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NON-*APIS* POLLINATORS AND THEIR ROLE IN SUSTAINABLE AGRICULTURE

Amarjit S Tanda

School of Horticulture University of Western Sydney Richmond Australia
Current Address 2/49 Arthur Street Rose hill NSW 2142, Australia
Email: drtanda101@gmail.com

ABSTRACT

In providing pollination services to a diverse array of crops, the native bees are crucial and crops like cotton, soybean, coffee and canola, though self-pollinated, however, there is sufficient evidence that they can also get benefits by the utilization of non-*Apis* spp. Recent research reported that except graminaceous and cereal crops, all other crops mentioned herein have benefited from both *Apis* and non-*Apis* bees. New findings indicate that in cotton and soybean there are many aspects between the native bees and nutritional crops offering nectar and pollen to the bees need to be studied. To explore pollination technology, additional research into the fundamental biology, nesting habitats, foraging preferences and bee abundance are required. These will assist in comprehending the role of non-*Apis* pollinators in sustainable agricultural programs.

Key words: Non-*Apis*, pollination, foraging, native, bees, bee hotels, nesting sites, conservation, agriculture, sustainable

More than 35% of Earth's ice-free terrestrial area is under agriculture, and in several areas, farming is diversifying to encounter the increasing demands of world population Ayers and Rehan, 2021; Tanda, 2021a, b, c). This crop escalation minimizes the natural or semi-natural habitats for native non-*Apis* bees and various floral food resources (Deguines et al., 2014; Bosch et al., 2021; Tanda, 2021a,c). About 87% of the global wild and uncultivated plant flora including 308,000 species, are cross pollinated by insect pollinators (Ollerton et al., 2011). The population diversity non-*Apis* bees are chief in offering pollination services to a vast assortment of plants (Winfree et al., 2011; Tanda, 1984; 2019- 2021a-e). Klein et al. (2007) described that 60% of world food production arises from field crops which do not require pollination, however an additional 35% is driven from crops that rely on pollinators, and 5% are from unknown resources (Klein et al., 2007). They further demonstrated that about 30 crops are totally reliant on insect pollinators, 27 crops are moderately dependent and 21 crops are slightly dependent on pollinators. The flower pollination in 7 crops was not so significant and was of unknown importance for the remaining 9 crops (Klein et al., 2007).

Globally, honey bees, primarily *Apis mellifera* L., (Hymenoptera: Apidae) are the most important and precious crop pollinators, particularly in monoculture system. In the absence of these bee pollinators, production of many fruit, seed, and nut crops would decline by more than 90% (Winfree et al., 2011; Tanda, 2021a-e). New findings spotlight the worth and diverse abundance of non-*Apis* species in crop production through pollination activities globally (Garibaldi et al., 2014). Non-*Apis* bees adding with honey bee hives boost the fruit set of almonds, blueberries, and few others (Garibaldi et al., 2013). Garibaldi et al., (2013) reported that non-*Apis* bee pollinators mostly cross pollinated crops more efficiently. Crop flower visitation by the non-*Apis* and *Apis* bees enhanced fruit set separately, so pollination by the honey bees added rather than acted as an alternative for the non-*Apis* pollinators. Great research work has been conducted on strengthening the native bee populations and their beneficial aspects for enhanced agricultural productivity (Evans et al., 2018, Dainese et al., 2019, Woodcock et al., 2019; Tanda, 2021a-e). Many studies have been carried out in almonds, apples, other fruit, and nut crops where higher yield rely on the commercial services of honey bees (Sardinas and Kremen, 2015).

