**The Effect of Neonicotinoids on Bumblebees (Bombus spp.): A systematic Review**

**Daisy Dennis and Alexandra J. Gibbs**

**Supplementary Table S1:** Overview of core research literature used to explore the role of neonicotinoids on Bumble bees (*Bombus* spp.)

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| --- | --- | --- | --- | --- | --- |
| **Reference** | **Species** | **Neonicotinoid compound** | **Type of effect** | **Location** | **Approach** |
| Aarønes, M.R., Paus‐Knudsen, J.S., Nielsen, A., Rundberget, J.T. and Borgå, K., (2021). Within‐body distributions and feeding effects of the neonicotinoid insecticide clothianidin in bumblebees (*Bombus terrestris*). *Environmental Toxicology and Chemistry*, *40*(10): 2781-2790. doi: 10.1002/etc.5154. | *Bombus terrestris* | Clothianidin | **Physiological** | Norway | Lab |
| Arce, A.N., David, T.I., Randall, E.L., Ramos Rodrigues, A., Colgan, T.J., Wurm, Y. and Gill, R.J., (2017). Impact of controlled neonicotinoid exposure on bumblebees in a realistic field setting. *Journal of Applied Ecology*, *54*(4): 1199-1208. Doi: 10.1111/1365-2664.12792 | *Bombus terrestris audax* | Clothianidin | **Behavioral, Reproductive, Pollination Efficiency** | UK | Lab |
| Bai, L., Pan, S., Sun, Y., Shan, Y., Song, X., Wang, D., Ma, Y., Hu, H., Ren, X., Cui, J. and Ma, Y., (2025). Spatiotemporal dissipation, metabolic dynamics and bumblebees’ toxicity risk of the neonicotinoid insecticide thiacloprid in greenhouse conditions. *Journal of Hazardous Materials*, *491*:137897. Doi: 10.1016/j.jhazmat.2025.137897 | Not stated | Thiacloprid | **Survival and Mortality, Physiological** | China | Glasshouse |
| Bebane, P.S., Hunt, B.J., Pegoraro, M., Jones, A.C., Marshall, H., Rosato, E. and Mallon, E.B., (2019). The effects of the neonicotinoid imidacloprid on gene expression and DNA methylation in the buff-tailed bumblebee *Bombus* *terrestris*. *Proceedings of the Royal Society B*, *286*(1905): 20190718.http://dx.doi.org/10.1098/rspb.2019.0718 | *Bombus terrestris audax* | Imidacloprid | **Physiological** | UK | Lab |
| Bryden, J., Gill, R.J., Mitton, R.A., Raine, N.E. and Jansen, V.A., (2013). Chronic sublethal stress causes bee colony failure. *Ecology letters*, *16*(12): 1463–1469. doi: 10.1111/ele.12188 | *Bombus terrestris* | Imidacloprid | **Survival and Mortality, Reproductive** | UK | Lab |
| |  | | --- | | Camp, A.A., Batres, M.A., Williams, W.C., Koethe, R.W., Stoner, K.A. and Lehmann, D.M., (2020). Effects of the neonicotinoid acetamiprid in pollen on *Bombus impatiens* microcolony development. *Environmental toxicology and chemistry*, *39*(12): 2560–2569. doi: 10.1002/etc.4886 | |  | | *Bombus impatiens* | Acetamiprid | **Reproductive** | U.S. | Lab |
| Camp, A.A., Williams, W.C., Eitzer, B.D., Koethe, R.W. and Lehmann, D.M., (2020). Effects of the neonicotinoid acetamiprid in syrup on *Bombus impatiens* (Hymenoptera: Apidae) microcolony development. *PLoS One*, *15*(10): e0241111. doi: 10.1371/journal.pone.0241111 | *Bombus impatiens* | Acetamiprid | **Reproductive, Survival and Mortality** | U.S | Lab |
