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# Biology and functional response of the predator, *Dortus primarius* (Distant) (Hemiptera: Miridae) preying on *Frankliniella schultzei* (Trybom) (Thysanoptera: Thripidae)

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## Abstract

**Background:** *Dortus primarius* (Distant) (Hemiptera: Miridae) is a general predator reported from the oriental region. This bug is naturally found in many crop ecosystems where it feeds on thrips, aphids, insect eggs and other soft-bodied insects. Although, the rearing protocol of this predatory mirid has been developed, the efficiency of this predator as a biocontrol agent is limited and needs to be investigated. The thrips, *Frankliniella schultzei* (Trybom) (Thysanoptera: Thripidae), is a polyphagous pest that attacks many crops in polyhouse in India. Therefore, in the present study, biology and functional response of this predator to different densities of *F. schultzei* larvae in the laboratory was investigated.

**Results:** The mirid predator was able to develop from egg to adulthood on tomato infested plant with *F. schultzei* larvae in 23–24 days with 15 and 11.76% mortality of 4th and 5th instar nymphs, respectively. Both 5th instar and female adults exhibited a type III functional response. At highest prey density (40) both 5th instar and female adults consumed 21.6 and 28.6 thrips larvae per day, respectively. Functional response parameters, viz. attack rate, handling time,  $a/T_h$  and  $T/T_h$  showed the potency of this predator against *F. schultzei*.

**Conclusion:** Based on the high fecundity, predation rate and density dependent behaviour, it is predicted that *D. primarius* might be an efficient and potential predator. However, further research is needed to assess its release rate and other ecological studies in the field situation.

**Keywords:** *Dortus primarius*, *Frankliniella schultzei*, Functional response, Developmental period

## Background

*Dortus primarius* (Distant) (Hemiptera: Miridae) belonging to subfamily Deraeocorinae is considered to prey upon various arthropods such as thrips, aphids, and other soft-bodied insects in okra, cauliflower, maize, brinjal and cucurbits crops (Wheeler 2001). This predator

is reported from the oriental region and has not explored for its biocontrol potential yet.

The common blossom thrips or tomato thrips, *Frankliniella schultzei* (Trybom) (Thysanoptera: Thripidae), is a pest of various economically important vegetable crops and ornamental plants covering 55 families worldwide (Milne et al. 1996). Both larvae and adults of *F. schultzei* feed on flowers, fruits, pollen, tender leaves resulting in discolouration and necrotic spots, dark dotted blemishes in fruits and stunted growth of the plant. It is also a vector of several viral diseases in many crops like tomato, groundnut and tobacco (Klose et al. 1996). In India, many

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crops such as tomato, tobacco, cotton, grain legumes, groundnuts and lettuce are attacked and damaged by this pest (Kakkar et al. 2010).

Biological control is an ecofriendly approach which is safer to environment, non-target organisms and pollinators. Success in biological control depends on biological and behavioural studies to understand the potency and the efficiency of any predator to further exploit it for management of insect pests. The functional response determines the efficiency of the predator and describes the rate at which a predator kills its prey at different prey densities (Murdoch and Oaten 1975). This is one of the key components to assess the efficacy of biocontrol agent (Lester and Harmsen 2002) and to understand predator prey interactions. Holling (1959) defined 3 types of functional responses for insects. In type I, graph shows linear relation between the number of prey killed and the prey density, type II explains that the rate of prey consumption increases with increasing pest density and eventually reaches to the predator's satiation point and type III exhibits a sigmoid relationship between the number of prey eaten and the number of prey offered. Functional response and developmental studies have been conducted for other mirid bugs, although this information is lacking for *D. primarius* and knowledge of these parameters would certainly determine the efficiency and potential of this predator against *F. schultzei*.

Therefore, the present study presents for the first time the life history, predation rate and functional response of *D. primarius* to varying densities of *F. schultzei* larvae. This information will provide key information to formulate and implement strategies for the biological control of *F. schultzei*.

## Methods

### Insect cultures

Individuals of *F. schultzei* were collected from a capsicum field, Bangalore, India, and reared in the laboratory on insecticide free bean pods. *Dortus primarius* was reared in laboratory on bean pods (ovipositional substrate) and provided with UV irradiated *Corcyra cephalonica* (Stainton) eggs as prey (Varshney et al. 2018). Both cultures were maintained at  $26 \pm 2$  °C,  $65 \pm 2\%$  relative humidity with a photoperiod of 12:12 (L:D). Larval stage of thrips was used in the experiment.

