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Neonicotinoid Insecticides: A Threat to Pollinators

Muhammad Imran

Abstract

Pollination is the fundamental requirement for healthier fruit set. More than 90% of flowering plant species in the hot and humid regions required pollination. Many plants species required animal pollination. Among these animals, insects play a vital role in pollination, and among the major insect pollinators, hymenopterans, honeybees, and bumblebees are regarded as the best pollinators of the crops around the world. Declining population of these important pollinators day by day is a major threat, and this declining is due to a variety of stressors. Among these possible reasons including environmental conditions, parasites, predators, malnutrition, and diseases, many researchers pointed finger at pesticides as playing a major role especially neonicotinoid. Neonicotinoids move in the environment and can be found throughout the areas where they are not applied. Neonicotinoids can drift offsite directly exposing bees and contaminate nontargeted areas when applied as spray. During plant uptake, neonicotinoid spreads through plant tissues and disrupts the physiology of pollen eaters, nectar feeders, and the insects that feed upon plant tissues. Therefore, the use of neonicotinoid is the major reason for the decline of bees in the world. So it is requested to all farmers and researchers to please find ways to kill pests not pollinators.

Keywords: pollinators, honeybees, bumblebees, insecticides, Neonicotinoid

1. Economic importance of pollinators

Consideration on sustainable growth generally agrees that environment still harbors much kind of living things that are potentially and unswervingly significant to mankind. Their lucrative utilize is now pending for the discovery of their worth or the formulation of how they should be propagated. There are about 25,000 species of bees [1] recognized in the world and only few play an important role in pollination producing fruits and seeds. Most of the world wide plant species depend upon animal pollination for their fertilization [2]. Among animal pollinators (any animal which transfer pollen between plants enabling fertilization and sexual reproduction from anther of male flower part to the stigma of female flower) insects provide better service of pollination [3]. Insect pollinators include bees (honey bees, bumblebees and solitary bees), flies (Carrion flies, flesh flies and hover flies), pollen wasp, ants, mosquitoes, beetles, butterflies and moths [4, 5].

Among these major insect pollinators; hymenopterans, honey bees and bumblebees are regarded as the best pollinators of the crops around the world. It has been

introduced globally due to its economic importance of honey production (honey bee) and pollination of the crops [5]. Bees are known to pollinate among 71 most familiar crops out of hundred plant species that accounts for 90% of world's food supply [6]. However, honey bees and bumblebees are the principal pollinators of the crops and it has been used successfully as pollinators in crop systems around the world [7, 8].

Many fields of current agriculture hang on pollinators. In each pollination season, these important pollinators mostly honey bees, bumblebees and native bees bring billions of U.S dollars in economic value. In several esteems, they play as a key role in the world economy [9]. But it is very important to know the real value of these important little creatures. About \$230 and \$580 billion U.S. dollars' worth of annual worldwide food production depend on the direct influence of these important pollinators [10].

Managed bees (domesticated bees by the beekeeper) are the greatest regarded pollinators in relations of agricultural economics. These pollinators (honeybees and bumblebees) can deliver pollination to almost any crop. Almond crop is entirely reliant upon honey bee pollination. Without these pollinators, yield for many fruit crops including watermelon, squash, blueberries and other fruits would be greatly reduced [11, 12]. According to the statistic presented by USDA, a honeybee colony value 100 times more to the public than to the beekeeper it mean that the value they deliver extends well beyond their actual price. Bee's pollination has aided make vegetables, nuts and fruits more accessible to consumers. There are many others species of insects called as wild species like leaf cutter bees, mason bees, alfalfa bees are not documented for their input to current agriculture. But these pollinating insects provide supplement to managed bees colonies but also pollinate some crops more professionally than their managed bees. Throughout blooming season honeybees and other native insects partner to deliver pollination for many crops. Although the economic values of their pollination is much less than managed bees, but the role of wild bees is important [11].

2. Ecosystem essentials

Preserving our indigenous flora, including wild for example bluebells, poppies, cornflowers and, along with trees, also be contingent on pollinator populations. This is much closer relationship between the declining of pollinator's population and the plant they pollinate and this relationship goes parallel throughout the world [13, 14]. It is estimated that in Europe and UK about 76% of plants that are pollinated by or called as liked by bumblebees have declined in recent decades. Pollinator's population declines spell bad news for previously declining wildflowers, which are pollinated mostly by insects and among them one fourth are endangered. In short wildlife also depends on these important pollinators, declining of wild flora means declining of wildlife including birds their shelter. Even though the insects themselves provide a significant link in the food chain as prey for other insects, birds and other animals that feed on insect [15, 16].