| Chole, H., de Guinea, M., Woodard, S.H. and Bloch, G., (2022). Field-realistic concentrations of a neonicotinoid insecticide influence socially regulated brood development in a bumblebee. *Proceedings of the Royal Society B*, *289*(1987) : 20220253. doi: 10.1098/rspb.2022.0253. | *Bombus terrestris* & *Bombus impatiens.* | Imidacloprid | **Reproductive, Physiological, Behavioral** | Israel | Lab |
| Colgan, T.J., Fletcher, I.K., Arce, A.N., Gill, R.J., Ramos Rodrigues, A., Stolle, E., Chittka, L. and Wurm, Y., (2019). Caste‐and pesticide‐specific effects of neonicotinoid pesticide exposure on gene expression in bumblebees. *Molecular ecology*, *28*(8): 1964-1974. doi: 10.1111/mec.15047 | *Bombus terrestris* | Clothianidin, Imidacloprid | Physiological | UK | Lab |
| Crall, J.D., Switzer, C.M., Oppenheimer, R.L., Ford Versypt, A.N., Dey, B., Brown, A., Eyster, M., Guérin, C., Pierce, N.E., Combes, S.A. and de Bivort, B.L., (2018). Neonicotinoid exposure disrupts bumblebee nest behavior, social networks, and thermoregulation. *Science*, *362*(6415): 6 83-686. doi: 10.1126/science.aat1598. | *Bombus impatiens* | Imidacloprid | **Behavioral** | U.S. | Lab |
| Ellis, C., Park, K.J., Whitehorn, P., David, A. and Goulson, D., (2017). The neonicotinoid insecticide thiacloprid impacts upon bumblebee colony development under field conditions. *Environmental science & technology*, *51*(3): 1727-1732. doi: 10.1021/acs.est.6b04791. | *Bombus terrestris audax* | Thiacloprid | **Survival and Mortality, Reproductive** | UK | Field |
| European Food Safety Authority, 2013. Evaluation of the FERA study on bumble bees and consideration of its potential impact on the EFSA conclusions on neonicotinoids. *EFSA Journal*, *11*(6): 3242. doi:10.2903/j.efsa.2013.3242 | *Bombus terrestris* | Thiamethoxam, Imidacloprid, Clothianidin | **Survival and Mortality** | UK | Field |
| Feltham, H., Park, K. & Goulson, D (2014). Field realistic doses of pesticide imidacloprid reduce bumblebee pollen foraging efficiency. *Ecotoxicology* **23**, 317–323 . doi: 10.1007/s10646-014-1189-7 | *Bombus terrestris* | Imidacloprid | **Behavioral** | UK | Lab |
| Goulson, D., (2015). Neonicotinoids impact bumblebee colony fitness in the field; a reanalysis of the UK’s Food & Environment Research Agency 2012 experiment. *PeerJ*, *3*: :e854. doi: 10.7717/peerj.854 | *Bombus terrestris audax* | Clothianidin, Imidacloprid | **Reproductive, Survival and Mortality** | UK | Lab |
| Kenna, D., Cooley, H., Pretelli, I., Ramos Rodrigues, A., Gill, S.D. and Gill, R.J., (2019). Pesticide exposure affects flight dynamics and reduces flight endurance in bumblebees. *Ecology and Evolution*, *9*(10): 5637-5650. doi: 10.1002/ece3.5143. | *Bombus terrestris audax* | Imidacloprid | **Behavioral** | UK | Lab |
| Kolano, P., Borgå, K. and Nielsen, A., (2021). Temperature sensitive effects of the neonicotinoid clothianidin on bumblebee (*Bombus terrestris*) foraging behaviour.  *Journal of Pollination Ecology*, *28*, 138–152. Doi: 10.26786/1920-7603(2021)633 | *Bombus terrestris* | Clothianidin | **Behavioral, Pollination Efficiency** | Norway | Lab |