Regarding non-*Apis* bees, sufficient reports are not available from the agriculture sector that are not necessarily important to need the services of bees such as self-pollinating crops, however seem to have profited by the bee foraging activities. High populations of bumblebees were not associated to the semi-natural habitats in a crop landscape, but were operated by the mass-flowering of crops which are greatly rewarding to the flower visitors. In 4 weeks, Canola plants (about

350,000 to 700,000 plants per hectare) generate 100 flowers extra, whereas soybean can produce 800 florets per plant and about half-million florets per acre, offering in incredible food for bee pollinators (Gill and O'Neal 2015). Holzschuh et al., (2013) observed that in grasslands the number of *Osmia bicornis* L. brood cells in trap nests was 55% greater close to canola plantations as against to isolated grassland habitats. Our focus in this appraisal is to reframe the recent investigations on the non-*Apis* bee diversity and their abundance in chief mass producing flowering crops for instance cotton, soybean, graminaceous, and other important crops that are self-pollinating, for their utilization in sustainable agroindustry worldwide.

Cotton

To manage heliothine pests (Lepidoptera: Heliothinae) and the cotton boll weevil (*Anthonomus grandis* Boheman, Coleoptera: Curculionidae) was once operated by intensive insecticidal sprays (Luttrell et al., 2015). This was partially achieved by the use of transgenetically developed Bt cotton against the heliothine and the boll weevil management strategy (Luttrell et al. 2015). Though cotton is a self-pollinating species, it can also benefit from cross-pollination by insects, including bees (Esquivel et al., 2020; Tanda, 1983; 1984). The accessibility of cotton blossoms at the level of landscape as a floral resource for long period and a reduction in use of insecticides in the fields of cotton could be profitable to non-*Apis* bee species. In *Bombus*, *Diadasia*, and *Melissodes* (Hymenoptera: Apidae), *Agapostemon* (Hymenoptera: Halictidae), and *Perdita* (Hymenoptera: Andrenidae) non-*Apis* pollinators were reported foraging cotton blooms together with honey bees. With the abundance of non-*Apis* bees observed in the cotton, three species were sufficient to be effective pollinators for hybrid seed production in cotton alongwith *Melissodes* and *A. mellifera*. In spite of proof that non-*Apis* bees were important in hybrid cottonseed production, in most research experiments from 1970 to 2000 utilized honey bees. In Australia, Cunningham (2014) described 31 reports of honey bee pollination and its beneficial role in cotton production. Though honey bees are mostly found in cotton and refereed in cotton research, however utilization of these bees is unusual outside of the cotton fields.

In Mississippi and Texas, the native bee diversity within cotton fields comprised 33 and 41 bee species, respectively (Parys et al., 2020). The native bee groups were belonging to the genera *Agapostemon*, *Augochloropsis*, *Halictus*, *Lasioglossum* (Hymenoptera: Halictidae), and *Melissodes* predominately, but *A. mellifera* was observed in low numbers comparatively in both states. The most dominating bee species were related to the genera *Melissodes*, *Melissodes bimaculatus* (Lepeletier) (Hymenoptera: Apidae) in Mississippi, and *Melissodes tepaneca* (Cresson) (Hymenoptera: Apidae) in Texas state. In Texas, another research report described effective groups of 37 non-*Apis* bees and *M. tepaneca* was more dominating, however 15 other efficient flower pollinators were beetles and flies (Cusser et al., 2016). This abundant array of non-*Apis* bees foraging cotton blooms is not restricted to the states of United States. Research reports from Burkina Faso and Zambia described 32 and 20 non-*Apis* species, respectively (Mayes and Petrillo 2017, Stein et al., 2017). About 29 non-*Apis* species were reported in different reports and the highest populations of these bees were found in Brazil on cotton blooms (Pires et al., 2014, Cusser et al., 2019). In Zambia and Burkina Faso, Africa, the density of genus *Tetralonia* (Apidae) were next to the honey bees as the most dominant bee species working in the cotton plantations (Stein et al., 2017) and most interesting pollinators were belonging to *Eucerini* having *Melissodes* and *Tetralonia* species. In both the United States and Brazil and Africa, the bees related to this tribe were the most effective non-*Apis* pollinators being nesting in cotton fields.

