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Effects of Pesticides on the Breeding Behavior, Hatching Success and Survival Rate of Indian Roller (*Coracias benghalensis*) in Bahawalpur Division, Punjab, Pakistan

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Key words
Indian roller, Pesticide, Tree, Agriculture, Nest

ABSTRACT

Indian roller (*Coracias benghalensis*) feeds on insects which are harmful for the crops thus playing an important role in agricultural ecology and increasing crop yield. In present study, population density, habitat preferences, breeding behavior and nest survival rate of Indian roller were assessed at three different sites in district Bahawalpur, Southern Punjab, Pakistan. However, the results obtained after this study, revealed that the population density was damagingly affected by the high usage of pesticide, as the population density in areas with less pesticide (100.1±18.33 birds /km^2) was far greater than the areas where pesticide was used in high quantities (34.26±7.46 birds /km^2) and the population density of these birds at the forest (78.44±11.2 birds/km^2) was nearly similar to the field area where pesticides were not much used. It preferred the trees having an average height of 8.94±2.18m for their habitat selection and at the height of 5.45±2.06m. They mostly preferred dead trees (56.25%) for nesting as compared to (43.75%) living trees. The tree species preferred most for nesting was *Tamarix aphylla* (31.25%). The lowest hatching success and survival rate were noted in the highest pest used sites. It was concluded that the high usage of pesticide is a significant threat to Indian roller for its survival and there is much need of replacing pesticides which are harmful for birds as well as humans with biological control method, which is eco-friendly and healthy for both the bird and humans and also very economic.

INTRODUCTION

Wild birds are vital for ecosystems (Ali *et al*., 2020). They respond very quickly against anthropogenic impacts and act as biological indicators (Babar and Kanwal, 2021; Khan *et al*., 2021). In agricultural ecosystems birds have supreme importance because they are the natural predators of insects (Dhindsa and Saini, 1994; Ali *et al*., 2020). Agricultural landscapes provide the avian fauna with food directly in the variety of grains or seeds and indirectly in the variety of rodents and insects. About 95% insectivorous birds feed on a number of insects: butterfly, grass hoppers, dragonfly and bugs and these are abundantly observed in agriculture crops (Asokan *et al*., 2010b). In developing countries, biological control by insectivorous birds is highly effective, environment and farmer friendly technique especially for low revenue crops as the use of pesticides is very expensive, environment deteriorating and habitat destructive (Sivakumaran and Thiyagesan, 2003).

Indian roller (*Coracias benghalensis*) is among the most important insectivorous birds as it feeds on a verity of insects which are harmful for agricultural crops and provide security against various pest attacks (Asokan *et al*., 2009).

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Indian roller is a stocky bird of an average size of about 26 to 27 cm long. The main habitat of the bird is agricultural farms (Sivakumaran and Thiyagesan, 2003). The species is secondary cavity nester and cannot build its own cavity. It resides in the naturally formed cavities or abandoned nests of primary hole nesting birds such as rose ringed parakeet and golden backed woodpecker (Manikandan and Balasubramanian, 2018). It used no nesting material like dry crop straws, pieces of fabrics or small twigs etc for nest building and lay eggs at the bottom of the cavity on delicate surface. The Indian roller mostly preferred to reside in tree species like coconut (*Cocos nucifera*), palm trees (*Borassus flabellifer*), date palm (*Phoenix dactylifera*) and frash (*Tamarix aphylla*). Male Indian roller performs beautiful ornate sexual displays while flying high in air and rolling down freely flapping their wings and high pitch voice to attract females in their breeding season that's why they named roller (Nithiyanandam and Asokan, 2015). Pesticides are chemicals utilized to control or kill any type of pest causing diseased, harm flora and fauna or may interfere with the production, crops, transportation, storage processing, marketing of agriculture and wood products. This is present in following types such as fungicide, herbicide, plant growth regulators, insecticides and rodenticides (Johnson and Albright, 1992; Cooper and Dobson, 2007; Bright *et al*., 2008; Raina and Hamid, 2013).

Most of the studies about cavity nesting birds were carried out in artificially placed nest boxes where survival, clutch size, hatching and fledging success is significantly better as compare to natural cavities (Møller, 1992). The studies performed in nest boxes deviates from the real data of availability of natural cavities of Indian roller especially with respect to Pakistan. Moreover, there is a huge gap in our knowledge about the ecology of the Indian roller in Pakistan. Therefore, the present research work was carried out with the prime objective to investigate the population, nesting and breeding behavior, fledging and hatching success and the survival rate of Indian roller in Bahawalpur division, Punjab, Pakistan.

MATERIALS AND METHODS

Study area

The study was carried out in the Bahawalpur division, Punjab Pakistan (28°30' N, 71°30' E). Bahawalpur is the most important division of the country with a total area of 23928.22 km^2 and comprises of dynamic landscapes including agricultural areas, forest and Cholistan desert. Most of the area about 16,000 km^2 in the south is under Cholistan desert whereas 5167.37 km^2 and 214.74 km^2 area out of the total land is under agriculture and forest (Lal Suhanra National Park), respectively (Wariss *et al*., 2014; GOP, 2016). The woody vegetation in the remaining area is sparse and mostly in the form of roadside and farm trees along the agricultural farm fields. The climate of the study area is desert type with an average rainfall of 143 mm throughout the year. There is a difference of 48 mm of precipitation between the driest and wettest months. The average temperatures vary during the year by 22.2°C (Fig. 1) and most of the time wind rose from northern directions velocity may vary from 0-28 km/h but most of the time wind speed is less than 5 km/h.