| Lämsä, J., Kuusela, E., Tuomi, J., Juntunen, S. and Watts, P.C., (2018). Low dose of neonicotinoid insecticide reduces foraging motivation of bumblebees. *Proceedings of the Royal Society B: Biological Sciences*, *285*(1883): 20180506. Doi: 10.1098/rspb.2018.0506 | *Bombus terrestris* | Imidacloprid | **Behavioral, Pollination Efficiency** | Finland | Lab |
| Laycock, I. and Cresswell, J.E., (2013). Repression and recuperation of brood production in *Bombus terrestris* bumble bees exposed to a pulse of the neonicotinoid pesticide imidacloprid. *PloS one*, *8*(11): e79872. doi: 10.1371/journal.pone.0079872 | *Bombus terrestris* | Imidacloprid | **Reproductive** | UK | Lab |
| Laycock, I., Cotterell, K.C., O’Shea-Wheller, T.A. and Cresswell, J.E., (2014). Effects of the neonicotinoid pesticide thiamethoxam at field-realistic levels on microcolonies of *Bombus terrestris* worker bumble bees. *Ecotoxicology and environmental safety*, *100*: 153-158. doi: 10.1016/j.ecoenv.2013.10.027. | *Bombus terrestris audax* | Thiamethoxam | **Survival and Mortality, Reproductive, Behavioral** | UK | Lab |
| Laycock, I., Lenthall, K.M., Barratt, A.T. and Cresswell, J.E., (2012). Effects of imidacloprid, a neonicotinoid pesticide, on reproduction in worker bumble bees (*Bombus terrestris*). *Ecotoxicology*, *21*: 1937-1945. doi: 10.1007/s10646-012-0927-y. | *Bombus terrestris* | Imidacloprid | **Reproductive, Behavioral** | UK | Lab |
| Martín-Blázquez, R., Calhoun, A.C., Sadd, B.M. and Cameron, S.A., (2023). Gene expression in bumble bee larvae differs qualitatively between high and low concentration imidacloprid exposure levels. *Scientific reports*, *13*(1): 9415. doi: 10.1038/s41598-023-36232-y. | *Bombus impatiens* | Imidacloprid | Physiological | U.S. | Lab |
| Martínez de Castro Dubernard, A., Goulson, D., Solís-Montero, L. and Vandame, R., (2022). Effects of imidacloprid on survival and nest development in the neo-tropical bumblebee *Bombus ephippiatus*. *Apidologie*, *53*(3): 34. Doi: 10.1007/s13592-022-00946-1 | *Bombus ephippiatus* | Imidacloprid | **Survival and Mortality, Reproductive** | Mexico | Lab |
| Minnameyer, A., Strobl, V., Bruckner, S., Camenzind, D.W., Van Oystaeyen, A., Wäckers, F., Williams, G.R., Yañez, O., Neumann, P. and Straub, L., (2021). Eusocial insect declines: insecticide impairs sperm and feeding glands in bumblebees. *Science of the Total Environment*, *785*: 146955. Doi: 10.106/j.scitotenv.2021.146955 | *Bombus terrestris* | Thiamethoxam | **Reproductive** | Switzerland and U.S. | Lab |
| Moffat, C., Buckland, S.T., Samson, A.J., McArthur, R., Chamosa Pino, V., Bollan, K.A., Huang, J.T.J. and Connolly, C.N., (2016). Neonicotinoids target distinct nicotinic acetylcholine receptors and neurons, leading to differential risks to bumblebees. *Scientific reports*, *6*(1): 24764. doi: 10.1038/srep24764. | *Bombus terrestris audax* | Imidacloprid,  Thiamethoxam, Clothianidin | **Physiological Behavioral Reproductive** | UK | Lab |