3. Current declines in pollinator populations

To maintain the plant genetic diversity pollination is very important for plant reproduction [12]. Due to its important role in agriculture many scientist worked on

population dynamics of these important pollinators. There are many reason behind the decreasing population of these important pollinators such as bats, beetles, flies birds and bees, the main reasons behind this are habitat destruction [17, 18] and the introduction chemicals sprayed on crops in form of pesticides [11, 19]. Monitoring programs of NASS led by the USDA have documented the decline in managed bee's population since 1947, making them the most important example of pollinator decline in North America [11, 20]. Reasons behind the decline of these important pollinators including managed and wild bees are of mites that feed on honeybee larvae and adult body making them weak, pathogens, use of antibiotics to control these pathogen and pesticides [21–23]. Among these all factors pesticides paly vial role for the declining of population. A huge amount of these pesticides are sprayed on crops for the control of insect pest that damage crops, and bees are non-target organism on these sprayed crops. When bees visit on these sprayed crops to collect pollen and nectar become contaminated. Among these pesticides many are neuro-toxic in nature such as parathion, diazinon, and carbaryl play vial role in population decline [21].

However, the population of honeybee is declining day by day due to intemperate uses of pesticides [8]. Generally the bees are exposed to these pesticides; which are either used to control the parasitic mites and the pathogens attacked in the hives or to control the diseases and pest in the crops on which the bees are visited for pollen and nectar [21]. The experiments conducted in Europe and the United States found the miscellaneous range of pesticides on healthy and unhealthy bee's colonies along with their pollen, honey and bee waxes [12]. One possible cause of distressing bee mortality is the use of very active systemic insecticide called neonicotinoids [19].

4. Neonicotinoid, a real threat to pollinators

Neonicotinoids; systemic insecticides, easily soluble in water but slowly break in the environment. These insecticides are absorbed by the plants through roots system and become the part of plant. The photo-degradation, half-life of neonicotinoids is about 30 ± 4 days when exposed to sunlight [24]. It is highly toxic to insects as compare to mammals and birds because they are unable to cross the blood-brain barrier due to the lack of a charged nitrogen atom and the uncharged molecule can penetrate the insect blood–brain barrier [25]. It is derived from nicotine, which is accountable for bees decline and are highly selective neuro-active insecticides [26].

Neonicotinoids were introduced into the market in 1990 [27]. This new class of insecticide is neurotoxic, includes imidacloprid, thiamethoxam, dinotefuran, nitenpyram, acetamiprid, thiacloprid and clothianidin [28]. The first commercial neonicotinoid was imidacloprid meanwhile clothianidin and thiamethoxam were the first two introduced insecticides in early 2000s in the market [27].

Neonicotinoids are systemic poisons acquire by plants through their root system and they may endured in the plants for weeks to months and mostly depends on the abiotic conditions and application rate [29, 30]. Neonicotinoids are used to protect a variety of vegetables, fruits, and major crops like corn, cotton, potato, rice, etc. against sucking insects like aphids, whiteflies, thrips, leaf- and plant hoppers [31]. In Pakistan, these insecticides are recommended for the control of sucking pests of cotton, as they are most effective against thrips, jassid, and whitefly [32, 33].

The insecticides having the neonicotinoid compounds were applied on 140 different crops in more than 120 countries around the world. The excessive use of the neonicotinoids has been reported as the major factor in declining of both domestic and wild bees. Neonicotinoids are broad spectrum insecticides and are moderately

to highly effective and toxic to bees that depends upon the presence of active ingredient in the insecticides [34]. Neonicotinoids are mainly used in seed and soil treatment and sometimes they also directly applied to plant foliage [27]. Many of the neonicotinoids are highly toxic to the insect pollinators and also to the honey bees. It changes the behavior that results in the behavioral disturbances, orientation difficulties and impairment of social activities [35–41].