In Brazil, Pires et al. (2014) demonstrated a positive correlation between the higher abundance of non-*Apis* bees and cotton seed weight improvement by 12% and an enhancement in the seed numbers by 17%. In a cotton pollination trial in Texas, Cusser et al. (2016) reported up to an 18% improvement in the weight of cotton seeds. Cotton bolls developed from flowers that were hand-pollinated with outcross pollen gave greater seed-cotton weights in comparison to the bolls produced from no outcross pollen or those were self-pollinated (Tanda, 1984, 2019). No significant difference was observed between bolls developed from hand pollinated and naturally pollinated flowers. Additionally, they observed a negative correlation between pollen limitation and pollinator abundance in their cotton trials, connecting these effective pollinators to enhanced cotton production (Cusser et al., 2016). Cotton yield and quality significantly enhanced in bolls by 62% developed after the foraging of honey bees and non-*Apis* bees in comparison to the bolls produced from blooms in Burkina Faso excluding bees (Stein et al., 2017). Among 26 non-*Apis* bee species found foraging cotton flowers, 20 of them effectively contributed in seed setting. The seed weight and fiber weight of cotton bolls when compared to other non-*Apis* bees, significantly improved after foraging by honey bees and *Tetralonia fraterna* Friese (Hymenoptera: Apidae) (Stein et al., 2017). In some cotton pollination studies using non-*Apis* bees, Esquivel et al., (2020) reported an increase in production from 12 to 15% from bolls developed from blooms pollinated by *M. tepaneca*. With new findings in cotton yield increases, there is a sufficient boost for cotton farmers to make excellent improvement in future for honey bees and non-*Apis* bee management and further conservation of biodiversity for sustainable agro ecosystem.

Soybean

With up to 800 florets/ plant and a half-million florets/ ac, soybeans (*Glycine max* (L) Merril), are a huge resource of both nectar and pollen that impacts the bee populations in whole regions (Gill and O'Neal 2015). Gill and O'Neal (2015) observed 28 and 39% of the non-*Apis* bees were dispersing soybean pollen in the fields of soybean. As common flower foragers, 3 species of bees in India and 6 species in North Carolina were reported from soybean fields, and no research was carried out on the potential use of non-*Apis* bees for hybrid seed production in soybean. About 23 species in Delaware, including 6 with soybean pollen loads in Wisconsin and ten species in Missouri were reported. About non-*Apis* biodiversity in soybean, in a recent study in Brazil, Milfont et al. (2013) found 14 bee species in fields with sweep nets. In Argentina, Le Féon et al., (2015) described 33 morpho species belonging to different taxa with modified bee bowls from a soybean field. Another report found 5 bee foragers to Argentinean soybean and recorded that 40% of the flower visitors comprised of non-*Apis* bees (Monasterolo et al., 2015). In soybean fields, 32 bee species were caught with bee bowls, and 38% of bees were carrying soybean pollen in Iowa (Gill and O'Neal 2015, Wheelock et al., 2016). More observations with bee bowls have collected 53 species in Ohio and 33 species in Indiana from the soybean fields (Dennis 2018; Cunningham-Minnick et al., 2019). As opposed to intensifying on agriculture, offering nesting sites and natural environment surrounding soybean crop for native wild bees has resulted in enhancing the crop yield (Cunningham-Minnick et al., 2019; St Clair et al., 2020). Many reports described greater soybean productions near to bee colonies and then a decrease at long distances (Santos et al., 2013).

