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Assessment of Predation Capability of Four Species of Spiders (Arachnida: Araneae) to Green Apple Aphid, *Aphis pomi* De Geer (Homoptera: Aphididae)

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ABSTRACT

Experiments in laboratory conditions were performed to determine the functional response of four species of spiders, *Pardosa altitudis* Tikader and Malhotra (Lycosidae), *Leucage celebesiana* Walckenaer (Teragnathiade), *Neoscona sillongensis* Tikader, (Araneidae), *Theridion manjithar* Tikader (Theridiidae) preying on different densities of green apple aphid, *Aphis pomi* De Geer (Homoptera: Aphididae). All four species of spiders exhibited a type II functional response on different densities of prey as determined by a non-linear logistic regression model. The estimates of maximum prey consumption per day were 58.9 for *N. sillongensis*, 53.4 for *P. altitudis*, 40.2 for *L. celebesiana*, and 34.5 for *T. manjithar* at highest density of green apple aphids (320 aphids). The search rates and handling time were estimated as 3.073 h^{-1} and 0.393 h for *P. altitudis*, 3.032 h^{-1} and 0.553 h for *L. celebesiana*, 3.043 h^{-1} and 0.362 h for *N. sillongensis*, 2.970 h^{-1} and 0.575 h for *T. manjithar*, respectively. Estimates of handling times of *T. manjithar* and *L. celebesiana* were significantly greater than those of *N. sillongensis* and *P. altitudis* and however, coefficient of search rate, didn't vary significantly in most of the treatments. Among all predator species, *N. sillongensis* and *P. altitudis* were more capable against green apple aphids as compared to *L. celebesiana* and *T. manjithar*. *N. sillongensis* was found to be the most potent predator as it possessed the high search rate with lowest handling time.

Key Words: Biological Control; Search Rate; Predation Capability; . Handling Time; · Functional Response

INTRODUCTION

The most common aphid species in apple orchards of Kashmir are the green apple aphid, *Aphis pomi* De Geer (Hemiptera: Aphididae) (Khan et al. 2009). It is a pest, feeding on sap from tender leaves, flower and buds which may lead to leaf curl and a vector of viruses (Hamilton et al. 1986, Blackman and Eastop 2007), reducing tree growth and non-structural carbohydrate concentration in young apple trees resulting in decreased fruit production (Fréchette et al. 2008).

The important natural enemies of *A. pomi* are predators including the coccinellids *Adalia teraspilota* (Hope), *Hippodamia variegata* (Goeze), *Harmonia eucharis* (Mulsant), *Calvia punctata* (Mulsant) and *Coccinella septumpunctata* (L.) (Coleoptera: Coccinellidae) (Khan *et al*. 2007, Khan and Mir 2008, Khan et al. 2009), spiders including *Pardosa altitudis* Tikader and Malhotra (Araneae: Lycosidae), *Leucage celebesiana* (Walckenaer) (Araneae: Teragnathiade), *Neoscona sillongensis* Tikader, *Neoscona mukerjei* Tikader (Araneae: Araneidae), *Cheiracanthium himalayensis* Gravely and Bal (Araneae: Miturgidae), *Theridion manjithar* Tikader (Araneae: Theridiidae) (Khan 2009, 2012a) and the Chrysopids, *Chysoperla carnea* (Neuroptera: Chrysopidae) (Mushtaq and Khan 2010a,b). Among the spiders, *P. altitudis, L. celebesiana*, *N. sillongensis*, *T. manjithar* are the most abundant and important predator species of green apple aphid other than coccinellids in Kashmir (Khan 2011, 2013) and understanding factors that contribute to its success as a predator may be practically important for enhancing its impact in pest aphid populations. The response of spiders to prey density is also of special importance because there is increasing evidence that spiders represent an underexploited source of predators for biological control programmes (Nyffeler and Benz 1987, Richert and Bishop 1990).

