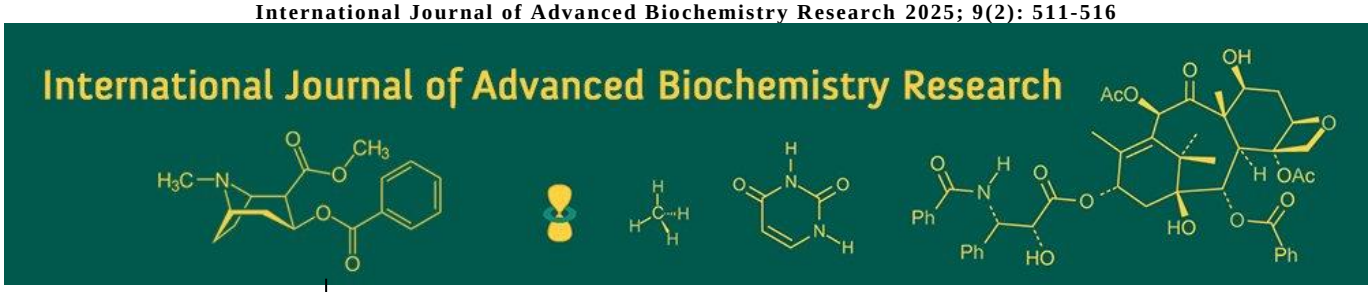

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2025; 9(2): 511-516
www.biochemjournal.com
Received: 16-12-2024
Accepted: 19-01-2025

Katta Subramanya Sai Teja
Department of Entomology, Post Graduate College of Agriculture, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Nagendra Kumar
Department of Entomology, Post Graduate College of Agriculture, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Corresponding Author:
Katta Subramanya Sai Teja
Department of Entomology, Post Graduate College of Agriculture, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Thiamethoxam-induced changes in honey bee colony dynamics: A study in mustard fields

Katta Subramanya Sai Teja and Nagendra Kumar

DOI: https://doi.org/10.33545/26174693.2025.v9.i2g.3853

Abstract
Honey bees (*Apis mellifera*) are vital pollinators for global ecosystems and agriculture, yet their populations are declining due to multiple stressors, including pesticide exposure. Neonicotinoids, such as Thiamethoxam, are widely used systemic insecticides known for their detrimental effects on pollinators. This study investigates the impact of Thiamethoxam on honey bee biology, colony health, and resource management over two seasons. Key developmental parameters, including larval and pupal periods, fecundity, and body weight, were significantly affected by Thiamethoxam exposure. Treated colonies exhibited prolonged larval (5.85±0.41 days) and pupal (10.00±0.62 days) periods, reduced fecundity (823.35±58.99 eggs), and lower larval (88.60±8.57 mg) and pupal (88.15±6.62 mg) weights compared to controls. Additionally, Thiamethoxam exposure led to significant declines in brood area, pollen storage, nectar storage, and colony weight, with minimal recovery over time. These findings align with previous studies demonstrating the sublethal effects of neonicotinoids on bee behavior, reproduction, and colony dynamics. The results underscore the adverse impacts of Thiamethoxam on honey bee health and highlight the urgent need for sustainable pest management practices to mitigate the risks posed by neonicotinoid insecticides to pollinators.

Keywords: Thiamethoxam, neonicotinoids, colony health, developmental toxicity, resource management, pollinator decline

Introduction
Honey bees (*Apis mellifera*) are among the most important pollinators in both natural and agricultural ecosystems, contributing significantly to global food security and biodiversity (Potts *et al*., 2010) [13]. They play a pivotal role in the pollination of a wide variety of crops, including fruits, vegetables, and nuts, which are essential for human nutrition and economic stability (Klein *et al*., 2007) [10]. However, in recent decades, honey bee populations have faced unprecedented declines, with colony losses reported across North America, Europe, and other regions (VanEngelsdorp *et al*., 2008) [16]. This phenomenon, often referred to as Colony Collapse Disorder (CCD), has been attributed to a combination of factors, including habitat loss, climate change, pathogens, parasites, and exposure to pesticides (Goulson *et al*., 2015) [3, 8].

Among the various stressors contributing to bee declines, the widespread use of neonicotinoid insecticides has garnered significant attention due to their potential sublethal and lethal effects on pollinators (Godfray *et al*., 2014) [7]. Neonicotinoids, such as Thiamethoxam, are systemic insecticides that are absorbed by plants and distributed throughout their tissues, including pollen and nectar, which are primary food sources for bees (Bonmatin *et al*., 2015) [3]. While these chemicals are effective in controlling agricultural pests, their persistence in the environment and their high toxicity to non-target organisms, including bees, have raised concerns about their ecological impact (Pisa *et al*., 2017) [12].

