of an insecticide. *J. Econ. Entomol.* 18 (2): 265–267.
- Adedire C.O. 2001. Biology, ecology and control of insect pests of stored cereal grains. p. 59–94. In: "Pests of Stored Cereals and Pulses in Nigeria" (T.I. Ofuya, N.E.S. Lale, eds.). Dave Collins Publishers, Nigeria, 174 pp.
- Adedire C.O., Ajayi T.S. 1996. Assessment of insecticidal properties of some plants as grain protectants against the maize weevil, *Sitophilus zeamais* (Motsch.). *Nig. J. Entomol.* 13: 93–101.
- Apitz-Castro R., Cabrera S., Cruz M.R., Ledezma E., Jain M.K. 1983. Effects of garlic extract and of three pure components isolated from it on human platelet aggregation, arachidonate metabolism, release reaction and platelet ultrastructure. *Thromb Res.* 32 (2): 155–169.
- Arannilewa S.T., Ekrakene T., Akinneye J.O. 2006. Laboratory evaluation of four medicinal plants as protectants against the maize weevil, *Sitophilus zeamais* Motsch. *Afr. J. Biotechnol.* 5 (21): 2032–2036.
- Asawalam E.F., Emosairue S.O. 2006. Comparative efficacy of *Piper guineense* Schum and Thonn and Pirimiphos methyl on [*Sitophilus zeamais* (Motschulsky)]. *Trop. Subtrop. Agroecosys.* 6: 143–148.
- Bautista D.M., Movahed P., Hinman A., Axelsson H.E., Sterner O. 2005. Pungent products from garlic activate the sensory ion channel TRPA1. *Proc. Natl. Acad. Sci.* 102 (34): 12248–12252.
- Block E. 1985. The chemistry of garlic and onions. *Sci. Am.* 252 (3): 94–99.
- Block E., Ahmad S., Jain M.K., Crecey R.W., Apitz-Castro R., Cruz M.R. 1984. (E, Z)-Ajoene: a potent antithrombotic agent from garlic. *J. Am. Chem. Soc.* 106 (26): 8295–8296.
- Cavallito C.J., Bailey J.H. 1944. Alliin, the antibacterial principle of *Allium sativum*. I. Isolation, physical properties and antibacterial action. *J. Am. Chem. Soc.* 66 (11): 1950–1951.
- Cavallito C.J., Buck J.S., Suter C.M. 1944. Alliin, the antibacterial principle of *Allium sativum*. II. Determination of the chemical structure. *J. Am. Chem. Soc.* 66 (11): 1952–1954.
- Curtis H., Noll U., Störmann J., Slusarenko A.J. 2004. Broad-spectrum activity of the volatile phytoanticipin alliin in extracts of garlic (*Allium sativum* L.) against plant pathogenic bacteria, fungi and Oomycetes. *Physiol. Mol. Plant Pathol.* 65 (2): 79–89.
- Fahey J.W., Zalcmann A.T., Talalay P. 2001. The chemical diversity and distribution of glucosinolates and isothiocyanates among plants. *Phytochemistry* 56 (1): 5–51.
- FAO 1985. Prevention of Post-harvest Food Losses: A Training Manual. FAO, Rome.
www.fao.org/docrep/x00039e [Accessed: September 19, 2013].
- Gonzalez-Coloma A., Reina M., Diaz C.E., Fraga B.M. 2010. Natural product-based biopesticides for insect control. p. 237–268. In: "Comprehensive Natural Products" Vol. 3. (L. Mander, H.W. Liu, eds.), Elsevier, Oxford, 1315 pp.
- Hamed R.K.A., Ahmed S.M.S., Abotaleb A.O.B., El-Sawaf B.M. 2012. Efficacy of certain plant oils as grain protectants against the rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae) on wheat. *Egypt. Acad. J. Biol. Sci.* 5 (2): 49–53.
- Ho S.H., Koh L., Ma Y., Huang Y., Sim K.Y. 1996. The oil of garlic, *Allium sativum* L. (Amaryllidaceae), as a potential grain protectant against *Tribolium castaneum* (Herbst) and *Sitophilus zeamais* Motsch. *Postharvest Biol. Technol.* 9 (1): 41–48.
- Huang Y., Chen S.X., Ho S.H. 2000. Bioactivities of methyl allyl disulfide and diallyltrisulfide from essential oil of garlic to two species of stored-product pests, *Sitophilus zeamais* (Coleoptera: Curculionidae) and *Tribolium castaneum* (Coleoptera: Tenebrionidae). *J. Econ. Entomol.* 93 (2): 537–543.
- Huang Y., Tan J.M.W., Kini S., Ho H. 1997. Toxic and antifeedant action of nutmeg oil against *Tribolium castaneum* (Herbst) and *Sitophilus zeamais* Motsch. *J. Stored Prod. Res.* 33 (4): 289–298.
- Iberl B., Winkler G., Knobloch K. 1990. Products of alliin transformation: ajoenes and dithiins, characterization and their determination by HPLC. *Planta Medica* 56 (2): 202–211.
- IITA 2009. Cereals and legumes systems: Maize.
http://old.iita.org/cms/details/maize_project_details.aspx?zoneid=63&articleid=273 [Accessed: September 20, 2013].
- Isman M.B. 2000. Plant essential oils for pest and disease management. *Crop Prot.* 19 (8–10): 603–608.