Neonicotinoids also affects the CNS (central nervous system) of the insects as it binds agonistically to the post-synaptic nicotinic acetylcholine receptors that results in the spontaneous discharge of nerve impulses and eventual failure of the neuron to propagate any signal [42]. The neonicotinoids and their metabolites have the capability to persistent in the soil and aquatic sediments [43] and their persistence at shallow depths could increase the chances of aquatic life and other wildlife including honey bees could get exposed to the insecticide [44].

The neonicotinoids are considered to be most effective insecticide other than organophosphates and carbamates [45]. Imidacloprid is the most widely used insecticide and has drawn more attention on the health of bees than other neonicotinoids. More than 400 products of this insecticides accounting for about 15th of the globally insecticide marketed [46]. Honeybees are exposed to neonicotinoids in different ways from ingestion, contact and inhalation [47]. The pollen foragers which are different from the nectar foragers; they do not consume pollen by itself but it brings to the hives to consumed for the nurse bees and larvae hence the nurse bees and larvae exposed to neonicotinoids and their metabolites [48].

The forager bees used honey from their hive before they leave for foraging. It depends upon the distance that it will travel from their hive to foraging field, the forager bees have to consume more or less amount of nectar or honey from their hive for energy and foraging. Therefore the foragers may ingest more or less amount of residues of neonicotinoids [49]. The colony become contaminated when the worker bees come into contact with pollen or nectar contaminated with neonicotinoid and transport them to the hive, where they are normally observed in honey and bee bread [50, 51]. Bee hives made up of trees treated with neonicotinoids could have residues which may cause trouble for bees [52]. Oral route of neonicotinoid uptake is highest in forager honeybees, winter honeybees and larvae [53, 54]. Serious pests of citrus in Pakistan and other Asian countries are mostly control by using various classes of neonicotinoids. The foraging bees visiting citrus flowers get exposed to the residues of neonicotinoids which are responsible for damaging their physiology [55].

Neonicotinoids increased worker mortality and queenlessness over time. The toxicity of the neonicotinoids increases when it encountered with fungicides. In corn growing areas, the health of honey bees are reduced when are exposed to neonicotinoids in the field [56]. The irretrievable and cumulative damage to central nervous system of insects is often caused by neonicotinoid insecticides. There is no safe level of neonicotinoids and even only a very minute quantity of these systemic poisons could have long lasting drastic effects [57]. The activities of the acetyl cholinesterase is increased by the thiamethoxam at each developmental stages of the insects and the activities of glutathione-S- transferase and carboxyl esterase para increases at the pupal stages and reduced the survival of larvae and pupa that results in the decreasing of percentage emergence of honeybees [58]. The effects of thiamethoxam cause the reduction of forager bees returning to the hive [59]. When honey bees are exposed to a sub-lethal doses of imidacloprid and clothianidin that results in the reduction of foraging activities as well as longer foraging flights [60]. The bees become detract when it became exposed to nonlethal doses to thiamethoxam and causes high mortality at levels that may collapse the colony.

Among distinctive behaviors of honey bees, foraging is one of idiosyncratic behavior of the *Apis mellifera*. This type of behavior is like an association between the bee colonies and the ambient environment [59].

5. Conclusion

After World War II, we started using pesticides on a large scale, and this became necessary because of the monocultures that put out a feast for crop pest. Recently, researchers from Penn State University has started looking at the pesticides residue in the loads of pollen that bees carry home as food, and they have found that every batch of pollen that honeybee collects has at least six detectable pesticides in it, and this includes every class of insecticides, herbicides, fungicides and even inert and unlabeled ingredients that are part of the pesticides formulation that can be more toxic than the active ingredient. One of these classes of insecticides, the neonicotinoids is making headlines around the world right now you have probably heard about it. This is the new class of insecticides, it move through the plant so that a crop pest, a leaf eating insect would take a bite of plant and get a lethal dose and die. In most agricultural settings, on most of our farms it's only the seed that's coated with insecticides and so a smaller concentration move through the plant and gets into the pollen and nectar, and if a bee consumes this lower dose either nothing happens or the bee becomes intoxicated and disoriented and she may not find her way to home.

5.1 Strategies to conserve the pollinators


Every one of us needs to behave a little bit more like a bee society, and insect society, where each of our individual actions can contribute to grand solution and emergent property. So let the small act of planting flowers and keeping them free of pesticides be the driver to large scale change. Please find the ways to kill pest not bees.