Thiamethoxam, a second-generation neonicotinoid, is widely used in agriculture due to its broad-spectrum efficacy against insect pests. However, studies have shown that even sublethal doses of Thiamethoxam can impair honey bee behavior, physiology, and colony health (Henry *et al*., 2012) [9]. For instance, exposure to Thiamethoxam has been linked to reduced foraging efficiency, impaired navigation, and increased mortality in honey bees (Aliouane *et al*., 2009; Fischer *et al*., 2014) [1, 5]. Additionally, sublethal exposure to Thiamethoxam has been shown to affect the reproductive capacity of queen bees and the development of larvae, ultimately threatening colony sustainability (Wu-Smart & Spivak,

2016; Pettis *et al*., 2013) [17, 11]. Despite the growing body of evidence on the adverse effects of neonicotinoids, there is still a need for comprehensive studies that examine the long-term impacts of Thiamethoxam on honey bee colonies under realistic field conditions. Most previous research has focused on individual bees or short-term laboratory experiments, which may not fully capture the complex interactions between pesticide exposure, colony dynamics, and environmental factors (Blacquière *et al*., 2012) [2]. Furthermore, the mechanisms by which Thiamethoxam affects honey bee development, reproduction, and resource management remain poorly understood.

This study aims to address these gaps by investigating the effects of Thiamethoxam on honey bee biology and colony health, with a focus on developmental stages, fecundity, brood production, and resource storage. By examining these parameters, we seek to provide a more holistic understanding of how Thiamethoxam exposure impacts honey bee colonies and to contribute to the ongoing debate on the risks posed by neonicotinoid insecticides to pollinators. The findings of this study have important implications for the development of sustainable pest management practices and the conservation of pollinator populations, which are vital for maintaining ecosystem health and agricultural productivity.

Materials and Methods

The study was conducted in a mustard field at the Apiary of Dr. Rajendra Prasad Central Agricultural University (RPCAU), Pusa, Bihar, India, a site dedicated to honeybee domestication and research. Two disease-free honeybee (*Apis mellifera*) colonies, each containing all stages of bees (eggs, larvae, pupae, and adults), were selected and placed in separate plots within the same mustard field to ensure uniform environmental conditions. One colony served as the control and received a 50% sucrose solution and water, while the other was treated with Thiamethoxam at 0.1 g/L, administered in a 50% sucrose solution. Both colonies were provided with fresh water and their respective food sources daily. Developmental parameters (egg, larval, and pupal periods; fecundity; larval and pupal weights), colony growth metrics (brood area, pollen and nectar storage, colony weight), and behavioral observations (foraging activity, worker bee mortality) were monitored weekly over two consecutive seasons.

Results

Table 1: Effect of Thiamethoxam on the biology of Honey bees during First Season

S. No	Biology	Control	Thiamethoxam treated	
1	Egg period (days)	3.00±0.00	2.80±0.42	NS
2	Larval period(days)	4.80±0.63	5.70±0.67	Sig.
3	Pupal period (days)	8.30±0.48	9.30±0.94	Sig.
4	Fecundity (no.)	1199±38.71	847±52.45	Sig.
5	Larval weight (mg)	114.90±6.13	88.60±7.93	Sig.
6	Pupal weight (mg)	113.90±3.63	90.90±3.60	Sig.

The egg period remained unaffected, showing no significant difference between the treated (2.80±0.42 days) and control (3.00±0.00 days) groups. However, significant differences were observed in other parameters. The larval period increased in the Thiamethoxam-treated group (5.70±0.67 days) compared to the control (4.80±0.63 days), while the pupal period was also extended from 8.30±0.48 days in the control to 9.30±0.94 days in the treated group. Fecundity was notably reduced in the treated bees (847±52.45 eggs) compared to the control (1199±38.71 eggs). Additionally, both larval and pupal weights were significantly lower in the treated group, with larval weight decreasing from 114.90±6.13 mg in the control to 88.60±7.93 mg in the treated group, and pupal weight dropping from 113.90±3.63 mg to 90.90±3.60 mg is detailed in Table 1.