- Jain M.K., Apitz-Castro R. 1987. Garlic: molecular basis of the putative 'vampire-repellant' action and other matters related to heart and blood. *Trends Biochem. Sci.* 12 (C): 252–254.
- Jordt S.E., Bautista D.M., Chuang H.H., McKemy D.D., Zygmunt P.M., Högestätt E.D., Meng I.D., Julius D. 2004. Mustard oils and cannabinoids excite sensory nerve fibres through the TRP channel ANKTM1. *Nature* 427 (6971): 260–265.
- Krest I., Keusgen M. 2002. Biosensoric flow-through method for the determination of cysteine sulfoxides. *Chim. Acta* 469 (2): 155–164.
- Lale N.E.S. 1992. A laboratory study of the comparative toxicity of products from three spices to the maize weevil. *Postharvest Biol. Technol.* 2 (1): 61–64.
- Lalla F.D., Ahmed B., Omar A., Mohieddine M. 2013. Chemical composition and biological activity of *Allium sativum* essential oils against *Callosobruchus maculatus*. *J. Environ. Sci. Toxicol. Food Technol.* 3 (1): 30–36.
- Lee B., Annis P.C., Tumaalii F., Choi W. 2004. Fumigant toxicity of essential oils from the Myrtaceae family and 1,8-cineole against 3 major stored-grain insects. *J. Stored Prod. Res.* 40 (5): 553–564.

- Macpherson L.J., Geierstanger B.H., Viswanath V., Bandell M., Eid S.R. 2005. The pungency of garlic: activation of *TRPA1* and *TRPV1* in response to allicin. *Curr. Biol.* 15 (10): 929–934.
- Miron T., Rabinkova A., Mirelman D., Wilchek M., Weiner L. 2000. The mode of action of allicin: its ready permeability through phospholipid membranes may contribute to its biological activity. *Biochim. Biophys. Acta* 1463 (1): 20–30.
- Nwachukwu I.D., Gruhlke M.C.H., Slusarenko A.J. 2012. Sulfur and sulfur compounds in plant defence. *Nat. Prod. Commun.* 7 (3): 395–400.
- Odeyemi O.O. 1993. Insecticidal properties of certain indigenous plant oils against *Sitophilus zeamais* Mots. *Appl. Entomol. Phytopathol.* 60 (1–2): 19–27.
- Ofuya T.I., Olotuah O.F., Ogunsola O.J. 2010. Fumigant toxicity of crushed bulbs of two *Allium* species to *Callosobruchus malulatus* (Fabricius) (Coleoptera: Bruchidae). *Chilean J. Agric. Res.* 70 (3): 510–514.
- Portz D., Koch E., Slusarenko A.J. 2008. Effects of garlic (*Allium sativum*) juice containing allicin on *Phytophthora infestans* and downy mildew of cucumber caused by *Pseudoperonospora cubensis*. *Eur. J. Plant Pathol.* 122 (1): 197–206.
- Qi I.T., Burkholder W.E. 1981. Protection of stored wheat from the granary weevil by vegetable oils. *J. Econ. Entomol.* 74 (5): 502–505.
- Regnault-Roger C., Hamraoui A., Holeman M., Theron E., Pinel R. 1993. Insecticidal effect of essential oils from mediterranean plants upon *Acanthoscelides obtectus* Say (Coleoptera, Bruchidae), a pest of kidney bean (*Phaseolus vulgaris* L.). *J. Chem. Ecol.* 19 (6): 1233–1244.
- Shaaya E., Ravid U., Paster N., Juven B., Zisman U., Pissarev V. 1991. Fumigant toxicity of essential oils against four major stored-product insects. *J. Chem. Ecol.* 17 (3): 499–504.
- Slusarenko A.J., Patel A., Portz D. 2008. Control of plant diseases by natural products: Allicin from garlic as a case study. *Eur. J. Plant Pathol.* 121 (3): 313–322.
- Staba John E., Lash L., Staba Joyce E. 2001. A commentary on the effects of garlic extraction and formulation on product composition. *J. Nutr.* 131: 1118S–1119S.
- Udo I.O. 2005. Evaluation of the potential of some local spices as stored grain protectants against the maize weevil *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae). *J. Appl. Sci. Environ. Manage.* 9 (1): 165–168.
- Van Etten H.D., Mansfield J.W., Bailey J.A., Farmer E.E. 1994. Two classes of plant antibiotics: phytoalexins versus “phytoanticipins”. *Plant Cell* 6 (9): 1191–1192.
- Voigt M., Wolf E. 1986. Knoblauch: HPLC-Bestimmung von Knoblauchwirkstoffen in Extrakten, Pulver und Fertigarzneimitteln. [HPLC determination of the active ingredients in garlic extracts, powder and finished medicinal products]. *Dtsch. Apoth. Ztg.* 126: 591–593.
- Wang H., Woolf C.J. 2005. Pain TRPs. *Neuron* 46 (1): 9–12.
- Yang F-L., Zhu F., Lei C-L. 2012. Insecticidal activities of garlic substances against adults of grain moth, *Sitotroga cerealella* (Lepidoptera: Gelechiidae). *Insect Sci.* 19 (2): 205–212.
- Zhou H.Y., Zhao N.N., Du S.S., Yang K., Wang C.F., Liu Z.L., Qiao Y.J. 2012. Insecticidal activity of the essential oil of *Lonicera japonica* flower buds and its main constituent compounds against two grain storage insects. *J. Med. Plants Res.* 6 (5): 912–917.