### Determination of biology

Four adult pairs of *D. primarius* (4 days old) were released in methacrylate cages ( $40 \times 40 \times 40$  cm) with 4 tomato plants (3–4 leaf stage). They were provided either irradiated *C. cephalonica* eggs or larvae of *F. schultzei* as food ad libitum on every alternate day. Plants were checked for egg laying on each day. When egg laying was observed,

plant parts bearing eggs were cut off and kept in plastic box (60 mm diameter) lined with filter paper. Once eggs are hatched, newly emerged nymphs were transferred to individual plastic box to observe developmental stages and time. Each Petri dish containing tomato leaflet and either larvae of *F. schultzei* or *C. cephalonica* eggs were offered to each nymph. Each instar of predator was provided with a constant number of eggs or thrips larvae (always higher than their daily requirement) according to the developmental stage of the predator. Developmental period (indicated by the presence of exuviae) and survival of nymph until the adult stage were recorded daily. Food and leaflets were changed daily. After adult emergence, one pair of adults was exposed to a tomato plant and provided with either larvae of *F. schultzei* or *C. cephalonica* eggs for recording the pre-oviposition period, fecundity and per cent hatching. For each prey 20 replicates were maintained. The entire experimental set up was kept at  $26 \pm 2$  °C,  $65 \pm 2\%$  RH with a photoperiod of 12:12 (L:D) in a climatic chamber.

### Determination of functional response

Young female and/or 5th instar nymph of *D. primarius* was exposed to different densities of *F. schultzei* larvae. One complete generation of this predator was maintained on *F. schultzei* larvae to acclimatize them under laboratory conditions before initiating the experiments. Prior to the functional response study, each female adult and/or 5th instar nymph of the predator, was kept starved for 24 h. The experimental arena had a tissue paper at the base on which a tomato leaflet was kept in a small-ventilated round plastic box (13.0 cm diameter and 4.0 cm height). Based on preliminary tests, the 8 densities (1, 3, 6, 9, 15, 18, 30 and 40/leaf arena) of *F. schultzei* were presented to each female and nymph of mirid bug. Larvae of thrips were transferred on the leaf arena gently using a fine paint brush. The plastic boxes were held in an incubator ( $26 \pm 2$  °C,  $65 \pm 10\%$  RH, 12L:12D photoperiod). The experimental units were examined after 24 h to record the number of thrips larvae survived after removing the predator. For each prey density, 6 replications were maintained. Thrips larvae consumed by the predator in each replication were not replaced during the experimental periods.

### Statistical analyses

Data on biology were not normally distributed and thus analysed by performing Mann–Whitney *U* test. The shape of the curve was determined by polynomial logistic regression of the proportion of prey consumed as a function of the initial prey density (Trexler et al. 1988; Juliano 2001). Here, the logistic regression is appropriate because of the dichotomous nature thrips consumed or not) of

dependent variable and the errors associated with such a variable are likely to be distributed binomially (Trexler and Travis 1993; Queiroz et al. 2015). To fit the data, the polynomial function from Juliano (2001) was used:

$$\frac{N_e}{N_o} = \frac{\exp(P_0 + P_1N_o + P_2N_o^2 + P_3N_o^3)}{(1 + \exp(P_0 + P_1N_o + P_2N_o^2 + P_3N_o^3))} \quad (1)$$

where  $N_e$  is the number of preys consumed,  $N_o$  is the initial prey number available and  $P_0, P_1, P_2$  and  $P_3$  are the intercept, linear, quadratic and cubic coefficients, respectively, estimated using the method of maximum likelihood (Pervez and Omarkar 2005). Linear terms ( $P_1$ ) if not differ significantly from zero indicate a type I response. Significant negative or positive linear coefficients (i.e.  $P_1$ ) from regression indicate type II or type III response, respectively (Juliano 2001).

In order to identify which functional response model better suits the data, Akaike information criterion i.e. AIC was used. The maximum likelihood approach was used to obtain parameter estimates of Holling’s type II, Roger’s random predator equation and Hassell’s type III response (Hassell 1977). Therefore, 4 different functional response models were fitted using R package *frair* and maximum likelihood estimate of parameters were obtained.