Table 2: Effect of Thiamethoxam on the biology of Honey bees during Second Season

S. No	Biology	Control	Thiamethoxam treated	
1	Egg period (days)	2.90±0.31	2.70±0.48	NS
2	Larval period(days)	5.10±0.31	6.00±0.66	Sig.
3	Pupal period (days)	780±0.42	10.10±0.73	Sig.
4	Fecundity (no.)	1158.90±49.47	814.50±80.27	Sig.
5	Larval weight (mg)	117.50±2.55	90.10±9.32	Sig.
6	Pupal weight (mg)	113.40±4.00	91.10±4.71	Sig.

From Table 2 the egg period showed no significant difference between the control (2.90±0.31 days) and the Thiamethoxam-treated group (2.70±0.48 days). However, the larval period was significantly prolonged in the treated group (6.00±0.66 days) compared to the control (5.10±0.31 days). The pupal period was also extended from 7.80±0.42 days in the control to 10.10±0.73 days in the treated group. Fecundity was notably

Table 3: Pooled Effect of Thiamethoxam on the biology of Honey bees

S. No	Biology	Control	Thiamethoxam treated	
1	Egg period (days)	2.95±0.15	2.80±0.24	NS
2	Larval period (days)	4.95±0.28	5.85±0.41	Sig.
3	Pupal period (days)	8.05±0.36	10.00±0.62	Sig.
4	Fecundity (no.)	1180.45±39.79	823.35±58.99	Sig.
5	Larval weight (mg)	116.45±3.32	88.60±8.57	Sig.
6	Pupal weight (mg)	114.05±3.14	88.15±6.62	Sig.

The egg period showed no significant variation between the control (2.95±0.15 days) and the Thiamethoxam-treated group (2.80±0.24 days). However, the larval period was significantly prolonged in the treated group (5.85±0.41 days) compared to the control (4.95±0.28 days). Similarly, the pupal period increased from 8.05±0.36 days in the

control to 10.00±0.62 days in the treated group. A marked reduction in fecundity was observed, with the treated group laying fewer eggs (823.35±58.99) than the control (1180.45±39.79). Additionally, larval and pupal weights significantly declined under Thiamethoxam exposure. The larval weight decreased from 116.45±3.32 mg in the control to 88.60±8.57 mg in the treated group, while pupal weight dropped from 114.05±3.14 mg to 88.15±6.62 mg is detailed in Table 3.

Table 4: Effect of Thiamethoxam on the brood area of Honey bees

First Season			Second Season		
Total brood area (cm2)			Total brood area (cm2)		
Days after spray	**Control colonies**	**Thiamethoxam-treated colonies**	**Days after spray**	**Control colonies**	**Thiamethoxam-treated colonies**
Before spray	1023.33	1016.67	Before spray	1035.00	1023.33
7 days	1050.00	783.33	7 days	1058.33	775.00
14 days	1066.67	816.67	14 days	1075.00	808.33
21 days	1083.33	866.67	21 days	1091.67	858.33
28 days	1100.00	933.33	28 days	1108.33	925.00

Table 4 shows in the first season, the brood area in control colonies increased steadily from 1023.33 cm² before spraying to 1100.00 cm² by day 28. In contrast, Thiamethoxam-treated colonies exhibited a significant decline in brood area, dropping from 1016.67 cm² before spraying to 783.33 cm² by day 7. A gradual recovery was observed over time, with the brood area reaching 933.33 cm² by day 28, yet it remained lower than the control group. Similarly, in the second season, control colonies showed an increase in brood area from 1035.00 cm² before spraying to 1108.33 cm² by day 28. However, Thiamethoxam-treated colonies exhibited a marked decline from 1023.33 cm² to 775.00 cm² by day 7. Though a partial recovery was noted by day 28 (925.00 cm²), the brood area in treated colonies remained lower than in the control group.