| |  | | --- | | Moffat, C., Pacheco, J.G., Sharp, S., Samson, A.J., Bollan, K.A., Huang, J., Buckland, S.T. and Connolly, C.N., (2015). Chronic exposure to neonicotinoids increases neuronal vulnerability to mitochondrial dysfunction in the bumblebee (*Bombus* *terrestris*). *The FASEB Journal*, *29*(5): 2112-2119.   doi: 10.1096/fj.14-267179. | | *Bombus terrestris audax* | Imidacloprid | **Physiological, Behavioral** | UK | Lab |
| Muth, F. and Leonard, A.S., (2019). A neonicotinoid pesticide impairs foraging, but not learning, in free-flying bumblebees. *Scientific Reports*, *9*(1): 4764. doi: 10.1038/s41598-019-39701-5. | *Bombus impatiens* | Imidacloprid | Behavioral | U.S. | Lab |
| Muth, F., Francis, J.S. and Leonard, A.S., (2019). Modality-specific impairment of learning by a neonicotinoid pesticide. *Biology letters*, *15*(7): 20190359. Doi: 10.1098/rsbl.2019.0359 | *Bombus impatiens* | Imidacloprid | Behavioral | U.S. | Lab |
| Paus‐Knudsen, J.S., Sveinsson, H.A., Grung, M., Borgå, K. and Nielsen, A., (2023). The Neonicotinoid Imidacloprid Impairs Learning, Locomotor Activity Levels, and Sucrose Solution Consumption in Bumblebees (Bombus terrestris). *Environmental Toxicology and Chemistry*, *42*(6): 1337-1345. doi: 10.1002/etc.5611. | *Bombus terrestris* | Imidacloprid | **Behavioral** | Netherlands | Lab |
| Richman, S.K., Maalouf, I.M., Smilanich, A.M., Marquez Sanchez, D., Miller, S.Z. and Leonard, A.S., (2022). A neonicotinoid pesticide alters how nectar chemistry affects bees. *Functional Ecology*, *36*(4): 1063-1073. Doi: 10.1111/1365-2435.14016 | *Bombus impatiens* | Imidacloprid | **Survival and Mortality, Physiological, Behavioral** | U.S. | Lab |
| Samson-Robert, O., Labrie, G., Mercier, P.L., Chagnon, M., Derome, N. and Fournier, V., (2015). Increased acetylcholinesterase expression in bumble bees during neonicotinoid-coated corn sowing. *Scientific Reports*, *5*(1): 12636. Doi: 10.1038/srep12636 | *Bombus*  *impatiens* | Not stated | **Physiological** | Canada | Field |
| Samuelson, E.E., Chen-Wishart, Z.P., Gill, R.J. and Leadbeater, E., (2016). Effect of acute pesticide exposure on bee spatial working memory using an analogue of the radial-arm maze. *Scientific Reports*, *6*(1): 38957. Doi: 10.1038/srep38957 | *Bombus terrestris* | Thiamethoxam | **Behavioral** | UK | Lab |
| Sargent, C., Ebanks, B., Hardy, I.C., Davies, T.E., Chakrabarti, L. and Stöger, R., (2021). Acute imidacloprid exposure alters mitochondrial function in bumblebee flight muscle and brain. *Frontiers in Insect Science*, *1*: 765179. doi: 10.3389/finsc.2021.765179 | *Bombus terrestris audax.* | Imidacloprid | **Physiological, Behavioral** | UK | Lab |
| Scholer, J. and Krischik, V., (2014). Chronic exposure of imidacloprid and clothianidin reduce queen survival, foraging, and nectar storing in colonies of *Bombus impatiens*. *PLoS One*, *9*(3): e91573. doi: 10.1371/journal.pone.0091573. | Bombus impatiens | Imidacloprid,  Clothianidin | **Reproductive. Behavioral. Survival and Mortality** | U.S. | Lab |
| Simmons, W.R. and Angelini, D.R., (2017). Chronic exposure to a neonicotinoid increases expression of antimicrobial peptide genes in the bumblebee *Bombus impatiens*. *Scientific Reports*, *7*(1): 44773. doi: 10.1038/srep44773. | *Bombus impatiens* | Imidacloprid | **Physiological** | U.S. | Lab |
