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# DEFENSIVE BEHAVIOUR RELATIONS OF *APIS CERANA HIMALAYA* AND PREDATORY WASP AT MID-HILLS OF MEGHALAYA

**RACHNA PANDE+, SANDIP PATRA*, SAMARENDRA HAZARIKA** AND RAMKRUSHNA GI*****

*Division of Crop Protection; **Division of Natural Resource Management;
***Division of Crop Production,
ICAR Research Complex for NEH Region, Umiam, Meghalaya 793103
+Present address: Division of Crop Protection,
ICAR-Central Institute for Cotton Research, Nagpur 440010
+Email: rachna.ento@gmail.com (corresponding author)

**ABSTRACT**

**Prey predator interaction was investigated between native bees of Meghalaya *Apis cerana himalaya* and predatory wasp. The study was aimed to know the capability of native bees against the predatory wasps and the mechanism involved under natural condition. We have analyzed the response of honey bees and wasp towards each other under different parameters. Attack of wasp significantly reduced the number of foragers during peak dearth period. The main defensive behaviour exhibited by honey bees was balling reaction. Number of dead wasp was more when intensity of attack increased, as honey bees killed maximum 13 wasps by losing only 0.67 bees during 3rd week of August. The thermal lethal limit of both prey and predator was different which reflect the safety factor in heat ball reaction for honey bees. The overall result showed that native bee has well organized defense system against the predatory wasp.**

**Key words:** *Apis cerana himalaya*, balling, dearth period, defensive behaviour, foragers, Meghalaya, predatory wasps, safety factor, thermal lethal limit

Honey bees are the important pollinator of wide variety of ecosystem (Suttle, 2003; Jha and kremen 2013). Their colonies are targeted by various diseases and insects especially during dearth period (Gulati and kaushik, 2004; Indu-Varshneya et al., 2009; Pande et al., 2015). Among them, worldwide predatory wasps (Vespinae) are one of the serious enemies of native honey bee (*Apis cerana*) and introduced honey bee (*Apis mellifera*) (Wildman 1770; Shah and shah, 1991; Abrol, 1994; Ken et al., 2005; Abrol, 2006; Tan et al., 2007; Chhuneja, et al., 2008; Vishwakarma et al., 2012). Predatory wasps visit the apiary in search of food viz., bees or larva as protein source and nectar or honey as carbohydrate source (Matsuura and Yamane, 1990), causing up to 30% losses to the colony directly or indirectly (Sakagami and Akahira, 1960; Ken et al., 2005; Hanna, 2012).

It is well studied that more number of foragers indicates the good health of honey bee colonies. Attack of predatory wasp significantly reduces the number of foragers and fruit set (Hanna et al., 2012), play vitol role in absconding of colonies (Burgett and Akratanakul, 1982; Abrol, 2006). Although several management strategies have been developed against the predatory wasps but like other species on earth, honey bee itself has its behavioral defensive system viz., Bee-carpet behavior, shimmering (abdominal shaking) (Butler, 1954; Kastberger et al., 2008), hissing (alarm sound) (Sen et al., 2002; Papachristoforou et al., 2008), walls of propolis (to prevent entry of hornets into the hive) (Papachristoforou et al., 2011) and balling reaction.

Balling reaction is a well-defined defense strategy in most of the *Apis* spp. (Matsuura and Sakagami 1973; Ono et al. 1987; Alexander 1991; Kastberger and Stachl 2003; Tan et al., 2012) in which death of wasp is caused inside the ball because of heat, suffocation and bee sting. This strategy was found to be adopted prominently by Asian honey bees (Ono et al., 1987) specifically in response to predatory wasp (Matsuura and Sakagami 1973; Ken and Wang 2004). Many studies have described the defensive behavior performed by honey bees against predatory wasp. Ono et al. (1987) and Ichino and Okada (1994) reported the defensive balling reaction in *Apis cerana japonica* against the predatory wasp by generating heat and suffocation inside the ball, *A.cerana* against *Vespa mandarinia* in Asia (Ono et al., 1995; Ken et al., 2005; Sugahara and Sakamoto, 2009; Tan et al., 2012, 2013a; Sugahara et al*.,* 2012), *A. mellifera cypria* against *Vespa orientalis* in Cyprus (Papachristoforou et al*.,* 2007, 2008, 2011), *A. mellifera ligustica* against *V. crabro* in Italy (Baracchi et al*.,* 2010). Therefore, the present investigation was carried out to evaluate if local honey bee of Meghalaya *Apis cerana himalaya* possess any defensive strategy against predatory wasp or not.