One of the most important criteria for evaluating the efficiency of a predator is its feeding response i.e. change in the number of prey that an individual predator kills as a function of prey density (Holling 1966). Holling (1966) identified three types of functional response based on the shape of the functional response curve. The functional response gives a quantitative description of the behavior of predator when it encounters different densities of its prey (Riechert and Lockley 1984). The two parameters widely used to describe the functional response are the predator's "attack rate" or "searching rate" (a) and its handling time (T_h) (Hassell et al. 1976). When a predator encounters different varying densities of prey, different values of a and T_h will characterize each predator: prey combination. The coefficient of searching efficiency estimates the steepness of an increase in predation with the satiation threshold (Hassell 1978). Thus, the objective of this study is to determine the functional response of *P. altitudis, L. celebesiana*, *N. sillongensis* and *T. manjithar* feeding on the various densities of green apple aphid *A. pomi*. This information will enhance our understanding about their pradtion capability and their realative contribution towards keeping the pest population under check in field conditions.

MATERIALS AND METHODS

Predator and Prey Rearing

The four species of spiders viz., *Pardosa altitudis* Tikader and Malhotra, *Leucage celebesiana* (Walckenaer), *Neoscona sillongensis* Tikader and *Theridion manjithar* Tikader. were collected from apple orchard of Kashmir, India during 2009 in the month of June-July and maintained in culture room in vials (4 centimeter diameter and 5 centimeter height) indivi-dually at 25 ± 2°C temperature, 70 ± 10% relative humidity and a photoperiod of 14 hour light: 10 hour dark and provided sufficient green apple aphids as prey. Green apple aphid, *Aphis pomi* De Geer were reared on potted apple plants at 21± 1°C and 70 ± 10% relative humidity and a photoperiod of 14 hour light: 10 hour dark. The apple plant were planted (height upto 30 cm) in potted cage that were filled with sawdust and supplemented with micro and macro nutrients (2% solution of water) every 3 days.

Functional Response

The females of all four species of spiders were taken from the culture for experiments and starved for 24 hr in vials (4 cm diameter and 5 cm height) individually before the experiments. This was to minimize differences in individual hunger levels (Nakamura 1977). Thereafter, they were introduced individually in plastic container (height 20 cm and diameter 15 cm) together with green apple aphids density of 10 20, 40, 80, 160 and 320 per vial on excised apple leaves stuck to agar medium. The test predators were randomly assigned to the aphid density treatments and one treatment (control) was also designed for natural mortality of aphids. At each aphid density 10 replicates were used for female of four species of spiders. After 24 hours, the numbers of preys consumed by the species of spiders were recorded by counting the remaining live green apple aphids present in each cage.

Data Analysis

Data analysis for functional responses based on two steps (Juliano 2001). The type of functional response is determined in the first step. The type of functional response (type II or III) was determined using logistic regression analysis of the proportion of eaten prey versus initial number of prey offered (Trexler et al. 1988). To do this, data were fitted to a polynomial logistic regression (Juliano 2001) (equation 1):

$$\frac{N_e}{N_0} = \frac{P_0 + P_1 N_0 + P_2 N_0^2 + P_3 N_0^3}{1 + \exp(P_0 + P_1 N_0 + P_2 N_0^2 + P_3 N_0^3)}$$

where N_e express the number of prey consumed, N_0 the initial prey density and P_0, P_1, P_2, P_3 are the intercept, linear, quadratic and cubic coefficients, respectively. The above six data sets were fitted individually to equation 1 and types of functional responses were determined by examining the signs of P_1 and P_2. If the positive linear parameter P_1 together with a negative quadratic parameter P_2 would indicate a type III functional response, whereas if the linear parameter is negative, a type II functional response is indicated (Juliano 2001).

Nonlinear least squares regression analysis indicated that the data fit to Holling's Disc equation (Holling 1959) for type II functional response:

$$N_a = \frac{a(N/V)T_t}{1 + aT_h(N/V)}$$

where, N_a is the number of prey consumed by one predator during a time period T_t. N is the initial prey density; V is the volume of the experimental cage and a and T_h are as above. This equation gives a measure of instantaneous predation (Royama 1971, Rogers 1972). In contrast, the "random predator equation (3)" of Rogers (1972) takes prey exploitation into consi-deration. It is derived from

$$\frac{dN}{dt} = -\frac{a(N/V)}{1 + aT_h(N/V)}$$

This integrates to
:

$$N_a = \left(\frac{N}{V}\right)\left(1 - \exp\left(-a(T_t - T_h N_a\right)\right)$$

Equation 4 now allows a and T_h to be calculated by iteration from experiments in which the consumed prey individuals are not replaced. In order to avoid the errors incurred by applying the linear regression method to estimate a and T_h as suggested by Rogers (1972), we used the non-linear function (nls) provided by the R-software (R Development Core Team 2014).

