Pakistan J. Zool., vol. 48(6), pp. 1811-1815, 2016.

Foraging Behaviour of *Hottentotta tumulus* (Fabricius, 1798) and *Odontobuthus odonturus* (Pocock, 1897)

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Article Information
Received 11 January 2016
Revised 31 March 2016
Accepted 24 May 2016
Available online 25 September 2016

Authors' Contribution
MHT conceived and designed the study, also helped in field collection and data analysis. MMA conducted field and laboratory work, and wrote the article.

Key words
Scorpions, Foraging, Prey, *Hottentotta tumulus, Odontobuthus odonturus*

A B S T R A C T

In the present study the foraging activities of two common scorpions *i.e*., *Hottentotta tumulus* (Fabricius, 1798) and *Odontobuthus odonturus* (Pocock, 1897) of Sargodha Division, Punjab, Pakistan were recorded in both the laboratory and field. Six different prey types were collected from the field and subjected to choice and no choice feeding experiments in the laboratory. Feeding activities of both scorpion species were also recoded directly in the field. Both scorpion species consumed significantly higher number of flies *i.e*., *Musca domestica* (Linnaeus, 1758) than other prey types (*i.e*., grasshopper nymphs, grasshopper adults, lycosid spiders, moths and house crickets) during no choice feeding experiment. However, in choice feeding experiment both scorpion species preferred grasshopper nymphs. Scorpions consumed only soft body parts of the larger sized prey but, consumed the whole body of small sized prey. Prey consumption of both scorpion species increased with temperature. However, consumption rate of studied species was found to be negatively correlated with the humidity level.

INTRODUCTION

Scorpions are the most primitive terrestrial arthropods (Ozkan *et al.,* 2007). Some species of scorpions are highly venomous (Gomes *et al.*, 2010) and cause health problems in humans (Bawaskar and Bawaskar, 2012; Kassiri *et al.*, 2012; Rafizadeh *et al.*, 2013). The bio-active molecules of scorpion venoms are being used in pharmaceutical research (Oukkahche *et al.*, 2008), anti-microbial studies (Harrison *et al.*, 2014), investigating anti-inflammatory (Menez, 1998) and anti-tumoral potentials (Cheong *et al.*, 2010), and production of eco-friendly bio-insecticides (Zlotkin *et al.*, 2000). Furthermore, scorpions are an integral part of natural ecosystems because of their importance in the food web (Bernhard *el al.*, 2005).

Being a natural predator, these arachnids play a vital role in the maintenance of prey populations in their habitat. Many scorpions have restricted ranges and inhabit specific habitats (Prendini, 2001). But habitat destruction and the pet trade are the leading causes of their extinction (Prendini *et al.*, 2003). Understanding the feeding behaviour of scorpions is crucial to maintaining them in the laboratory for venom extraction and conservation. The foraging activities of scorpions has been systematically examined by Polis (1990) and McCormick and Polis (1990). Scorpions prey upon insects, lizards and small rodents (Bernhard *el al.*, 2005).

Many researchers have studied the feeding behaviour of scorpions. For example, Casper (1985) found that adult emperor scorpion *i.e*., *Pandinus imperator* (Koch) feed on the common house cricket *Acheta domesticus* (Linnaeus, 1758) and do not use their venom to subdue prey. Rein (1993) studied the feeding behaviour of *Parabuthus* (Pocock, 1890) scorpions (Buthidae) and found that the scorpions avoid to use their stings on smaller prey type. Similarly, Candido and Lucas (2004), Schultze (1927), Yokota (1984) and Sarhan *et al.* (2013) also investigated the feeding activities of scorpions. Physiological aspects of prey capturing in scorpions have also been well studied (Brownell, 2001; Gaffin and Brownell, 2001).

For conservation of threatened scorpion species and rearing them in the laboratory, it is crucial to collect complete information about scorpion natural history *i.e*., habitat preference, reproductive season, and temperature and humidity preferences. The aim of present study was to record the foraging activities (*i.e*., prey preference and prey consumption rate) of *Hottentotta tumulus* (Fabricius, 1798) and *Odontobuthus odonturus* (Pocock, 1897) in the laboratory and in their natural habitat. Effect of temperature and humidity level on prey consumption of these scorpions was also studied.