## MATERIALS AND METHODS

Present study was carried out at the ICAR research complex of NEH Region, Umiam, during 2015-16 situated in the mid hills of Meghalaya (25° 41'21″ N, 91° 55'25″ E, 970 masl). Observations on attack of predatory wasp were recorded under natural condition from 3rd week of June 2015 to 3rd week of September 2015 which is considered as the peak rainy season of Meghalaya and dearth period for honey bees (Anonymous, 2013). The total annual rainfall of Umiam was 2551 mm with monsoon rainfall (June to September, 2015) of 1630 mm contributing 64% of the total annual rainfall. Population of predatory wasp reached its maximum during this duration (Abrol, 2006; Monceau et al*.,* 2013a, 2013b) because colony remains weak and become the soft target for all the natural enemies of honey bees.

For experimental trials, 10 colonies of native honey bee species *Apis cerana,* each with a uniform strength (8 frames) in terms of bees and broods were marked. Behavioural interactions between honey bees and wasps was observed visually in terms of strategies adopted by the wasp as a predator and counter attack skill adopted by the honey bees to save their colonies and bees. During investigation observations were made to the count the number of wasps visiting the apiary for 2 hrs during morning, midday and afternoon. Number of wasp returning with honey bees was also calculated by counting visually; and % success was calculated.

Wasp killed by bees in balling reaction was calculated to check the survival rate of wasps at the end of the balling reaction. For counting of honey bees involved in ball reaction after 3 min of ball formation, balls were sealed in a transparent Ziploc plastic bag, which was refrigerated for 3 to 4 mins for better visualization and easy counting of bees (Tan et al*.,* 2013a). Balling period was recorded in mins as time spent by honey bees after 3 min of ball formation up to death of wasp. loss of bee hours was calculated by following formula:

Loss of bee hours= (balling period x number of bees involved in balling)/60

An LCD Portable Multi-Stem Thermometer was used to measure the temperature inside the ball. Thermometer has measurement range of -50°C to + 200°C which was connected with a highly accurate (±0.1◦C) external sensing probe (Abrol, 2006). Number of bees killed in balling process was recorded visually by collecting dead bees involved in balling process. Thermal lethal limits of the honey bees *A. cerana* (N=15) and wasps (N=15) were recorded by placing three separate rearing and breeding cages in an incubator. Initial temperature was fixed at 42°C and raised 1°C every 20 min until all bees/wasps were found dead. For each degree increase in temperature number of dead bees and wasps were counted (Ken, 2005). Number of workers going out from the entrance of the hive was counted for one min at every 2 hr interval. Statistical software SPSS Version 16.0 for Windows was used to calculate mean and SEm. For comparison of mean values Tukey's HSD (honest significant difference) test at p=0.05 (SPSS, 2007).

## RESULTS AND DISCUSSION

**The observed n**atural behavioral interaction between honey bees and predatory wasp is depicted in Table 1. Defensive behaviour of bees may vary as it depends on the strength as well as (Arca et al*.,* 2014), genetics of the bees (Guzmán-Novoa and Page, 1993). In present study, different behavioural patterns among the worker honey bees were observed when colony was under attack of wasp. More than 50% bees remained gathered (bee carpet) on flight board, vertical walls near the entrance to attack the wasp and made hissing sound frequently. Other bees followed the movement of wasp. Wasp never attempted to visit the boxes in which flight board had bees' gathering. Wasp which had come in contact with gathered bees engulfed and faced ball reaction therefore tried to intercept or catch the foraging bees leaving or returning to the hive (Tan et al*.,* 2013b). Returning bees with pollen load were targeted by the wasp as they were heavier, slower and easy to catch (Arca et al*.,* 2014; Monceau et al*.,* 2013a). Against the response of wasp visits, bees of the few colonies sealed the cracks of boxes with propolis. Similar behavioural response viz., bee-carpet behaviour, sealing of cracks with propolis (Baracchi et al*.,* 2010; Papachristoforou et al*.,* 2011), was reported by many other workers.