RESULTS

Studies on functional responses provide insights into the suitability of a predator as a biocontrol agent. In all experiments, the number of aphid consumed by all four spider species was found to increase with increasing aphid densities at a decreasing rate (Figure 1, Tables 1 and 2). The linear coefficient (P_1) in the polynomial logistic regression of the proportion of green apple aphid consumed versus initial density was negative for all the four species of predators. The functional responses were therefore fitted to Holling's Disc equation (2). The *N. sillongensis* adult female consumed the maximum number of *A. pomi* (58.9/24 h) at highest densities (Figure 1 c) which was higher than that of *P. altitudis* (53.4/24 h), *L. celebesiana* (40.2/24 h) and *T. manjithar* (38.5/24h) (Figures 1 a, b, d).

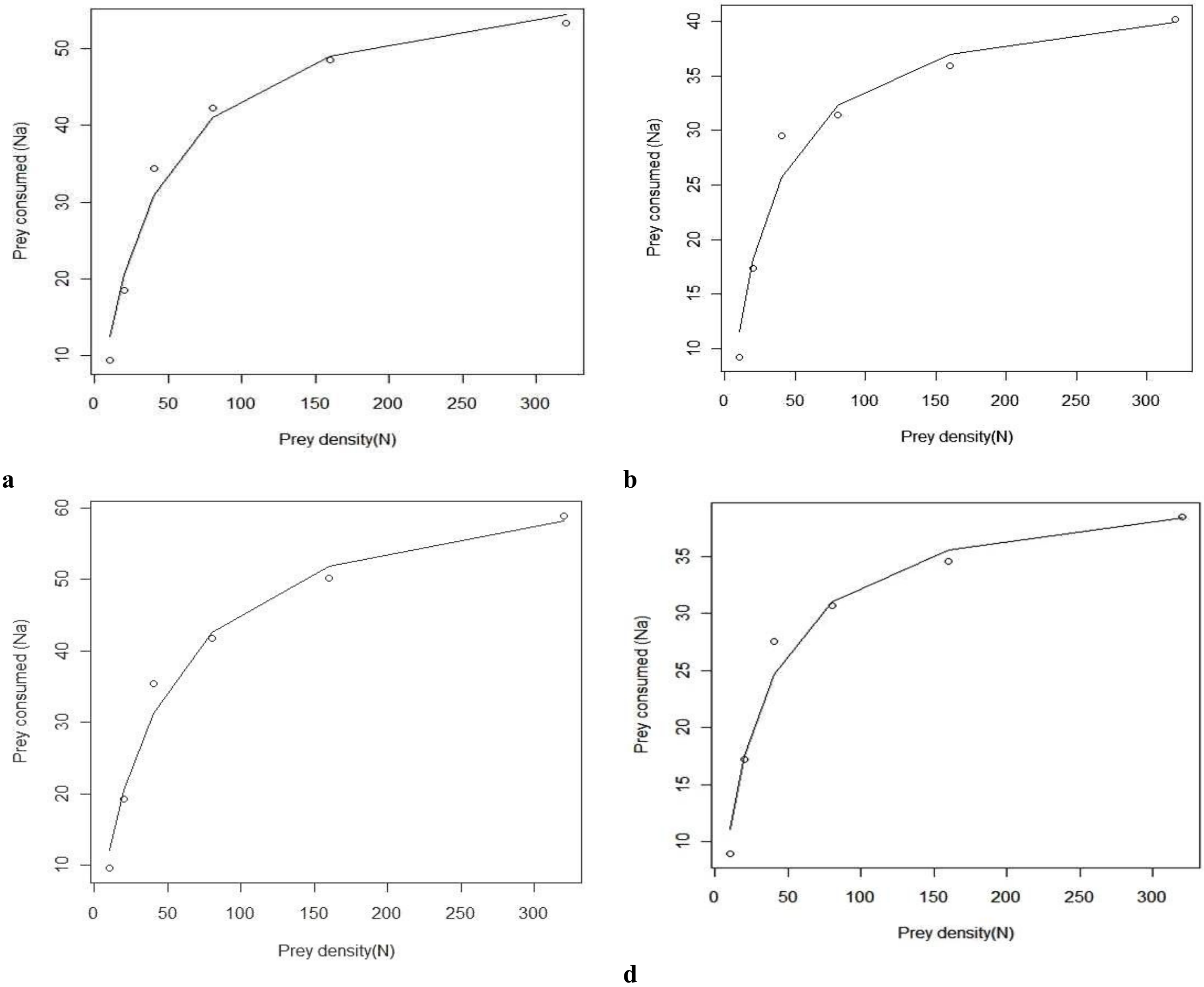
Table 1. Results of logistic regression analysis of the proportion of green apple aphid (*A. pomi*) eaten by different spiders against initial number of aphid offered.