| Siviter, H., Johnson, A.K. and Muth, F., (2021). Bumblebees exposed to a neonicotinoid pesticide make suboptimal foraging decisions. *Environmental Entomology*, *50*(6): 1299–1303, doi: 10.1093/ee/nvab087 | *Bombus impatiens* | Imidacloprid | **Behavioral** | U.S. | Lab |
| Smith, D.B., Arce, A.N., Ramos Rodrigues, A., Bischoff, P.H., Burris, D., Ahmed, F. and Gill, R.J., (2020). Insecticide exposure during brood or early-adult development reduces brain growth and impairs adult learning in bumblebees. *Proceedings of the Royal Society B*, *287*(1922): 20192442. doi: 10.1098/rspb.2019.2442. | *Bombus terrestris audax* | Imidacloprid | **Behavioral, Physiological** | UK | Lab |
| Stanley, D.A. and Raine, N.E., (2016). Chronic exposure to a neonicotinoid pesticide alters the interactions between bumblebees and wild plants. *Functional Ecology*, *30*(7): 1132-1139. doi: 10.1111/1365-2435.12644. | *Bombus terrestris audax* | Thiamethoxam | **Behavioral, Pollination Efficiency** | UK | Lab |
| Stanley, D.A. and Raine, N.E., (2017). Bumblebee colony development following chronic exposure to field-realistic levels of the neonicotinoid pesticide thiamethoxam under laboratory conditions. *Scientific reports*, *7*(1): 8005. doi: 10.1038/s41598-017-08752-x. | *Bombus terrestris* | Thiamethoxam | **Reproductive. Survival and Mortality** | UK | Lab |
| Stanley, D.A., Garratt, M.P., Wickens, J.B., Wickens, V.J., Potts, S.G. and Raine, N.E., (2015). Neonicotinoid pesticide exposure impairs crop pollination services provided by bumblebees. *Nature*, *528*(7583): 548-550. Doi: 10.1038/nature16167. | *Bombus terrestris audax* | Thiamethoxam | **Pollination Efficiency, Behavioral** | UK | Field |
| Stanley, D.A., Russell, A.L., Morrison, S.J., Rogers, C. and Raine, N.E., (2016). Investigating the impacts of field‐realistic exposure to a neonicotinoid pesticide on bumblebee foraging, homing ability and colony growth. *Journal of Applied Ecology*, *53*(5): 1440-1449. doi: 10.1111/1365-2664.12689. | *Bombus terrestris audax* | Thiamethoxam | **Behavioral, Pollination Efficiency** | UK | Lab |
| Stanley, D.A., Smith, K.E. and Raine, N.E., (2015). Bumblebee learning and memory is impaired by chronic exposure to a neonicotinoid pesticide. *Scientific reports*, *5*(1): 16508. doi: 10.1038/srep16508. | *Bombus terrestris* | Thiamethoxam | **Behavioral** | UK | Lab |
| |  | | --- | | Straub, L., Minnameyer, A., Camenzind, D., Kalbermatten, I., Tosi, S., Van Oystaeyen, A., Wäckers, F., Neumann, P. and Strobl, V., (2022). Thiamethoxam as an inadvertent anti-aphrodisiac in male bees. *Toxicology reports*, *9*: 36-45. doi: 10.1016/j.toxrep.2021.12.003. | |  | | *Bombus terrestris* | Thiamethoxam | **Reproductive** | Switzerland | Lab |
| Switzer, C.M., Combes, S.A. (2016) The neonicotinoid pesticide, imidacloprid, affects *Bombus impatiens* (bumblebee) sonication behavior when consumed at doses below the LD50. *Ecotoxicology* **25**, 1150–1159 (2016). Doi: 10.1007/s10646-016-1669-z | *Bombus impatiens* | Imidacloprid | **Behavioral** | U.S. | Lab |