Behavioural interaction studied in general trends showed that the average number of wasp visiting the apiary was 17.66 wasp/2h during June to September

Table 1. Behavioural interaction between honey bees and wasps (June to September 2015)

| Date of observation | No. of wasp observed/2hrs. | No. of wasp returning with bees | Success in bee capture (%) | Wasps killed in balling reaction | No. of bees involved in ball reaction | Balling period (min) | Loss of bees/ hour | Temperature inside the ball ($^0$C) | No. of bees killed in balling process | No. of forager bees/min. |
|---|---|---|---|---|---|---|---|---|---|---|
| 3rd week of June 2015 | $7.67^{a}\pm0.33$ | $3.33^{ab}\pm0.33$ | $43.43^{b}\pm3.62$ | $4.67^{a}\pm0.33$ | $153.33^{ab}\pm4.41$ | $52.00^{ab}\pm4.00$ | $132.77^{a}\pm10.38$ | $46.00^{a}\pm0.58$ | $0.33^{a}\pm0.33$ | $19.00^{c}\pm0.58$ |
| 1st week of July 2015 | $13.00^{b}\pm1.00$ | $3.00^{ab}\pm0.58$ | $23.88^{a}\pm5.80$ | $7.67^{abc}\pm0.33$ | $171.67^{bc}\pm6.01$ | $63.33^{b}\pm5.93$ | $182.38^{ab}\pm22.89$ | $44.67^{a}\pm0.88$ | $0.67^{ab}\pm0.33$ | $13.00^{b}\pm2.08$ |
| 3rd week of July 2015 | $17.33^{bcd}\pm1.20$ | $4.33^{bc}\pm0.33$ | $25.53^{a}\pm3.91$ | $7.33^{abc}\pm0.33$ | $171.33^{bc}\pm4.67$ | $61.00^{b}\pm7.55$ | $224.50^{b}\pm27.48$ | $46.33^{a}\pm0.33$ | $0.67^{ab}\pm0.33$ | $11.67^{b}\pm1.67$ |
| 1st week of August 2015 | $21.33^{d}\pm2.40$ | $5.00^{c}\pm0.58$ | $24.57^{a}\pm5.19$ | $10.00^{c}\pm1.15$ | $163.33^{b}\pm10.14$ | $57.00^{b}\pm5.51$ | $154.08^{a}\pm22.95$ | $45.67^{a}\pm1.20$ | $1.33^{b}\pm0.33$ | $10.00^{b}\pm0.58$ |
| 3rd week of August 2015 | $31.00^{e}\pm0.58$ | $7.33^{d}\pm0.67$ | $23.60^{a}\pm1.81$ | $13.00^{d}\pm1.53$ | $131.67^{a}\pm14.24$ | $67.00^{b}\pm3.21$ | $146.63^{a}\pm15.38$ | $45.67^{a}\pm0.88$ | $0.67^{ab}\pm0.33$ | $5.33^{a}\pm0.33$ |
| 1st week of September 2015 | $18.67^{cd}\pm1.86$ | $4.33^{bc}\pm0.33$ | $23.54^{a}\pm2.30$ | $8.00^{bc}\pm1.15$ | $190.00^{c}\pm5.77$ | $40.00^{a}\pm2.08$ | $126.38^{a}\pm4.96$ | $46.67^{a}\pm1.86$ | $0.00^{a}\pm0.00$ | $10.67^{b}\pm0.67$ |
| 3rd week of September 2015 | $14.67^{bc}\pm2.40$ | $2.00^{a}\pm0.58$ | $13.05^{a}\pm1.94$ | $6.33^{ab}\pm1.20$ | $151.67^{ab}\pm6.01$ | $50.00^{ab}\pm5.77$ | $125.33^{a}\pm15.81$ | $46.67^{a}\pm0.67$ | $0.00^{a}\pm0.00$ | $13.00^{b}\pm1.15$ |
| Mean | 17.66 | 4.18 | 25.37 | 8.14 | 161.85 | 55.76 | 156.01 | 45.95 | 0.52 | 11.81 |
| SD | 7.34 | 1.71 | 9.01 | 2.69 | 18.57 | 9.20 | 36.14 | 0.71 | 0.47 | 4.10 |