Spider species	Coefficient	Estimate	SD	*Z* value	Pr(>|z|)
P. altitudis	Constant(P_0)	4.03600	0.9636	4.189	<0.0001
	Linear (P_1)	-0.07450	0.0249	-2.988	0.0028
	Quadratic(P_2)	0.00037	0.00017	2.140	0.0323
	Cubic(P_3)	-0.6106e-06	3.318e-07	-1.840	0.0657
L. celebesiana	Constant(P_0)	3.2850	0.77341	4.247	<0.0001
	Linear (P_1)	-0.07220	0.0214	-3.379	0.0007
	Quadratic(P_2)	0.00037	0.00015	2.416	0.0157
	Cubic(P_3)	-0.6234e-06	3.003e-07	-2.076	0.0378
N. sillongensis	Constant(P_0)	5.06800	1.166	4.348	<0.0001
	Linear (P_1)	-0.09885	0.02908	-3.399	0.0006
	Quadratic(P_2)	0.0005332	0.00019	2.681	0.0073
	Cubic(P_3)	-9.010e-07	3.742e-07	-2.408	0.0160
T. manjithar	Constant(P_0)	2.89700	0.71851	4.032	<0.0001
	Linear (P_1)	-0.06501	0.02028	-3.206	0.0013
	Quadratic(P_2)	0.00033	0.00015	2.221	0.0263
	Cubic(P_3)	-5.462e-07	2.899e-07	-1.884	0.0595

Table 2. Consumption rate of different spiders on different prey densities of *Aphis pomi.*

No. of aphids used	No. of spider used	Consumption rate (%) of spiders on *A. pomi**			
		P. altitudis	*N. sillongensis*	*L. celebesiana*	*T. manjithar*
10	1	94.0	96.0	92.0	89.0
20	1	92.5	91.5	87.0	86.0
40	1	86.0	88.5	73.7	68.7
80	1	52.8	52.2	39.2	38.3
160	1	30.3	31.3	22.4	21.6
320	1	16.7	18.4	12.6	12.0

*Mean of 10 replications



a

b

c

d

Figure 1. Functional response of four species of spiders on different densities of green apple aphid (*A. pomi*): (a) *P. altitudis* (b) *L. celebesiana* (c) *N. sillongensis* (d) *T. manjithar*. Symbols are observed data (mean of 10 replicates) and lines were predicted by model (equation 2).

Table 3. Parameter estimated by Holling disk equation (2) for functional response of four spiders on green apple aphids (*Aphis pomi*).

Spider species	Parameter	Estimate	SD	*t* value	Pr(>|t|)
P. altitudis	a	3.07334	0.39875	7.707	0.0015
	T_h	0.39326	0.02081	18.900	<0.0001
L. celebesiana	a	3.03205	0.49029	6.286	0.0032
	T_h	0.55315	0.03109	17.794	<0.0001
N. sillongensis	a	3.04378	0.34997	8.354	0.0011
	T_h	0.36275	0.01873	19.363	<0.0001
T. manjithar	a	2.97079	0.38406	7.735	0.0015
	T_h	0.57566	0.02626	21.924	<0.0001

a = search coefficient; Th =handling time.