| Tasman, K., Rands, S.A. and Hodge, J.J., (2020). The neonicotinoid insecticide imidacloprid disrupts bumblebee foraging rhythms and sleep. *Iscience*, *23*(12): 101827.   doi: 10.1016/j.isci.2020.101827 | *Bombus terrestris* | Imidacloprid | **Behavioral** | UK | Lab |
| Van Oystaeyen, A., Klatt, B.K., Petit, C., Lenaerts, N. and Wäckers, F., (2021). Short-term lab assessments and microcolonies are insufficient for the risk assessment of insecticides for bees. *Chemosphere*, *273*: 128518. doi: 10.1016/j.chemosphere.2020.128518 | *Bombus terrestris* | Acetamiprid, Thiacloprid | **Reproductive Behavioral Physiological** | Belgium | Lab |
| Weitekamp, C.A., Koethe, R.W. and Lehmann, D.M., (2022). A comparison of pollen and syrup exposure routes in *bombus impatiens* (Hymenoptera: Apidae) microcolonies: Implications for pesticide risk assessment. *Environmental entomology*, *51*(3): 613–620. doi: 10.1093/ee/nvac026 | *Bombus impatiens* | Acetamiprid | **Reproductive, Physiological** | U.S. | Lab |
| Whitehorn, P.R., O’Connor, S., Wackers, F.L. and Goulson, D., (2012). Neonicotinoid pesticide reduces bumble bee colony growth and queen production. *Science*, *336*(6079): 351-352. doi: 10.1126/science.1215025. | *Bombus terrestris* | Imidacloprid | **Reproductive, Survival and Mortality** | UK | Lab and field |
| Whitehorn, P.R., Wallace, C. and Vallejo-Marín, M., (2017). Neonicotinoid pesticide limits improvement in buzz pollination by bumblebees. *Scientific reports*, *7*(1): 15562. Doi: 10.1038/s41598-017-14660-x | *Bombus terrestris audax* | Thiamethoxam | **Behavioral, Pollination Efficiency** | UK | Lab |
| Wintermantel, D., Locke, B., Andersson, G.K., Semberg, E., Forsgren, E., Osterman, J., Rahbek Pedersen, T., Bommarco, R., Smith, H.G., Rundlöf, M. and de Miranda, J.R., (2018). Field-level clothianidin exposure affects bumblebees but generally not their pathogens. *Nature Communications*, *9*(1): 5446. Doi: 10.1038/s41467-018-07914-3 | *Bombus terrestris* | Clothianidin | Physiological, Reproductive | UK | Lab |
| Witwicka, A., López-Osorio, F., Arce, A. *et al.* (2025) Acute and chronic pesticide exposure trigger fundamentally different molecular responses in bumble bee brains. *BMC Biol* **23**, 72. Doi: 10.1186/s12915-025-02169-z | *Bombus terrestris audax* | Acetamiprid, Clothianidin | **Survival and Mortality, Physiological** | UK | Lab |
| Witwicka, A., López-Osorio, F., Chaudhry-Phipps, H. and Wurm, Y., (2025). A neonicotinoid pesticide causes tissue-specific gene expression changes in bumble bees. *Science of the Total Environment*, *959:* 178262. Doi: 10.1016/j.scitotenv.2024.178262 | *Bombus terrestris audax* | Clothianidin | Physiological | UK | Lab |
| Wu-Smart, J. and Spivak, M., (2018). Effects of neonicotinoid imidacloprid exposure on bumble bee (Hymenoptera: Apidae) queen survival and nest initiation. *Environmental Entomology*, *47*(1): 55-62. doi: 10.1093/ee/nvx175. | *Bombus impatiens* | Imidacloprid | **Survival and Mortality, Reproductive, Physiological** | U.S. | Lab |