Thermal lethal limits

| Temperature ($^0$C) | Dead bees | Dead wasps |
|---|---|---|
| 42 | $0.00^{a}\pm0.00$ | $0.00^{a}\pm0.00$ |
| 43 | $0.00^{a}\pm0.00$ | $0.00^{a}\pm0.00$ |
| 44 | $0.00^{a}\pm0.00$ | $1.33^{b}\pm0.33$ |
| 45 | $0.00^{a}\pm0.00$ | $3.33^{c}\pm0.33$ |
| 46 | $0.00^{a}\pm0.00$ | $5.00^{d}\pm0.00$ |
| 47 | $0.00^{a}\pm0.00$ | - |
| 48 | $0.00^{a}\pm0.00$ | - |
| 49 | $0.67^{a}\pm0.67$ | - |
| 50 | $0.67^{a}\pm0.67$ | - |
| 51 | $1.67^{b}\pm0.33$ | - |
| 52 | $4.33^{c}\pm0.33$ | - |
| 53 | $5.00^{c}\pm0.00$ | - |

Values followed by same letters not significant at $p = 0.05$ (Tukey's HSD test) ranging from $7.67^{a}\pm0.33$ wasp/2h to $31.00^{e}\pm0.58$ wasp/2h during 3rd week of June and 3rd week of August respectively. Due to peak rainy season in Meghalaya (Anonymous, 2013), in month of August colonies become weaker owing to unavailability of food which attracts the wasp more. It is clear from the finding that population of wasp gradually increased in early rainy season and declined during late rainy season (Indu-Varshneya et al. 2009).

Number of wasp returning with bees depends on the intensity of the attack (Abrol, 2006). Average number of wasp returning with bees for whole experimental period was 4.18 which were maximum during 3rd week of August (7.33±0.67) and minimum during 3rd week of September (2.00±0.58) because till September bees got attack several times and develop a behavioural defense strategy against wasp. Minimum capture during 3rd week of September was not significant as compared to 3rd week of June and 1st week of July which was the starting point of dearth period and predation was at its initial stage. This data confirmed the tendency of wasp to start attack with onset of dearth period and stop with end of dearth period. Maximum capture was directly related with maximum visit of wasp at apiary during same time period.

Success of wasp in capturing bees was 25.37%. Success of bee capture by wasp was minimum during 3rd week of September (13.05±1.94) and it was maximum (43.43±3.62) during 3rd week of June. Minimum% success was related with the minimum number of wasp returned with bees (2.00±0.58). However maximum success in bee capture was related with unawareness of the honey bees during initial week of attack which made them suffer more casualties in terms of %. Similar findings were observed by Abrol (2006).

During dearth period, number of wasp killed in balling reaction was 8.14. Highest number of dead wasps in balling reaction was observed in 3rd week of August (13.00±1.53) which had highest number of wasp visit (31.00±0.58) and lowest number of dead wasps in balling reaction was observed in 3rd week of June (4.67±0.33) which had lowest number of wasp visit (7.67±0.33) to the particular time period. Similarly study by Abrol, 2006 revealed that increase in the intensity of attack of hornets, corresponds to increase in the balling reaction of bees and the number of wasps killed. Honey bees had been attributed to make ball around the living predator and use the heat of ball and sting to kill the intruder (Ono et al*.,* 1987; Susan, 2005; Ono et al*.,* 1995; Ken et al*.,* 2005).

Depending on the intensity of wasp attack, number of bees involved in balling reaction may increase. Number of bees involved in balling reaction was 161.85, may go up to four to five hundred bees (Abrol, 2006) depends on the size of wasp (Tan et al*.,* 2013b). Maximum number of bees involved in ball reaction was found in 1st week of September (190.00±5.77) and minimum was in 3rd week of August (131.67±14.24). As fewer bees were involved in the process so more ball reaction had been occurred during that period therefore maximum number of dead wasp (13.00±1.53) was observed in same time period.

The balling period for honey bee to kill the predatory wasp was 55.76 min. Maximum balling period was observed during 3rd week of August (67.00 ±3.21 min) as minimum number of bees (131.67±14.24) was involved during that particular period for ball reaction so took highest time to kill the bees. Similarly least time was taken by bees during 1st week of September as maximum number of bees (190.00±5.77) was involved in balling reaction for that period. Similar result pattern was observed by Abrol (2006) that if the number of bees was higher, the time of balling was shorter. Mean loss of bee hrs for each colony was 156.01 hrs which was highest during 3rd week of July (224.50± 27.48) and lowest was in 3rd week of September (125.33±15.81).