MATERIALS AND METHODS

Scorpion collection

H. tumulus were collected from old muddy houses and grassy fields in rural areas of the Sargodha District

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0030-9923/2016/0006-1811 $ 8.00/0

(*i.e*., Bhagtanwala, Chak # 34/SB, Mateela, Chak # 104/NB, Chak # 120/ SB, Doda, Midh Ranjha and Mianwali (*i.e*., Chak # 16/DB). However, *O. odonturus* were captured from semi-sandy areas of Shorkot (*i.e*., Malumor, Aliabad, Kholara) and Sargodha (*i.e*., Dodha). Portable battery operated ultraviolet (UV) lamps were used to collect live specimens of both species at night. corpion sampling was accomplished during May to October 2013 and 2014.

Scorpion rearing

During rearing, pregnant (inactive and egg bearing) females, juvenile bearing females, injured and small sized scorpions were separated from the bulk field collection and placed in separate round bottom flasks (1000 ml). Only the healthy male adult scorpions (7.3 cm to 8 cm) were included in the experiments. To avoid cannibalism, each male adult scorpion was reared in different flasks (1000 ml). Flasks were covered with mesh cloth and maintained at 33–38˚C (temperature), 60–70% (humidity) and 10:14 h (light:dark cycle).

Prey collection

For recording the foraging activity of scorpions in the laboratory, common prey items *i.e*., grasshopper nymphs and adults, *Acrida conica* (Fabricius, 1781) (Orthoptera: Acrididae); houseflies, *Musca domestica* (Linnaeus, 1758) (Diptera: Muscidae); lycosid spiders, *Pardosa sumatrana* (Thorell, 1890) (Araneae: Lycosidae); moths, *Manduca quinquemaculata* (Haworth, 1803) (Lepidoptera: Sphingidae); and house crickets, *Acheta domestica* (Linnaeus, 1758) (Orthoptera: Gryllidae) were collected from scorpion habitats. For prey collection sweep nets and suction device (Siemens VK20C01) was used (Butt and Tahir, 2010).

No-choice feeding investigations in laboratory

All the scorpions were fed up to their satiation level and then kept without food for 7–9 days to standardize their hunger level. Ten flasks (1000 ml), each carrying an adult male scorpion, were used for the experiments. After 30 minutes of acclimation, each scorpion was offered a fixed number of grasshopper nymphs (n = 10), grasshopper adults (n = 5), houseflies (n = 20), lycosid spiders (n = 20), moths (n = 10), or house crickets (n = 10). A separate experiment was performed for each prey type. Control flasks (n = 5) also contained the same number of prey as in the experimental flasks but no scorpions were present. Although the number of different prey offered varied, the total density of prey was kept constant. The number of prey killed or consumed by each scorpion in the experimental group and the number of prey that died in the control group, was assessed after every 4 h till 24 h. The experiment was repeated thrice.

Choice feeding investigations in laboratory

In the choice feeding experiment, 10 round bottom flasks (1000 ml), each containing one scorpion was used. After an acclimation period of 30 minutes, a mixture of six prey types (*i.e*., grasshopper nymph (n = 10), grasshopper adult (n = 5), houseflies (n = 20), lycosid spiders (n = 20), moths (n = 10) and home crickets (n = 10), was offered to the scorpion of each flask. The number of prey consumed by scorpions was recorded every four hours for 24 h to determine their prey preference. This experiment was also repeated thrice.

Field observations for scorpion foraging behaviour

From May to October (2013 and 2014) foraging activities of *H. tumulus* and *O. odonturus* were observed directly in the field. Light emitting diode (LED) torches were used to observe the feeding activities of scorpions at night. Field study was conducted from 8–11 PM as both species were found active during this time frame. We walked in the fields randomly and whenever a scorpion was found eating a prey, it was identified to the lowest possible rank. Unidentified prey/remains of prey (if available) were brought to the laboratory for confirmation of their taxonomic status.