Based on AIC value the analysis to type III response was restricted. For modelling of type III functional response with prey depletion following equation suggested by Hassell (1978); Juliano (2001) was used.

$$N_e = \frac{N_o \{1 - \exp[(d + bN_o)(T_h N_e - T)]\}}{(1 + cN_o)} \quad (2)$$

where  $T$  is the total time available for search (24 h),  $N_e$  is the number of preys consumed,  $N_o$  is the initial prey number available,  $T_h$  is the prey-handling time and  $b, c$  and  $d$  are constants to be estimated for type III response. The number of preys eaten ( $N_e$ ) follow the same relationship defined for the Roger’s Type-II response, however the attack rate ( $a$ ) is assumed to vary with initial prey density in the following hyperbolic relationship:

$$a = \frac{d + bN_o}{1 + cN_o} \quad (3)$$

$$a = \frac{bN_o}{1 + cN_o} \quad (4)$$

where ‘ $d$ ’ is non-significantly different from 0, so it was removed. Predator’s attack rate per handling time ( $a/T_h$ ) (indicates the effectiveness of predation) and the maximum predation rate ( $T/T_h$ ) were also calculated (Rahman et al. 2012).

## Results

### Biology of *D. primarius*

In the biology trials, *D. primarius* adults could successfully complete its life cycle on both *C. cephalonica* eggs and *F. schultzei* nymphs. Nymphs of *D. primarius* hatched 7.9 days after oviposition. Nymphal duration was significantly lower on *C. cephalonica* eggs ( $15.2 \pm 0.26$  days) than on *F. schultzei* larvae ( $16.4 \pm 0.23$ ) (Mann-Whitney  $U$  test:  $U=96.0$ ;  $P=0.004$ ) (Table 1). Male longevity ( $15.95 \pm 0.64$  days) (Mann-Whitney  $U$  test:  $U=112.0$ ;  $P=0.017$ ), female longevity ( $21.6 \pm 0.47$  days) (Mann-Whitney  $U$  test:  $U=96.0$ ;  $P=0.004$ ) and per cent adult emergence ( $77.7 \pm 1.22$ ) (Mann-Whitney  $U$  test:  $U=112.0$ ;  $P=0.017$ ) were significantly higher on *F. schultzei* larvae than on *C. cephalonica* eggs (Table 1). During nymphal development, 5 and 10.52% mortality rate was observed in 3rd and 5th instar nymphs of *D. primarius*, respectively, when reared on *C. cephalonica* eggs. Similarly, when reared on *F. schultzei* larvae, 15 and 11.76% mortality rate was observed in 4th and 5th instar nymph of the predator.

### Functional response

The four functional response model fits were compared and Hassell’s type III model exhibited lower AIC value for both 5th instar and adult (Table 2). Significantly positive linear terms and negative quadratic terms detected from

**Table 1** Biology of *Dortus primarius* on tomato plant fed with *Corcyra cephalonica* eggs and *Frankliniella schultzei* larvae. In row means with different letters are significantly different with each other (Mann-Whitney U test;  $P < 0.05$ )

Stage	<i>C. cephalonica</i> eggs	<i>F. schultzei</i> larvae
	Mean ± SE	Mean ± SE
Pre-oviposition period (days)	4.0 ± 0.14 <sup>a</sup>	4.1 ± 0.14 <sup>a</sup>
Incubation period (days)	7.95 ± 0.15 <sup>a</sup>	7.9 ± 0.16 <sup>a</sup>
Duration of nymphal instars (days)		
I	3.6 ± 0.11 <sup>a</sup>	3.6 ± 0.11 <sup>a</sup>
II	2.6 ± 0.11 <sup>a</sup>	2.8 ± 0.09 <sup>a</sup>
III	2.8 ± 0.09 <sup>a</sup>	2.8 ± 0.09 <sup>a</sup>
IV	2.6 ± 0.11 <sup>b</sup>	3.4 ± 0.11 <sup>a</sup>
V	3.6 ± 0.11 <sup>a</sup>	3.8 ± 0.17 <sup>a</sup>
Total nymphal period (days)	15.2 ± 0.26 <sup>b</sup>	16.4 ± 0.23 <sup>a</sup>
Total developmental period (days)(eggs to adult)		
Male	21.8 ± 0.17 <sup>b</sup>	23.8 ± 0.17 <sup>a</sup>
Female	23.4 ± 0.23 <sup>a</sup>	24.2 ± 0.33 <sup>a</sup>
Longevity of male (days)	14.6 ± 0.23 <sup>b</sup>	15.95 ± 0.64 <sup>a</sup>
Longevity of female (days)	20.2 ± 0.17 <sup>b</sup>	21.6 ± 0.47 <sup>a</sup>
Eggs/female	127.6 ± 2.26 <sup>a</sup>	132 ± 1.80 <sup>a</sup>
Per cent hatching	90.9 ± 0.16 <sup>a</sup>	89.1 ± 0.25 <sup>b</sup>
Per cent adults developed	73.2 ± 0.32 <sup>b</sup>	77.7 ± 1.22 <sup>a</sup>