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References

- [1] Michener CD. The Bees of the World. Baltimore: John Hopkins, London Press; 2000. p. 873
- [2] Fulton M, Hodges SA. Floral isolation between *Aquilegia formosa* and *A. pubescens*. Proceedings of the Royal Society of London. 1999;266:2247-2252
- [3] Hodges SA, Whittall JB, Fulton M, Yang JY. Genetics of floral traits influencing reproductive isolation between *Aquilegia formosa* and *A. pubescens*. American Naturalist. 2002;159:51-60
- [4] Moreti ACCC, Silva ECA, Alves MLTMF. Observações sobre a polinização entomófila da cultura da soja (*Glycine max* Merrill). Boletim da Indústria Animal. 1998;55:91-94
- [5] Winfree R, Williams NM, Gaines H, Ascher JS, Kremen C. Wild bee pollinators provide the majority of crop visitation across land-use gradients in New Jersey and Pennsylvania, USA. Journal of Applied Ecology. 2008;45:793-802
- [6] Gallaia N, Sallesc JM, Setteled J, Vaissierea BE. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecological Economics. 2009;68:810-821
- [7] Artz DR, Hsu CI, Nault B. Influence of honey bee, *Apis mellifera*, hives and field size on foraging activity of native bee species in pumpkin fields. Environmental Entomology. 2011;40:1144-1158
- [8] Morse RA, Calderone NW. The value of honey bee as pollinator of U.S. crops. Bee Culture. 2000;128:1-15
- [9] Kremen C, Williams NM, Aizen MA, Herren BG, LeBuhn G, Minckley R, et al. Pollination and other ecosystem services produced by mobile organisms: A conceptual framework for the effects of land-use change. Ecology Letters. 2007;10:299-314
- [10] Vanbergen AJ, Insect Pollinators Initiative. Threats to an ecosystem service: Pressures on pollinators. Frontiers in Ecology and the Environment. 2013;11:251-259
- [11] Berenbaum M, Bernhardt P, Buchmann S, Calderone NW, et al. Status of Pollinators in North America. Washington, D.C: The National Academies Press; 2007. p. 322
- [12] Delaplane KS, Mayer DF. Crop Pollination by Bees. New York: CABI Publishing; 2000. p. 344
- [13] Morales CL, Aizen MA. Does invasion of exotic plants promote invasion of exotic flower visitors? A case study from the temperate forests of the southern Andes. Biological Invasions. 2002;4:87-100
- [14] Parker IM. Pollinator limitation of *Cytisus scoparius* (scotch broom), an invasive exotic shrub. Ecology. 1997;78:1457-1470
- [15] Levine JM, Vilà M, Antonio CM, Dukes JS, Grigulis K, Lavorel S. Mechanisms underlying the impacts of exotic plant invasions. Proceedings of the Royal Society of London. Series B, Biological Sciences. 2003;270:775-781
- [16] Richardson DM. Plant invasion ecology dispatches from the front line. Divers. Diversity and Distributions. 2004;10:315-319
- [17] Stephen WP. Alfalfa pollination in Manitoba. Journal of Economic Entomology. 1995;48:543-548
- [18] Aizen MA, Feinsinger P. Habitat fragmentation, native insect pollinators, and feral honey bees in argentine 'Chaco

Serrano'. Ecological Applications. 1994;4: 378-392

[19] Kevan PG. Forest application of the insecticide fenitrothion and its effect on wild bee pollinators (Hymenoptera: Apoidea) of lowbush blueberries (*Vaccinium* spp.) in Southern New Brunswick, Canada. Biological Conservation. 1975;7:301-309

[20] (NASS) National Agricultural Statistics Service. Honey. Washington, D.C.: United States Department of Agriculture; 1976-2008. Available from: <http://www.nass.usda.gov>, Dec 2008

[21] Johansen CA, Mayer DF. Pollinator Protection: A Bee and Pesticide Handbook. Cheshire, CT: Wicwas Press; 1990. p. 322

[22] Morse RA, Flottum K. Honey Bee Pests, Predators, and Diseases. Medina, OH: A.I. Root Company; 1997. p. 454

[23] Wilson WT, Pettis JS, Henderson CE, Morse RA. Tracheal mites. In: Morse RA, Flottum K, editors. Honey Bee Pests, Predators, and Diseases. 3rd ed. Medina, OH: A.I. Root Company; 1997. pp. 253-278