Cereals

These are chiefly wind-pollinated crops, and are poorly allured than other floral resources and offer no nectar, there are reports that both honey bees and native bees forage such crops for pollen (Gill et al., 2014; Gill and O'Neal, 2015). Native bees and *Syrphid* flies are foraging 10 wind-pollinated crops which are economically crucial, comprising rice, corn, sorghum, jojoba and linseed (Saunders, 2018). Though corn (*Zea mays* L.) and sorghum (*Sorghum bicolor* L.) provide no nectar, honey bees have been regularly found visiting both crops for pollen (Keller et al., 2015). Corn and sorghum pollen grains have been found in pollen traps put on bee colonies in different fields globally (Alburaki et al., 2018; Wood et al., 2018). New findings showed that a diverse abundance of wild, solitary, ground-nesting non-*Apis* bees forage to corn flowers in the United States (Wheelock et al., 2016; Bhandari et al., 2020). The non-*Apis* bees foraging sorghum flowers are poorly inspected than those visiting corn crop, may be *M. bimaculatus* is reported to gather pollen. In South Africa, workers of the genus *Lipotriches* have also been found foraging sorghum. Pearl millet (*Pennisetum glaucum* (L.) R.Br.) crop foragers comprise honey bees, *Bombus impatiens* Cresson, and Halictids including *Lasioglossum* (Dialictus) *pilosum* (Smith). Foragers to rice (*Oryza* sp.) recorded were 4 species of honey bees (*Apis* spp.) and 6 species of Halictids in China (Pu et al., 2014). Wild rice (*Zizania aquatica* L.) panicle foragers included many species of bees, with *Bombus*.

Canola, oilseeds and other crops

Bee pollination needs in several oil seeds crops have been spotlighted by Abrol and Shankar (2012). Canola (*Brassica napus* L.) is a mass-blooming crop with entomophilous blossoms manufacturing abundant quantities of nectar, making them greatly allured to the bee pollinators. Honey bees with non-*Apis* species such as *Andrena*, *Agapostemon, Bombus*, *Lasioglossum Halictus*, *Melissodes*, and have been recorded foraging flowers in canola fields. Additionally, native bees having an affection to canola blossoms, there is a proof showing insect foragings enhance canola production. New research have reported a powerful, positive correlation between the population and diversity of bees and decreased pollination deficit. Three species of bees especially *Apis dorsata* F., *Apis florea* F. (Hymenoptera: Apidae), and *Halictus* spp. were described to improve the pod length, pod weight, and the number of seeds per pod developed from the flower foraging in comparison to flowers keep out from other bee pollinators (Ali et al., 2011). In several tropical countries, coffee, lowland coffee (*Coffea canephora* Pierre ex. A Froehner), and highland coffee (*Coffea arabica* L.) are crucial cash crops. Although *C. canephora* is self-sterile and basically wind-pollinated and *C. arabica* is self-fertile, both can gain from foraging by non-*Apis* bees for efficient out-crossing and enhanced fruit setting and production. About 15.8% enhancement in fruit set in *C. canephora* was found as compared to a 12.3% increase in fruit set in *C. arabica* when cross-pollinated by non-*Apis* bees. Investigations have described gains from bee pollination and enhanced production in faba bean (*Vicia faba* L.). In Brazil, Giannini et al. (2015) reported faba beans as having a moderate reliance on bee pollination. In Germany, few findings described that honey bees were only seen collecting nectar from flowers, though bumble bees were the most effective flower pollinators (Marzinzig et al., 2018).

CONCLUSIONS

An unusual decrease in insects, along with non-*Apis* bees, that offer important environmental services like flower pollination to a large number of food crops has been recently spotlighted (Potts et al., 2010). There are many aspects to the talk on honey bees and non-*Apis* bee reduction, especially in the United States, including natural enemies and exposed to insecticides (Greenop et al., 2020; Main et al., 2020). Many of these managed non-*Apis* bees have great contribution as part of the pollinator-reliant crops, comprising the alkali bee (*Nomia melanderi* Cockerell (Hymenoptera: Halictidae) and the alfalfa leaf cutting bee (*Megachilie rotundata* F. (Hymeoptera: Megachilidae)) in alfalfa and fruit crops (Pits-singer and Cane 2011). Crops like cotton, soybean, canola, coffee, and faba bean greatly benefit from non-*Apis* bees in enhanced food production. Due to the intensification of farming practices, these non-*Apis* bees are adversely affected due to the destruction of their natural habitats and nesting sites. The abundance of non-*Apis* bees is not only significant in the self-pollinated as mass-flowering crops but also in many other crops which have not yet totally investigated (Tanda, 2019-2021a-e).