Mean temperature inside the ball was $45.95^{0}$C. Similar finding was reported by Ken et al. (2005) and Arca et al. (2014). However, temperature recorded during different week period was not significant with each other but highest temperature was recorded during 1st and 3rd week of September ($46.67^{0}$C) and lowest was during 1st week of July ($44.67^{0}$C). Abrol (2006) reported the temperature inside the ball was ranging between 45 to 46.8°C with an average temperature of 45.19±0.51°C which was at par to our present study. More number of bees in balling reaction did not affect the temperature inside the ball (Ono et al*.,* 1995; Abrol, 2006) which is again in agreement of our present study as temperature inside the ball was at par in whole experimental period. After balling reaction dead wasp was found may be due to heat and suffocation (Sugahara and Sakamoto, 2009; Papachristoforou et al*.,* 2007). Though, it was against the observation of Baracchi et al. (2010) who observed the cause of death in balling reaction was due to bee sting and toxicity of bee venom.

Number of bees dead in ball reaction was 0.52. Number of dead bees was very less during ball reaction because balling reaction is an organized defense strategy of honey bees against predatory wasp (Abrol, 2006).

Minimum number of dead bees during ball reaction was observed in 1st and 3rd week of September (0.00) and maximum bees was found dead during ball reaction in 1st week of August (1.33±0.33). Very less number of bee casualties during balling reaction cleared the picture that *Apis cerana* had very well organized defense system of balling reaction against predatory wasp. Many authors have reported this behaviour in different bee species against the attack of wasp (Ono et al*.,* 1987; Abrol, 2006;, Ono et al*.,* 1995, Sakagami 1960; Butler 1962).

Number of foragers at different time period was significantly reduced according to the number of wasp attacked the colony with 11.81 forager/ min during whole study period. Maximum number of foragers/ min 19.00±0.58 was observed during 3rd week of June 2015 when least number of wasps (7.67±0.33) attacked the apiary. Similarly, minimum foraging with 5.33±0.33 number of forager/min was observed in 3rd week of August 2015 when apiary was attacked with maximum number of wasps (31.00±0.58). Number of foragers depends on the health of colony as the colony stressed with abiotic and biotic factors has less number of foragers (Ken et al*.,* 2005; Arca et al*.,* 2014; Pande et al*.,* 2015) the possible rationale can be ascribed to involvement of bees in defense strategy rather than foraging (Kastberger and Thenius, 2009; Monceau et al*.,* 2013a, 2013b; Papachristoforou et al*.,* 2011).

Thermal lethal limits of honey bees and predatory wasp was observed under laboratory condition (Table 1) and it was found that lethal limit of bees ranged from 49$^0$C to 53$^0$C as all the bees was dead when temperature reached to this maximum extent. Lethal limit of wasp was ranged from 44$^0$C to 46$^0$C as all the wasp was dead at this temperature range, which indicates that to kill the wasp bees had to increase the temperature up to 46 $^0$C. While recording the data of temperature inside the ball we found that during all the time period temperature inside the ball was 46$^0$C or near to 46$^0$C. Temperature higher than 44$^0$C was lethal to predatory wasp but not for the honey bees which are in concurrence with studies done by Ono et al. (1987) and Arca et al. (2014). Same lethal temperature for bees (48 – 50$^0$C) and wasp (44-46°C) was observed by Ken et al. (2005) and Abrol (2006). Susane (2005) also reported that the death of predatory wasps at 45.7°C, which is closer to our data, but for the Asian honey bees survived temperatures was up to 50.7°C which is not similar to our study.

Thus, it is evident that native honey bee of Meghalaya *Apis cerana himalaya* has a natural and well organized strategy for the defense of colony against predatory wasp and these wasps can be managed by honey bee itself. However, loss of bees and bee hours can be saved by adopting some physical management tactics and proper monitoring in apiary against this menace which may increase the production of honey. Future line of work may be focussed on to find out the likely reasons of reduction in number of forager by conducting different experiments viz., predation or risk of predation.

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**REFERENCES**

Abrol D. 1994. Ecology, behaviour and management of social wasp, *Vespa velutina* Smith (Hymenoptera: Vespidae), attacking honey bee colonies. Korean Journal of Apiculture 9: 5-10.