[24] Cressey D. Europe debates risk to bees. Nature. 2013;496:408-409

[25] Izuru Y. Nicotine to nicotinoids. In: Yamamoto I, Casida J, editors. Nicotinoid Insecticides and the Nicotinic Acetylcholine Receptor. Springer-Verlag; 1999. pp. 3-27

[26] Cresswell JEE, Desneux N, Vangelsdrop D. Dietary traces of neonicotinoid pesticides are a cause of population declines in honeybees. Pest Management Science. 2012;68:819-827

[27] Tomizawa M, Casida J. Neonicotinoid insecticide toxicology: Mechanisms of selective action. Annual Review of Pharmacology and Toxicology. 2005;54:247-268

[28] Jeschke JM. Across islands and continents, mammals are more successful invaders than birds. Diversity and Distributions. 2008;14:913-916

[29] Bromilow RH, Chamberlain K, Evans AA. Physiochemical aspects of phloem translocation of herbicides. Weed Science. 1990;38:305-314

[30] Laurent FM, Rathahao E. Distribution of imidacloprid in sunflowers (*Helianthus annuus*) following seed treatment. Journal of Agricultural Food Chemistry. 2003;51: 8005-8010

[31] Elbert A, Haas M, Springer B, Thielert W, Nauen R. Applied aspects of neonicotinoid uses in crop protection. Pest Management Science. 2008;64: 1099-1105

[32] Bethke AJ, Redak RA. Effect of imidacloprid on the silver leaf whitefly, *Bemisia argentifolii* bellows and Perring (Homoptera: Aleyrodidae), and whitefly parasitism. Annals of Applied Biology. 2008;130:397-407

[33] Lopez JR, Jr D, Fritz BK, Latheef MA, Lan Y, Martin DE, et al. Evaluation of toxicity of selected insecticides against thrips on cotton in laboratory bioassays. Journal of Cotton Science. 2008;12:188-194

[34] Jeschke P, Nauen R, Schindler M, Elbert A. Overview of the status and global strategy for neonicotinoids. Journal of Agricultural Food Chemistry. 2011;59:2897-2908

[35] Guez D, Suchail S, Gauthier M, Maleszka R, Belzunces LP. Contrasting effects of imidacloprid on habituation in 7- and 8- day - old honeybees (*Apis mellifera*). Neurobiology Learning Memory. 2001;76:183-191

[36] Bortolotti L, Montanari R, Marcelino J, Medrzycki P, Aini S, Porrini C. Effects of sub-lethal

imidacloprid doses on the homing rate and foraging activity of honey bees. *Bulletin of Insectology*. 2003;**56**:63-67

[37] Medrzycki P, Montanari R, Bortolotti L, Sabatini AG, Maini S, Porrini C. Effects of Imidacloprid administered in sub-lethal doses on honey bees' behaviour. Laboratory tests. In: Proceedings of the 8th International Symposium "Hazards of Pesticides to Bees", September 4–6, 2002, Bologna, Italy (Eds). *Bulletin of Insectology*. Vol. 56. 2003. pp. 59-62

[38] Decourtye A, Armengaud C, Renou M, Devillers J, Cluzeau S, Gauthier M, et al. Imidacloprid impairs memory and brain metabolism in the honeybee (*Apis mellifera*). *Pesticide Biochemistry and Physiology*. 2004;**78**: 83-92

[39] Desneux N, Decourtye A, Delpuech JM. The sublethal effects of pesticides on beneficial arthropods. *Annual Review of Entomology*. 2007;**52**: 81-106

[40] Hassani AKEI, Dacher M, Gary V, Lambin M, Gauthier M, Armengaud C. Effects of sublethal doses of acetamiprid and thiamethoxam on the behavior of the honeybee (*Apis mellifera*). *Archives Environmental Contamination Toxicology*. 2008;**54**:653-666

[41] Maini S, Medrzycki P, Porrini C. The puzzle of honey bee losses: A brief review. *Bulletin of Insectology*. 2010;**63**: 153-160

[42] Matsuda K, Sattelle DB. Mechanism of selective actions of neonicotinoids on insect acetylcholine receptors. In: Clark JM, Ohkawa H, editors. *New Discoveries in Agrochemicals: American Chemical Society Symposium Series*. Oxford, UK: Oxford University Press; 2005. pp. 172-183