**Table 2** Functional response: Akaike Information Criterion (AIC) of four functional response models fitted for 5th-instar nymph and adult female of *Dortus primarius* when fed on *Frankliniella schultzei* larvae

Functional response models	<i>Dortus primarius</i>	
	5th Instar	Adult
Type-I	176.6	180.02
Rogers random predator	178.6	182.02
Holling's type II	178.6	182.02
Hassell type III	<b>169.3</b>	<b>166.22</b>

\* A lower value of AIC indicates a better fit

logistic regression analyses for both 5th instar and female predator revealed type III functional response, which is positively density dependent (Fig. 1a, b; Table 3). In the present study, predation increased after density value 6, with upper processing limit of 21.3 thrips per 24 h in 5th instar nymph and with a maximum limit of 28.6 thrips per 24 h in case of a female predator.

The functional response parameters of 5th instar and adult over a 24 h period were estimated using Eq. (2). The handling time ( $T_h$ ) as estimated by Eq. (2) for 5th instar was lower than adult, although there was non-significant difference in handling time between these two stages (Table 4). Attack rate for both stages was also determined using a reduced model (Eq. (4)) and nonlinear

**Table 3** Maximum likelihood estimates for parameters of the logistic model fit to proportion of *F. schultzei* larvae consumed by *D. primarius* versus initial prey density at  $26 \pm 2$  °C

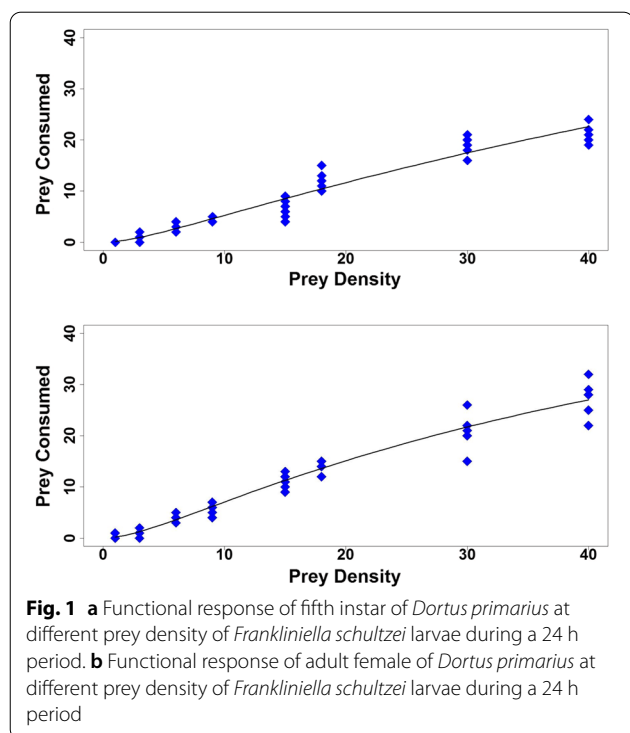
Parameters		Instar5	Adult
Constant ( $P_0$ )	Intercept ( $P_0$ )	-0.9350472	-0.2291953
	SE	0.3302015	0.3311785
	p-value	0.004629 **	0.488900
Linear ( $P_1$ )	Coefficient ( $P_1$ )	0.1065454	0.1104207
	SE	0.0315618	0.0326342
	p-value	0.000736 ***	0.000715 ***
Quadratic ( $P_2$ )	Coefficient ( $P_2$ )	-0.0019261	-0.0021791
	SE	0.0006354	0.0006634
	p-value	0.002437 **	0.001021 **