Estimate of search rate (a) was greater for *P. altitudis* (3.07334) and *N. sillongensis* (3.04378) followed by *L. celebesiana* (3.03205) (Table 3). The handling time of *N. sillongensis* and *P. altitudis* was 0.36275 and 0.39326 h, respectively, and were substantially shorter than the handling time of the other two spides species studied (Table 3). Comparison of search rates and handling times for *N. sillongensis*, *P. altitudis*, *L. celebesiana* and *T. manjithar* are shown in Figures 2 and 3. Among the four species of spider, the search rate of *P. altitudis* and *N. sillongensis* was significantly higher as compared to *L. celebesiana* and *T. manjithar* (Figure2) but search rate of *P. altitudis* and *N. sillongensis* was not significantly different. Handling time for *P. altitudis* and *N. sillongensis* was significantly lowest as compared to *L. celebesiana* and *T. manjithar* (Figure 3), but search rate and handling time for *P. altitudis* and *N. sillongensis* was not significantly different. Among the all spiders, *T. manjithar* showed significantly lowest search rate and highest handling time.

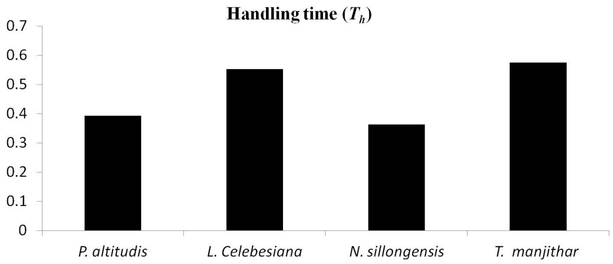


Figure 3. Comparison of handling times (T_h) for different spiders preying on *A. pomi*.

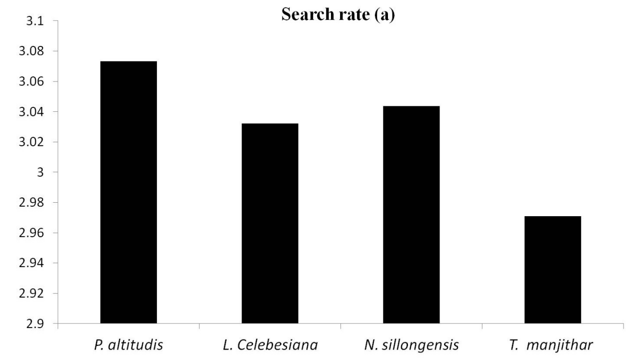


Figure: 2. Comparison of search rates for different spiders preying on *A. pomi*.

DISCUSSION

In present study, estimates of linear coefficient (P_1) in polynomial logistic regression between the proportions of green apple aphid consumed versus initial density were negative. The polynomial logistic regression demonstrated that all four species of spider exhibited type II functional response with the decreasing proportion of prey consumed with increasing densities of green apple aphids (Fig 1). This type of response is often called 'invertebrate curve' and indeed seems to be common in spiders (Smith and Wellingoton 1983, Riechert and Harp 1987, Samu and Biro 1993, Heong and Rubia 1989, Khan and Misra 2009). Holling (1966) defined three commonly accepted types of functional response that depict how capture rate influence by prey density. In type I response, prey consumption is propor-tional to prey density until satiation. This type response is representative of filter-feeding organism and is not seen in spiders (Richert and Lockely 1984, Richert 1999). In type II functional response, predators increase prey consumption at a decreasing rate, usually because of a decrease in search rate related with handling times and fail to create stable population (Rypstra 1995, Wyss et al. 1995, Khan 2013).