Further studies on mass-flowering crops like soybean and cotton are still required to assess the economic gains they may have on wild bees as in canola production. New corn cultivars can manufacture about 2.2 to 3.3 million pollen grains per plant, developing a big food resource for native insect fauna. The farming of traditional wind-pollinated crops for maximum flower production to feed large wild bee populations is presently not studied being hidden gains including bio-diverse agro-eco services (Tanda, 2021d,e). Several research reports on non-*Apis* bees in crop processes, as in self-pollinating crops cultivated in the similar areas globally show that recent cropscapes seem to be controlled by generalist species of bees in abundance (Wheelock et al., 2016; Parys et al., 2020). Comparative studies to assess different bee species in various crop plants in the same geographic area need detailed investigations. Several reports are under valuated in the natural ecosystem due to morpho species, particularly in the *Lasioglossum (Dialictus)* community (Gibbs, 2011). These crop pollinators are not only difficult to identify, however no keys are available for several species found in the western United States for comparative research or across crops impossible in the absence of availability of the preserved specimens (Gardner and Gibbs, 2020), except a few updated revised keys for identification in the eastern US and Canada (Gibbs 2010, 2011). Comparing the collection techniques, there is no one sampling method available to collect this bee group in an experimental areas (Geroff et al., 2014; Gill and O'Neal, 2015; Prendergast et al., 2020). Bee bowl single sampling technology captured huge individuals of *Halictidae* in several trials, but not in cotton research investigations (Parys et al., 2020; Portman et al., 2020).

Such mass-flowering and self-pollinated crops, can shelter a diverse array of non-*Apis* crop pollinators. Unlike canola prominent farming, mass-flowering crops supporting to wild bee pollinators, more research is required to determine potential food production values of non-*Apis* bees in crops including soybeans and cotton where reports are insufficient. To assess the basic methods, more work in fundamental biology and history, alongwith suitable habitats, nesting sites and foraging preferences of bees will aid in comprehending diverse bees species appear to persevere in diversified agro ecosystems as in cotton yield. This fact is important to design plans to strengthen and preserve bee abundance of non-*Apis* native bees in plant crop areas. With comprehension of nesting sites, appropriate habitats and bee preferences, strategies to conserve pollinators abundance can be reframed in harmony with managed-bee crop pollinators for instance the alkali bee (*Nomia melanderi* Cockerell), the alfalfa leaf cutter bee (*Megachiliae rotundata* F.), and other leaf cutter bee species like *Omsia spp*. To allure the gregarious alkali bees, the soil protection is in practice in areas of Washington State and Oregon where alfalfa is grown for seed production. Bee hotels, houses/ boxes are provided in fruit and nut plantations to offer nesting sites for native bees and conserve managed *M. rotundata* which are engaged in almond production (Pitts-Singer and Cane, 2011).

It's evident that with research reports on these self-pollinating crops, there seems to be clear gaps in the non-*Apis* native bee studies in various practices of farming designs. We here propose a bio-ecological hypothesis for studying in more details, self-pollinating crops for maximum economic gains using non-*Apis* bee species, offering them suitable habitats, abundant nesting sites surrounding the crop fields, redesigning farming procedures and using new bee population multiplication strategies under variable climatic environments. In cotton and soybean there are several aspects still need to be investigated between the native non-*Apis* bees and the nutritional advantages of nectar and pollen to the bee pollinators (Tanda, 2019- 2021a-e). Also, more studies are needed that investigate Correlations of crop cultivars and their efficiency in nectar and pollen manufacturing, or lack thereof, and their interplays between native bee species. Pollen and nectar quantities vary in soybean cultivars, however their nutritional worth to native wild pollinators needs to be studied or of any investigations in cotton or fava. Fighting the destruction in non-*Apis* bee populations could be alleviated by restructuring the agricultural patterns to add both mass-flowering crop cultivars that offer essential healthy nutrition to bees and safeguarding the natural and semi-natural habitats to supply nesting refuges for bee fauna multiplication. Still more significant studies are required on the potential economic benefits of bee foraging in several self-pollinating crops for sustainable agriculture.

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