Table 5: Effect of Thiamethoxam on the pollen storage area of Honey bees

First Season			Second Season		
Pollen storage area (cm2)			Pollen storage area (cm2)		
Days after spray	**Control colonies**	**Thiamethoxam-treated colonies**	**Days after spray**	**Control colonies**	**Thiamethoxam-treated colonies**
Before spray	58.66	70.66	Before spray	62.33	67
7 days	74.00	57.33	7 days	78.33	52.66
14 days	86.00	33.66	14 days	90.66	30.33
21 days	110.00	27.33	21 days	115.33	24.66
28 days	121.00	27.33	28 days	126.33	25

From Table 5 we can know that in the first season, control colonies exhibited a steady increase in pollen storage, from 58.66 cm² before spraying to 121.00 cm² by day 28. However, Thiamethoxam-treated colonies showed a significant reduction in pollen storage, declining from 70.66 cm² before spraying to 57.33 cm² by day 7, and further decreasing to 27.33 cm² by day 21. No significant recovery was observed by day 28, with pollen storage remaining at 27.33 cm². A similar trend was observed in the second season. Control colonies showed a consistent increase in pollen storage from 62.33 cm² before spraying to 126.33 cm² by day 28. In contrast, Thiamethoxam-treated colonies experienced a sharp decline from 67.00 cm² before spraying to 52.66 cm² by day 7, followed by a continuous decrease to 24.66 cm² by day 21. A slight increase was noted by day 28 (25.00 cm²), but pollen storage remained significantly lower than in the control colonies.

Table 6: Effect of Thiamethoxam on the nectar storage area of Honey bees

First Season			Second Season		
Nectar storage area (cm2)			Nectar storage area (cm2)		
Days after spray	**Control colonies**	**Thiamethoxam-treated colonies**	**Days after spray**	**Control colonies**	**Thiamethoxam-treated colonies**
Before spray	120	130	Before spray	125	135
7 days	140	100	7 days	145	105
14 days	160	70	14 days	165	75
21 days	180	40	21 days	185	45
28 days	200	20	28 days	205	25

In the first season, control colonies exhibited a steady increase in nectar storage, rising from 120 cm² before spraying to 200 cm² by day 28. In contrast, Thiamethoxam-treated colonies showed a sharp decline in nectar storage, decreasing from 130 cm² before spraying to 100 cm² by day 7, and further reducing to only 20 cm² by day 28.A similar trend was observed in the second season, where control colonies increased nectar storage from 125 cm² before spraying to 205 cm² by day 28. However, Thiamethoxam-treated colonies showed a drastic reduction from 135 cm² before spraying to 105 cm² by day 7, with storage continuously declining to 25 cm² by day 28 this is detailed in Table 6.

Table 7: Effect of Thiamethoxam on the weight of the colony of Honey bees

First Season			Second Season		
Weight of the colony (g)			Weight of the colony (g)		
Days after spray	**Control colonies**	**Thiamethoxam-treated colonies**	**Days after spray**	**Control colonies**	**Thiamethoxam-treated colonies**
Before spray	2540	2510	Before spray	2560	2530
7 days	2610	2430	7 days	2630	2450
14 days	2690	2370	14 days	2710	2390
21 days	2760	2320	21 days	2780	2340
28 days	2840	2280	28 days	2860	2300

Table 7 shows in the first season, control colonies showed a continuous increase in weight, from 2540 g before spraying to 2840 g by day 28. However, Thiamethoxam-treated colonies exhibited a progressive decline, dropping from 2510 g before spraying to 2430 g by day 7, and further decreasing to 2280 g by day 28. A similar pattern was observed in the second season. Control colonies steadily increased in weight from 2560 g before spraying to 2860 g by day 28. In contrast, Thiamethoxam-treated colonies experienced a gradual decline from 2530 g before spraying to 2450 g by day 7, eventually reaching 2300 g by day 28.

Discussion

The findings of this study provide robust evidence that Thiamethoxam, a widely used neonicotinoid insecticide, has significant adverse effects on the biology, development, and overall health of honey bee (*Apis mellifera*) colonies. These results are consistent with a growing body of literature that highlights the detrimental impacts of neonicotinoids on pollinators, particularly honey bees, which play a critical role in global ecosystems and agriculture. The observed effects on larval and pupal development, fecundity, colony growth, and resource storage underscore the multifaceted ways in which Thiamethoxam disrupts honey bee biology and colony dynamics.

Developmental and Reproductive Impacts

One of the most striking findings of this study is the significant prolongation of larval and pupal periods in honey bees exposed to Thiamethoxam, coupled with reductions in larval weight, pupal weight, and fecundity. These results align with previous studies that have documented the developmental toxicity of neonicotinoids. For instance, Wu-Smart and Spivak (2016) [17] demonstrated that sublethal exposure to neonicotinoids delays larval development and reduces the body weight of emerging adult bees, which can compromise their ability to perform essential tasks within the colony. Similarly, Henry *et al*. (2012) [9] found that neonicotinoid exposure impairs the foraging behavior of honey bees, which indirectly affects larval development by reducing the availability of high-quality nutrition.