Effect of temperature and humidity level

The effect of temperature on scorpion feeding was recorded both in laboratory and field. Ten round bottom flasks (1000 ml), each containing an adult male scorpion, was used. Each scorpion was offered grasshopper nymphs (n = 10) at different temperatures (*i.e*., 20°C, 25°C, 30°C, 35°C and 40°C) in the laboratory. The number of grasshopper nymphs consumed by each scorpion was recorded after 24 h. Feeding activities (number of prey and scorpions encountered/hour) at different temperature and humidity levels, were also recorded directly in the field.

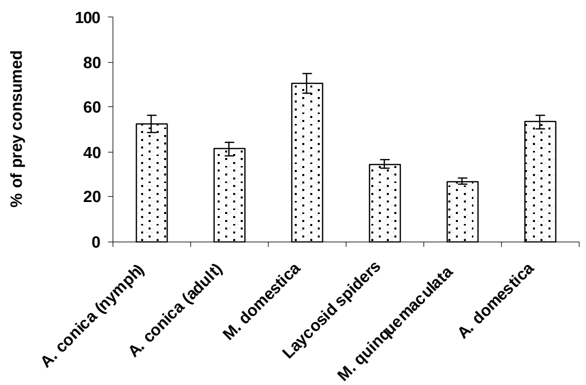
Statistical analyses

Normality of data was observed before applying any statistical analyses and a Chi- square test (χ^2) was used to compare the consumption rate of different prey types. Prey consumption of two scorpion species was compared using a two sample t-test. Pearson correlation was applied to find the relationship of prey consumption of scorpions with temperature and humidity levels. All statistical analyses were performed using MINITAB 14. Results were considered significant if P-value was $P<0.05$.

RESULTS

No choice feeding in laboratory

Both scorpion species consumed significantly higher number of houseflies (*M. domestica*) than other prey types (χ^2 =; df = 05; P < 0.001 for *H. tumulus* and χ^2 =; df = 05; P < 0.001) *O. odonturous*, Fig. 1). However, when both species of scorpion were compared for number of prey consumed, a non-significant difference was observed (t = 0.17; df =10; P = 0.86). Both scorpion species consumed the whole body of small sized prey (*i.e*., nymph of *A. conica, M. domestica,* lycosid spiders and *A. domestica*). However, they consumed only soft body parts of the large prey offered (*i.e*., *A. conica* and *M. quinquemaculata*).



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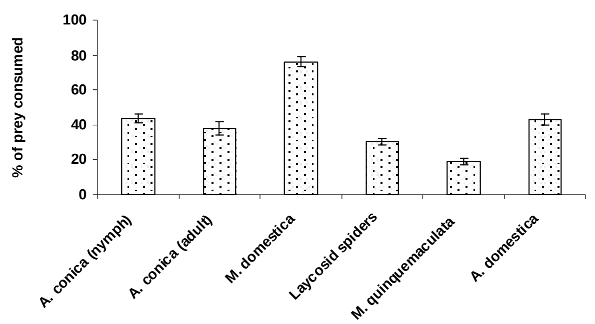

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Fig. 1. No choice feeding in *H. tumulus* (A) and *O. odonturus* (B). Error bars in the figure are representing standard errors.

Choice feeding in laboratory

The order of prey preference of *H. tumulus* was grasshopper nymph (*A. conica*) > grasshopper adult (*A. conica*) > home crickets (*A. domestica*) > moths (*M. quinquemaculata*) > lycosid spiders and houseflies (*M. domestica*). However, the order of prey preference was grasshopper nymph (*A. conica*) > houseflies (*M. domestica*) > grasshopper adult (*A. conica*) > house crickets (*A. domestica*) > moths *(M. quinquemaculata)* and lycosid spiders for *O. odonturus.* Both species preferred grasshopper nymphs over the other offered prey types.

Direct field observations

At night *H. tumulus* feeds on house crickets (*A. domestica*), black crickets (*Gryllus pennsylvanicus,* Burmeister 1838), grasshopper adults (*A. conica*) and moths (*M. quinquemaculata*). But during the day, the most preferred prey of *H. tumulus* were houseflies (*M. domestica*). *O. odonturus* mostly preys on black crickets (*G. pennsylvanicus*) in the field.