Abrol D P. 2006. Defensive behaviour of *Apis cerana* f. against predatory wasps. Journal of Apicultural Science 50(2): 39-46.

Alexander B. 1991. A cladistic analysis of the genus *Apis*. In: Smith DR (ed.), Diversity in the Genus *Apis*. Westview Press, Boulder.

Anonymous. 2013. Annual report ICAR Research Complex for NEH Region, (Indian Council of Agricultural Research) Umaim 793103 Nagpur.

Arca M, Papachristoforou A, Mougel F, Rortais A, Monceau K, Bonnard O, Tardy P, Thiery D, Ois Silvain J, Arnold G. 2014. Defensive behaviour of *Apis mellifera* against *Vespa velutina* in France: Testing whether European honey bees can develop an effective collective defence against a new predator. Behavioural Processes 106: 122-129.

Baracchi D, Cusseau G, Pradella D, Turillazzi S. 2010. Defence reactions of *Apis mellifera ligustica* against attacks from the European hornet *Vespa crabro*. Ethology Ecology & Evolution 22: 281-294.

Burgett M, Akratanakul P. 1982. Predation on the western honey bee, *Apis mellifera* L., by the hornet, *Vespa tropica* (L.). Psyche: A Journal of Entomology 89: 347-350.

Butler C G. 1954. The World of the Honey bee. Collins, London, 226pp.

Butler C G.1962. The World of Honey bee. 2nd edition, London.

Chhuneja P K, Singh J, Blossom, Gatoria G S. 2008. Population density of *Vespa orientalis* Linnaeus attacking *Apis mellifera* Linnaeus colonies in Punjab. Journal of Insect Science 21(2): 161-167.

Gulati R, Kaushik H D. 2004. Enemies of honey bees and their management- A Review. Agricultural Reviews 25(3): 189 -200.

Guzmán Novoa E, Page R. 1993. Backrossing Africanized honey bee queens to European drones reduces colony defensive behavior. Annals of the Entomological Society of America 86: 352-355.

Hanna C, Foote D, Kremen C. 2012. Invasive species management restores a plant-pollinator mutualism in Hawaii. Journal of Applied Ecology 50: 147-155.

Ichino H, Okada I. 1994. Japanese honey bees living in hornet nest. Honey bee Science 15(3): 123-124.

InduVarshneya, Pandey A K, Mall P, Rathore R R S. 2009. Seasonal incidence of predatory wasps in *A. mellifera* colony having different number of frames. Journal of Entomological Research 33(1): 45-49.

Jha S, Kremen C. 2013. Resource diversity and landscape-level homogeneity drive native bee foraging. Proceedings of the National Academy of Sciences 110: 555-558.

Kastberger G, Schmelzer E, Kranner I. 2008. Social waves in giant honey bees repel hornets. PLoS ONE3:e3141.

Kastberger G, Stachl R. 2003. Infrared imaging technology and biological applications. Behavior Research Methods, Instruments, & Computers 35: 429-439.

Kastberger G, Thenius R. 2009. Aggressive and docile colony defence patterns in *Apis mellifera*. A retreater releaser concept. Journal of Insect Behaviour 22: 65-85.

Ken T, Hepburn H R, Radloff S E, Yusheng Y, Yiqiu L, Danyin Z, Neumann P. 2005. Heat-balling wasps by honey bees. Naturwissenschaften 92(10): 492-495.

Ken T, Wang J M. 2004. Reduction of foraging activity by *A. cerana* colonies attacked by *Vespa velutina*. J Bee 2: 7-9.

Matsuura M, Sakagami S F. 1973. A bionomic sketch of the giant hornet, *Vespa mandarinia*, a serious pest for Japanese apiculture. Journal of the Faculty of Science 19: 125-162.

Matsuura M, Yamane S. 1990. Biology of the Vespine Wasps. Springer-Verlag, Berlin.

Monceau K, Arca M, Lepretre L, Mougel F, Bonnard O, Silvain J F, Maher N, Arnold G, Thiery D. 2013a. Native prey and invasive predator patterns of foraging activity: the case of the yellow-legged hornet predation at European honey bee hives. PLoS ONE 8: e66492.

Monceau K, Maher N, Bonnard O, Thiery D A. 2013b. Predation dynamics study of the recently introduced honey bee killer *Vespa velutina*: learning from the enemy. Apidologie 44, 209-221.