\* Significant at  $P < 0.05$ ; \*\*Significant at  $P < 0.01$ ; \*\*\*Significant at  $P < 0.001$

least square regression indicated non-significance of 'd' parameter; therefore, it was removed from the model. The estimated attack rates of 5th instar varied from 0.14 to 1.33. Similarly, for adult, attack rate varied from 0.21 to 2.73, at prey density from 1 to 40. The value of  $a/T_h$  for 5th instar was 8.54, 21.8, 35.9, 45.6, 58.2, 62.5, 73.5 and 78.6, and was 9.75, 26.4, 45.9, 61.0, 82.8, 90.9, 112.9 and 124.3 for female at density varied from 1 to 40. Maximum theoretical predation rate was higher in 5th instar than in adult (Table 4).

**Discussion**

It seems, this is the first study to investigate the biological parameters and functional response of *D. primarius* on *F. schultzei*. In this study, a detailed analysis of various biological parameters of *D. primarius* preying upon thrips larvae and of the factitious prey *C. cephalonica* eggs on tomato plants was explored. In present study, nymphal development period of *D. primarius* preying on *C. cephalonica* eggs (15.2 days) was more than 2 days longer than that reported for *Nesidiocoris tenuis* (Reuter) (12.9 days) (Sanchez et al. 2009) and for *Macrolophus pygmaeus* (Rambur) (13.68 days) (Perdikis and Lykouressis 2000). However, obtained results corroborate with the findings of Molla'et al. (2014) who reported 15.36 days nymphal development period of *M. pygmaeus* when fed on *Ephestia kuehniella* (Zeller) eggs. In the present study, nymphal development period was shorter on *C. cephalonica* eggs than on *F. schultzei* larvae. There are many reports on predatory mirids where, rapid development was observed when fed on *E. kuehniella* eggs compared to natural preys such as *Myzus persicae* (Sulzer), *Trialeurodes vaporariorum* Westwood and *Tetranychus urticae* Koch; (Tedeschi et al., 1999). It may be due to high nutritional quality of Lepidoptera eggs. Similarly, Kiman & Yeargan (1985) found that *Orius insidiosus* (Say) had



**Fig. 1** a Functional response of fifth instar of *Dortus primarius* at different prey density of *Frankliniella schultzei* larvae during a 24 h period. b Functional response of adult female of *Dortus primarius* at different prey density of *Frankliniella schultzei* larvae during a 24 h period



**Table 4** Coefficient of attack rate ( $a$ ) and handling time ( $T_h$ ) and other derived parameters for 5th instar and female of *D. primarius*

Predator stage	$b$	95% CI		$c$	95% CI		$T_h$	95% CI		$T/T_h$
		Lower	Upper		Lower	Upper		Lower	Upper	
instar5	0.159	0.078	0.545	0.094	0.008	0.565	0.017	0.001	0.037	58.82
Adult	0.227	0.149	0.484	0.058	0.009	0.294	0.022	0.007	0.034	45.45

<sup>a</sup> In the best fit type III model,  $a = bN_0/1 + cN_0$ ;  $b$  and  $c$  values have been given in table;  $N_0$ : Initial prey density;  $T = 1$  day

a shorter developmental period (13.4 days) when fed on *Heliothis virescens* (Fabricius) eggs than when fed on *Neohydatothrips variabilis* (Beach) (= *Sericothrips variabilis* (Beach)) (15.8 days). Male and female longevity of *D. primarius* were higher on *E. schultzei* larvae than on *C. cephalonica* eggs. The nutrition quality of host plant of prey may indirectly influences the survival, fitness and predation of the predators on these preys (Kumari et al., 2021). Studies revealed that anthocorid bugs, *Orius laevigatus* (Fieber) and *O. majusculus* (Reuter) fed on *Frankliniella occidentalis* (Pergande), nymphs lived longer (45.1 and 46.1, respectively) (Riudavets, 1995).

The overall number of *E. schultzei* larvae consumed by the nymphal instars of *D. primarius* was 196–210. Obtained findings indicate that *D. primarius* can complete its life cycle and reproduce when fed on *E. schultzei* larvae.