Praying Action

Predation appears to rises exponentially above a certain threshold of prey density, thus producing the characteristic lag and acceleration response (Riechert and Lockley 1984, Provincher and Coderre 1987). A stabilizing factor to the functional response is a high plateau in type III response; the point at which rate of attack ceases to increase relative to rate of encounter with prey. Spider functional responses often have a very high plateau, since often spiders will kill many prey items before the first one is digested. Numbers of prey killed may be much greater than the amount needed for the spider to reach satiation (Riechert and Lockley 1984, Nyffeler et al. 1994, Persons 1999). Type III response relationships have been demonstrated for *Cheiracanthium mildei* Koch (Clubionidae) feeding on *Spodoptera littoralis* (Boisduval) (Lepidoptera: Noctuidae), *Philidromus rufus* Dondale (Philidromidae) feeding on *Drosophila*, and Lycosidae in rice paddies (Marc et al. 1999). Shivakumar and Kumar (2010) reported that the male of *Oxyopes shweta* Tikader (Araenae: Oxyopidae) showed type II and female of same species showed a type III functional response on different densities of *Spodotera litura*.

Our estimates of maximum numbers of *A. pomi* attacked in 24 h were 58.9 for *N. sillongensis*, 53.4 for *P. altitudis*, 40.2 for *L. celebesiana* and 38.5 for *T. manjithar*. Thus preying efficiency of *N. sillongensis* and *P. altitudis* may be higher than *L. celebesiana* and *T. manjithar*. (Figure 1). There is no significant differen~~t~~ce in search rates (Figure 2) and handling times ~~of~~ between *N. sillongensis* and *P. altitudis*, but there is significant differen~~t~~ce among handling times of *N. sillongensis* as compared to *L. celebesiana* and *T. manjithar*. Similarly, *P. altitudis* take lowest handling times as compared to *L. celebesiana* and *T. manjithar* (Figure 3). This suggested that the greater consumption efficiency of *N. sillongensis* and *P. altitudis* compared with other two spiders arises because of differences in handling times. Their values differed significantly within and between the spider species when exposed to green apple aphid, which indicate that they have different abilities to respond to increasing prey densities. This also indicates that predators exhibiting similar functional response curves cannot be deemed to respond similarly. The differences in parametric values might be due to the variation in size, voracity, satiation time, hunger levels, digestive ability, walking speed etc. (Mills 1982, Khan 2011).

Amongst the four species of spider, *N. sillongensis* responded maximally to increasing densities of *A. pomi* followed by *P. altitudis* compared with other two spider species. This inference is strongly supported by the experimental confirmation of the reproductive biology of *N. sillongensis*, which achieve higher values in fitness and reproduction using this prey species (Samu 1993). The functional response curve showed that the comparative rate of prey utilization by *P. altitudis* was higher at lower prey density, representing that it could be more efficient at lower prey densities. At higher prey densities, it exhibited a significant decline in consumption rate, which might be due to the attainment of satiation (Mills 1982). The functional response curve of *N. sillongensis* elevated over that of *P. altitudis* which indicates faster digestive rate and a possible delayed satiation (Lucas 1985, Cloarec 1991).

The search rates did not differ very significantly in most of the treatments, which showed that parameter is least affected by the change of spider species. Similar insignificant effect of predator and prey type was reported in four heteropteran predators preying on whiteflies and thrips (Montserrat *et al*. 2000). The variation in handling times differs significantly both with and between the spider species.

The functional response is a component in selection of potential biocontrol agents, there is no general relationships between success in biological control and types of functional response. The experimental data give information as to how these spiders will respond to increasing prey density of green apple aphids under controlled conditions and for conclusive remarks of their biocontrol efficiency, more field based studied are required. Nevertheless, from the data of functional response curves, search rates and handling times, it can anticipated that among the four species of spider, *N. sillongensis* followed by *P. altitudis* are better at devouring green apple aphids. However, other factors, such as biology of prey and predator, including host preference, switching behaviour, intrinsic growth rates, consumption rate of predator, preying nature, prey patchiness, host plant, effect of biotic and abiotic factors, and intra and inter specific competition could be important effects on the ability of a biological control agent in managing the prey population (Sunderland et al. 1986, Snyder and wise 1999, Nilsson 2001, Farhadi et al. 2010, Khan 2012b, c).

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