Effect of temperature and humidity

Results of laboratory and field studies showed that both scorpion species more actively feed at higher temperatures rather than lower temperatures (Fig. 2). Our field study also revealed similar results for both scorpion species. A significant, positive, correlation was found between temperature and prey consumption of scorpions (r^2 = 0.779 for *H. tumulus* and r^2 = 0.709 for *O. odonturus*). However, prey consumption was negatively correlated with humidity levels in the field (r^2 = -0.594for *H. tumulus* and r^2 = -0.679 for *O. odonturus*). Statistically significant difference in prey consumption was recorded at different temperatures (χ^2 =; df = 04; P < 0.001 for both scorpion species).

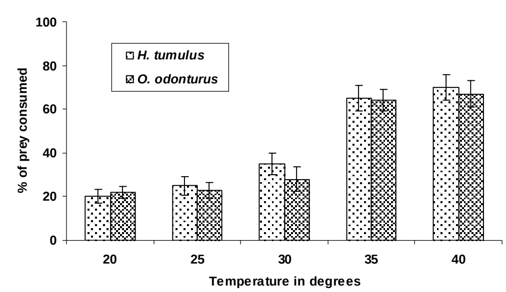

Fig. 2. Effect of temperature on feeding activities of O. *odonturus* and *H. tumulus* in the laboratory.

DISCUSSION

In the present study feeding activities of the two most common scorpions *i.e*., *H. tumulus* and *O. odonturus* of Punjab, Pakistan were observed on different prey types. Although in no choice feeding experiments both species consumed more flies (*M. demestica*) compared to other prey types, choice feeding experiments revealed that both studied species preferred grasshopper nymphs. The soft body parts of grasshopper nymphs might be the reason for higher consumption of these organisms than other offered prey species. Grasshopper nymphs spend more time on the ground compared to adults, which might make it easier for scorpions to catch them. Scorpions might also save their time and energy by selecting nymphs of grasshopper over the adults, which are difficult to handle.

H. tumulus uses a sit and waits strategy for capturing the prey that is in accordance to the finding of McCormick and Polis (1990). *O. odonturus* are active foragers that chase their prey in the fields. They use a sensory physiological mechanism to capture grasshoppers and flies (personal observations). A grasshopper nymph produces vibrations while walking and flies produce noise and vibrations, which might be detected more easily by scorpion trichobothria (Brownell, 2001). These types of detection and prey capture were also documented Mineo and Calro (2006).

Both scorpion species consumed more houseflies (*M. domestica*) compared to other prey items during the no choice experiment. However, during the choice feeding experiment, we did not find flies as the preferred prey of scorpions. This might be due to their small size and less energy contents. It is feeding strategy of animals to attack large prey that have more energy contents to maintain their energy budget (Stephens *et al.*, 2007). Both studied species did not select moths (*M. quinquemaculata*) as a preferred prey. The reason might be the scales present on surface of moths that leads toward difficulty in consumption of prey. Scoble (1992) also elaborated that moths shed their scales when they encounter predators.

Our results showed that both scorpion species were more active during summer and that they attack more prey at higher temperatures. Bridges *et al.* (1997), Warburg *et al.* (1980) and Polis (1990) also reported that scorpion activity increases with rising temperature. This may be because scorpions reproduce during warmer months. During reproductive season, female scorpions require more protein and energy for egg development. Similarly, males need more energy to search for mates.

The present study indicates that scorpion feeding was reduced with increased humidity levels in the field at night. Similar results have been reported by Warburg *et al.* (1980) and Warburg and Ben-horin (1978). The metabolic rate of scorpions is inversely proportional to high humidity levels. This could be the reason for less scorpion activity in the field.

CONCLUSION

It is concluded that both scorpion species preferred grasshopper nymphs when they had different prey options. Prey consumption by these scorpions was high in warmer days. There is negative correlation between humidity and prey consumption by scorpions.

Statement of conflict of interest

Authors have declared no conflict of interest.

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