It is evident from the functional response study that *D. primarius* can consume 22–28 thrips /day. Functional response parameters (attack rate and handling time) indicated the voracity of both stages of this predator. In the present study, 5th instar and adult female exhibited type III functional response with a density dependant predation at low and medium densities. Type III response was also observed in *M. caliginosus* at varying density of *T. vaporariorum* (Hamdan 2006); *Nesidiocoris tenuis* against *Bemisia tabaci* (Gennadius) pupae at 35 °C (Madbouni et al. 2017); *Macrolophus basicornis* (Stal) and *Engytatus varians* (Distant) at varying density of *Tuta absoluta* (Meyrick) eggs (Van Lenteren, et al. 2016). Type III response is associated with learning behaviour and earlier it was considered to be characteristic of vertebrate predators (Holling 1959). Later, Van Lenteren and Bakker (1978) reported this behaviour in invertebrate predators and parasitoids. Several studies indicated a type II response for most of the mirid bug (Montserrat et al. 2000; Fantinou et al. 2008, 2009; Alvarado et al. 1997; Maselou et al. 2014, 2015; Madbouni et al. 2017; Ingegno et al. 2019). Natural enemies exhibiting type III response could be considered as an efficient biocontrol agent to manage the prey population (Fernández-Arhex and Corley 2003). Types of response depend on various factors, viz. prey species, size (Streams 1994), predator's hunger level, size, stage (Varshney et al. 2018), temperature and

other abiotic factors (Madbouni et al. 2017), experimental arena (Hemerik and Yano 2011); types of analysis used for assessment of functional response (Van Lenteren et al. 2016). In the present study, lower handling time ( $T_h$ ) and higher theoretical predation rate ( $T/T_h$ ) were observed for 5th instar larvae. This could be attributed to their greater requirements for food and energy to grow and attain the adulthood (Hodek and Honek, 1996). The estimation of the predation effectiveness ( $a/T_h$ ) can be useful for determining the possibility of the optimal ratio between predator and target pest for inoculative release (Wang et al. 2019).

In predatory/zoophytophagous, mirid bug most of the studies are restricted to dicyphine bugs. This study improves the insight into the biology, predation rate and ability of *D. primarius* to reduce thrips population. Functional response studies are important to understand predator prey interaction and efficiency of new predator to reduce prey population at different density. For 5th instar and adult, the percentage prey killed increased up to density of 18 and then over this range the response was stabilized. Thus, it can be inferred that these two stages of predator are efficient to bring down the thrips population in a prey density range of upto 18 thrips /leaflet. Thus, there is a necessity to explore and develop suitable control strategies either through augmentation or conservation of this predator to manage *E. schultzei*.

This study was conducted in the laboratory and limited to a small arena unlike natural conditions where many factors may influence functional response parameters like characteristics of host plants (De Clercq et al. 2000), light intensity, spatial complexity (Zamani et al. 2006) and intraguild predation (Finke and Denno 2005).

## Conclusions

The study dealt with biology and the potential of *D. primarius* as biocontrol agent of *E. schultzei*. However, this predator has not been extensively explored. Hence, further studies are warranted to evaluate its establishment, survival, prey switching behaviour, prey preference and interaction with other predators in a natural ecosystem to understand their ecology and to incorporate this predator in a biocontrol program. In natural ecosystems, predators have overlapping niches and thus predator-predator

interaction also needs to be studied along with the functional response. Abundance and scarcity of prey influence conspecific and heterospecific interactions of predator and may hinder biocontrol program.

#### Abbreviations

$N_c$ : The number of preys consumed;  $N_o$ : The initial prey number available;  $T$ : Total time available for search (24 h);  $T_h$ : Prey-handling time;  $a$ : Attack rate;  $a/T_h$ : Predator's attack rate per handling time;  $T/T_h$ : Maximum predation rate.

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#### Authors' contributions

RV conceived the study. RV performed experiments and analysed the biology data. NB conducted functional response analysis. RV wrote the manuscript. Both the authors read and approved the manuscript.

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#### Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

#### Declarations

#### Ethics approval/consent to participate

This manuscript does not contain any studies with human participants or animals performed by any of the authors.

#### Consent for publication

Not applicable.

#### Competing interests

The authors have not found any potential conflicts of interest, and all ethical aspects are considered.

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