The reduction in fecundity observed in this study is particularly concerning, as it suggests that Thiamethoxam may impair the reproductive capacity of queen bees. This finding is consistent with the work of Pettis *et al*. (2013) [11], who reported that neonicotinoid exposure reduces the sperm viability of drone bees and the egg-laying capacity of queen bees, ultimately threatening colony sustainability. The lack of significant effects on the egg period, however, indicates that Thiamethoxam may not directly interfere with the earliest stages of development. Instead, its primary impacts appear to manifest during the larval and pupal stages, potentially through neurotoxic mechanisms or disruption of hormonal regulation, as suggested by Aliouane *et al*. (2009) [1].

Brood Area and Colony Growth

The decline in brood area following Thiamethoxam exposure is a critical indicator of the insecticide's impact on colony growth and vitality. The initial reduction in brood area, followed by partial recovery, suggests that Thiamethoxam may impair the queen's ability to lay eggs or the workers' ability to care for the brood. This observation is supported by Schneider *et al*. (2012) [14], who found that neonicotinoids reduce brood production and delay colony development, leading to smaller and less resilient colonies. The partial recovery observed in this study may reflect a compensatory mechanism within the colony, such as increased egg-laying by the queen or improved brood care by workers. However, the fact that brood area in treated colonies remained significantly lower than in controls indicates that these compensatory mechanisms are insufficient to fully mitigate the negative effects of Thiamethoxam.

Pollen and Nectar Storage

The significant reduction in pollen and nectar storage in Thiamethoxam-treated colonies highlights the insecticide's impact on foraging behavior and resource collection. This finding is consistent with Gill *et al*. (2012) [6], who demonstrated that neonicotinoids impair the foraging efficiency of honey bees, leading to reduced pollen and nectar collection. The sharp decline in storage observed in this study suggests that Thiamethoxam may affect the bees' ability to locate and retrieve resources, or it may alter their motivation to forage. This could be due to the neurotoxic effects of neonicotinoids, which disrupt the bees' ability to navigate and communicate, as reported by Fischer *et al*. (2014) [5]. The lack of recovery in pollen and nectar storage over time further underscores the long-term negative effects of Thiamethoxam on colony resource management, which can have cascading effects on colony survival, especially during periods of resource scarcity.

Colony Weight

The progressive decline in colony weight in Thiamethoxam-treated colonies is a clear indicator of the insecticide's detrimental impact on overall colony health. This finding aligns with Tsvetkov *et al*. (2017) [15], who reported that chronic exposure to neonicotinoids leads to reduced colony weight and increased colony mortality. The decline in weight may be attributed to a combination of factors, including reduced brood production, impaired foraging efficiency, and increased worker mortality. These factors collectively contribute to a weakened colony structure, making it more susceptible to additional stressors such as

pathogens, parasites, and environmental changes (Doublet *et al*., 2015) [4].

Implications for Bee Health and Ecosystem Services

The results of this study have significant implications for bee health and the ecosystem services they provide. Honey bees are essential pollinators of both agricultural crops and wild plants, and their decline due to pesticide exposure poses a serious threat to biodiversity and food security (Potts *et al*., 2010) [13]. The findings of this study add to the growing body of evidence that neonicotinoids, including Thiamethoxam, are a major contributing factor to pollinator decline. This underscores the urgent need for stricter regulations on the use of neonicotinoids and the development of alternative pest management strategies that minimize harm to pollinators.

Moreover, the sublethal effects of Thiamethoxam observed in this study, such as reduced fecundity and impaired foraging, may have long-term consequences for colony survival and resilience. These effects are particularly concerning given the increasing prevalence of multiple stressors, such as habitat loss, climate change, and disease, which can interact synergistically with pesticide exposure to further exacerbate bee declines (Goulson *et al*., 2015) [3, 8].

Future Implications

This study demonstrates the adverse effects of Thiamethoxam on honeybee colony performance, including delayed development, reduced fecundity, and impaired resource management. Future research should investigate the long-term and cumulative impacts of neonicotinoids under field conditions, considering interactions with other stressors like pathogens and climate change. Exploring the mechanisms of Thiamethoxam's toxicity, its effects on other bee species, and the potential of lower, sublethal doses is essential. Developing alternative pest management strategies, such as integrated pest management (IPM) and biopesticides, is critical to minimize harm to pollinators. Policymakers should consider stricter regulations on neonicotinoid use, especially in pollinator-dependent crops, while promoting pollinator-friendly practices through education and awareness. This research underscores the need for sustainable agricultural practices to protect pollinators, ensuring ecosystem stability and global food security.