[43] Doering J, Maus C, Schoening R. Residues of imidacloprid in blossom

samples of rhododendron sp after soil treatment in the field application. *Environmental Chemistry*. 2004;**62**: 483-494

[44] Lu Z, Jonathan K, Challis WCS. Quantum yields for direct photolysis of neonicotinoid insecticides in water: Implications for exposure to non-target aquatic organisms. *Environmental Science and Technology*. 2015;**2**:188-192

[45] Bonmatin JM, Marchand PA, Charvet R, Moineau I, Bengsch ER, Colin ME. Quantification of Imidacloprid uptake in maize crop. *Journal of Agricultural and Food Chemistry*. 2005;**53**:5336-5341

[46] Chen M, Lin T, Collins E, Lu MC. Simultaneous determination of residues in pollen and high fructose corn syrup from eight neonicotinoid insecticides by liquid chromatography-tandem mass spectrometry. *Analytical and Bioanalytical Chemistry*. 2013;**405**: 9251-9264

[47] Girolami KM, Kahng SW, Hilker KA, Girolami PA. Differential reinforcement of high rate behavior to increase the pace of self-feeding. *Behavioral Interventions*. 2009;**24**:17-22

[48] Rortais A, Arnold G, Halm MP, Briens TF. Modes of honey bee exposure to systemic insecticides: Estimated amounts of contaminated pollen and nectar consumed by different categories of bees in France. *Apidologie*. 2005;**36**: 71-83

[49] Maxim L, Slujis VD. Seed dressing systemic insecticide and honeybees. *European Environment Agency*. 2013; **376**:1-17

[50] Blacquiere T, Smagghe G, Van Gestel CA, Mommaerts V. Neonicotinoids in bees: A review on concentrations, side-effects and risk assessment. *Ecotoxicology*. 2012;**21**: 973-992

- [51] Genersch E, Ohe VDW, Kaatz H, Schroeder A, Otten C, Buechler R, et al. The German bee monitoring project: A long term study to understand periodically high winter losses of honey bee colonies. *Apidologie*. 2010;**41**:332-352
- [52] Beekman M, Ratnieks FLW. Long range foraging by honey bees *Apis mellifera*. *Functional Ecology*. 2000;**14**: 490-496
- [53] Chauzat MP, Faucon JP, Martel AC, Lachaize CN, Aubert M, et al. Journal of Economical Entomology. 2006;**99**: 253-262
- [54] Reetz JE, Zühlke S, Spiteller M, Wallner K. Neonicotinoid insecticides translocated in guttated droplets of seedtreated maize and wheat: A threat to honeybees? *Apidologie*. 2011;**42**: 596-606
- [55] Khan AA, Afzal M, Raza AM, Khan AM, Iqbal J, Tahir HM, et al. Toxicity of botanicals and selective insecticides to Asian citrus psylla, *Diaphorina citri* K. (Homoptera: Psyllidae) in laboratory conditions. *Jokull Journal*. 2013;**63**:52-72
- [56] Tsvetkov N, Robert OS, Sood K, Patel HS, Malena DA, Gajiwala PH, et al. Chronic exposure to neonicotinoids reduces honey bee health near corn crops. *Science*. 2017;**356**:1395-1397
- [57] Tennekes HA. The significance of the Druckrey-Küpfmüller equation for risk assessment—the toxicity of neonicotinoid insecticides to arthropods is reinforced by exposure time. *Toxicology*. 2010;**276**:1-4
- [58] Tavares DA, Dussaubat C, Kretzschmar A, Carvalho SM, Zacarin ECMS, Malaspina O, et al. Exposure of larvae to thiamethoxam affects the survival and physiology of the honey bee at post-embryonic stages. *Environmental Pollution*, Elsevier. 2017; **229**:386-393
- [59] Henry M, Beguin M, Requier F, Rollin O, Odoux JF, Aupinel P, et al. A common pesticide decreases foraging success and survival in honey bees. *Science*. 2012;**336**:348-350
- [60] Schneider S, Eisenhardt D, Rademacher E. Sublethal effects of oxalic acid on *Apis mellifera* (Hymenoptera: Apidae): Changes in behaviour and longevity. *Apidologie*. 2012;**43**:218-225