Ono M, Igarashi T, Ohno E, Sasaki M. 1995. Unusual thermal defense by a honey bee against mass attack by hornets. Nature 377: 334-336.

Ono M, Okada I, Sasaki M. 1987. Heat production by balling in the Japanese honey bee, *Apis cerana japonica* as a defensive behavior against the hornet, *Vespa simillima xanthoptera* (Hymenoptera: Vespidae). Experientia 43: 1031-1032.

Pande R, Thakur N S A, Ngachan S V, Rajkhowa D J. 2015. First record of wax beetle, *Platybolium alvearium* Blair (Coleoptera: Tenebrionidae), in Eastern Himalaya: A new threat to Indian honey bee (*Apis cerana* fabricius) colonies. Journal of entomological Research 39(3): 269-273.

Papachristoforou A, Rortais A S, Zafeiridou G, Theophilidis G, Garnery L, Thrasyvoulou A, Arnold G. 2007. Smothered to death: hornets asphyxiated by honey bees. Current Biology 17: 795-796.

Papachristoforou A, Rortais A, Sueur J, Arnold G. 2011. Attack or retreat: con-trasted defensive tactics used by Cyprian honey bee colonies under attack from hornets. Behavioural Processes 86: 236-241.

Papachristoforou A, Sueur J, Rortais A, Angelopoulos S, Thrasyvoulou A., Arnold G. 2008. High frequency sounds produced by Cyprian honey bees *Apis mellifera cypria* when confronting their predator, the Oriental hornet *Vespa orientalis*. Apidologie 39: 468-474.

Sakagami S F. 1960. Preliminary report on the specific difference behaviour and the other ecological characters between European and Japanese honey bee. Acta Hymenopterologica 1: 171-198.

Sakagami S, Akahira Y. 1960. Studies on the Japanese honey bee, *Apis cerana cerana* Fabricius. VIII. Twoopposing adaptations in the post-stinging behavior of honey bees. Evolution 14, 29-40.

Sen Sarma M, Fuchs S, Werber C, Tautz J. 2002. Worker piping triggers hissing for coordinated colony defence in the dwarf honey bee *Apis florea*. Zoology 105:215-223.

Shah F, Shah T. 1991. *Vespa velutina*, a serious pest of honey bees in Kashmir. BeeWorld 72: 161-164.

SPSS. 2007. Inc. SPSS for windows, Released version 16.0. Chicago, SPSS Inc.

Sugahara M, Nishimura Y, Sakamoto F. 2012. Differences in heat sensitivity between Japanese honey bees and hornets under high carbon dioxide and humidity conditions inside bee balls. Zoological Science 29, 30-36.

Sugahara M, Sakamoto F. 2009. Heat and carbon dioxide generated by honey bees jointly act to kill hornets. Naturwissenschaften 96: 1133-1136.

Susan M. 2005. Balls of fire: Bees carefully cook invaders to death. Science News Science News 168(13): 197.

Suttle K B. 2003. Pollinators as mediators of top-down effects on plants. Ecology Letters 6: 688-694.

Tan K, Hu Z, Chen W, Wang Z, Wang Y, Nieh J C. 2013a. Fearful Foragers: Honey Bees Tune Colony and Individual Foraging to Multi-Predator Presence and Food Quality PLOS ONE 8: (9) e75841.

Tan K, Radloff S, Li J J, Hepburn H. 2007. Bee-hawking by the wasp, *Vespa velutina* on the honey bees *Apis cerana* and *A. mellifera*. Naturwissenschaften 94: 469-472.

Tan K, Wang Z, Chen W, Hu Z, Oldroyd B P. 2013b. The 'I see you' prey–predatorsignal of *Apis cerana* is innate. Naturwissenschaften 100: 245-248.

Tan K, Wang Z, Li H, Yang S H, Kastberger Z, Oldroyd G B P. 2012. An "I see you" prey–predator signal between the Asian honey bee, *Apis cerana*, and the hornet, *Vespa velutina*. Animal Behaviour 83: 879-882.

Vishwakarma R, Singh R P, Ghatak S S. 2012. Incidence of insect enemies on honey bee, *Apis mellifera* L. during floral dearth period. Indian Journal of Entomology 74(1): 78- 81.

Wildman T. 1770. A treatise on the management of bees. Book III. Of wasps and hornets, and of the means of destroying them. 2nd edition. London.

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