Conclusion

This study provides compelling evidence that Thiamethoxam adversely affects honey bee biology, colony growth, and resource management. The findings are consistent with previous research and highlight the urgent need for action to protect pollinators from the harmful effects of neonicotinoid insecticides. Future research should focus on understanding the mechanisms underlying these effects and developing strategies to mitigate the impacts of pesticides on pollinators. Policymakers and agricultural stakeholders must also prioritize the adoption of sustainable practices that balance the need for pest control with the preservation of pollinator health and ecosystem services.

References

1. Aliouane Y, El Hassani AK, Gary V, Armengaud C, Lambin M, Gauthier M. Subchronic exposure of honeybees to sublethal doses of pesticides: Effects on behavior. Environmental Toxicology and Chemistry. 2009;28(1):113-122.
2. Blacquière T, Smagghe G, van Gestel CAM, Mommaerts V. Neonicotinoids in bees: A review on concentrations, side-effects, and risk assessment. Ecotoxicology. 2012;21(4):973-992.
3. Bonmatin JM, Giorio C, Girolami V, Goulson D, Kreutzweiser DP, Krupke C, *et al*. Environmental fate and exposure; neonicotinoids and fipronil. Environmental Science and Pollution Research. 2015;22(1):35-67.
4. Doublet V, Labarussias M, de Miranda JR, Moritz RFA, Paxton RJ. Bees under stress: Sublethal doses of a neonicotinoid pesticide and pathogens interact to elevate honey bee mortality across the life cycle. Environmental Microbiology. 2015;17(4):969-983.
5. Fischer J, Müller T, Spatz AK, Greggers U, Grünewald B, Menzel R. Neonicotinoids interfere with specific components of navigation in honeybees. PLoS ONE. 2014;9(3):e91364.
6. Gill RJ, Ramos-Rodriguez O, Raine NE. Combined pesticide exposure severely affects individual-and colony-level traits in bees. Nature. 2012;491(7422):105-108.
7. Godfray HCJ, Blacquière T, Field LM, Hails RS, Petrokofsky G, Potts SG, *et al*. A restatement of the natural science evidence base concerning neonicotinoid insecticides and insect pollinators. Proceedings of the Royal Society B: Biological Sciences. 2014;281(1786):20140558.
8. Goulson D, Nicholls E, Botías C, Rotheray EL. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science. 2015;347(6229):1255957.
9. Henry M, Béguin 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(6079):348-350.
10. Klein AM, Vaissière BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, *et al*. Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society B: Biological Sciences. 2007;274(1608):303-313.
11. Pettis JS, Lichtenberg EM, Andree M, Stitzinger J, Rose R, vanEngelsdorp D. Crop pollination exposes honey bees to pesticides which alters their susceptibility to the gut pathogen Nosema ceranae. PLoS ONE. 2013;8(7):e70182.
12. Pisa LW, Amaral-Rogers V, Belzunces LP, Bonmatin JM, Downs CA, Goulson D, *et al*. An update of the Worldwide Integrated Assessment (WIA) on systemic insecticides. Environmental Science and Pollution Research. 2017;24(1):85-101.
13. Potts SG, Biesmeijer JC, Kremen C, Neumann P, Schweiger O, Kunin WE. Global pollinator declines: Trends, impacts and drivers. Trends in Ecology & Evolution. 2010;25(6):345-353.
14. Schneider CW, Tautz J, Grünewald B, Fuchs S. RFID tracking of sublethal effects of two neonicotinoid insecticides on the foraging behavior of Apis mellifera. PLoS ONE. 2012;7(1):e30023.
15. Tsvetkov N, Samson-Robert O, Sood K, Patel HS, Malena DA, Gajiwala PH, *et al*. Chronic exposure to

neonicotinoids reduces honey bee health near corn crops. Science. 2017;356(6345):1395-1397.
16. VanEngelsdorp D, Evans JD, Saegerman C, Mullin C, Haubruge E, Nguyen BK, *et al*. Colony Collapse Disorder: A descriptive study. PLoS ONE. 2008;3(12):e4071.
17. Wu-Smart J, Spivak M. Sub-lethal effects of dietary neonicotinoid insecticide exposure on honey bee queen fecundity and colony development. Scientific Reports. 2016;6:32108.