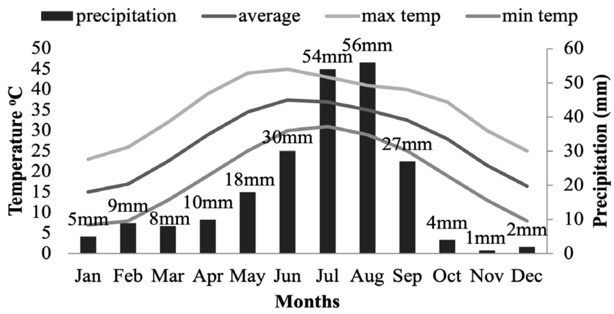

Fig. 1. Climate and temperature of Division Bahawalpur.

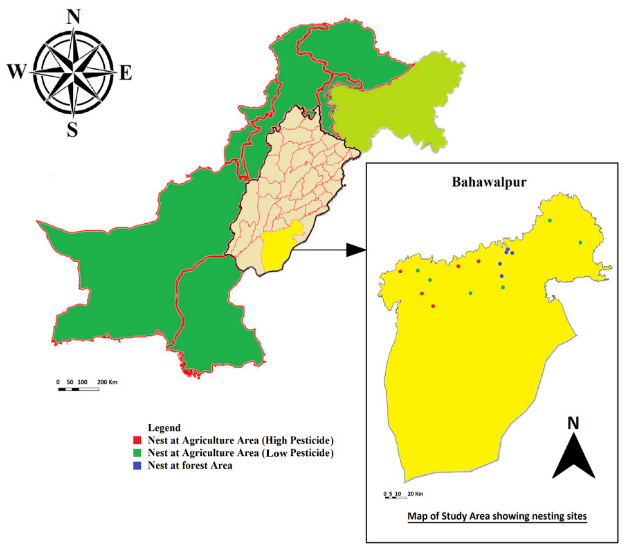

Fig. 2. Map of study area showing location of nests of Indian roller (*Coracias Banghalensis*).

Field visits

Field visits were carried out from April 2017 to June 2018 for monitoring the nests of Indian roller in three habitats: Agricultural lands with high pesticide (HP) use, Agricultural lands with low pesticide (LP) use and forest area (Lal Suhanra National Park), high pesticide area. The pesticide usage intensity in agricultural area was determined by local survey and by direct asking to the farmers. Overall, n=16 Indian roller nests were documented and noted occasionally in breeding season across all three selected habitats (Fig. 2 and Table I).

Table I. Description of location of nests found.

No	Area	Latitude	Longitude
1	Agriculture (LP)	29°8'17.3436"N	71°40'58.3248"E
2	Forest	29°20'44.5882"N	71°55'37.218"E
3	Agriculture (HP)	29°2'52.8252"N	71°21'47.772"E
4	Forest	29°25'18.54"N	71°58'31.849"E
5	Agriculture (LP)	29°25'14.052"N	72°1'25.644"E
6	Agriculture (HP)	29°21'50.043"N	71°44'45.854"E
7	Agriculture (LP)	29°17'56.62"N	71°14'26.952"E
8	Agriculture (HP)	29°19'30.68"N	71°34'28.488"E
9	Forest	29°26'45.36"N	71°59'01.570"E
10	Forest	29°25'14.052"N	72°1'25.644"E
11	Agriculture (LP)	29°38'49.236"N	72°20'14.982"E
12	Agriculture (LP)	29°38'49.236"N	72°20'14.982"E
13	Agriculture (HP)	29°17'14.442"N	71°5'33.335"E
14	Agriculture (HP)	29°8'19.2912"N	71°16'24.564"E
15	Agriculture (LP)	29°13'33.7512"N	71°20'23.683"E
16	Forest	29°15'27.0144"N	71°56'16.789"E

LP, low pesticide; HP, high pesticide.

Statistical analysis

Density of bids, hatching success, fledging success and daily survival probability was measure with help of MS Excel, 2010. ANOVA was calculated through statistics 8.1 statistical package.

The population densities of the bird in question in the three selected landscapes were estimated by line transects method. This method was applied separately in each selected area and 3 replicates were made in each area for precise results (3 months). Total 2 km long line was supposed and crossing that line was documented. Counting of the bird was avoided by noted, it going in single direction only. The selected areas were surveyed for 2 h 8am to 10am. Survey was carried out under normal weather conditions with clear sky (no smog and heavy winds during the survey process). The distance of each bird from line transect was measured and recorded. The population density of Indian roller was computed.

$$\text{Density} = \frac{\text{No of birds}}{2 \times L \times W}$$

Where L is length of the transect and W is mean perpendicular distance.

Trees and plant species having nests were documented. Status of tree was also documented either dead or alive. The nest cavity and nesting tree height from the ground was calculated in feet by utilizing altimeter. Breast diameter was calculated utilizing tape. Nest cavity orientation was documented by utilizing a compass. Nest cavity length, depth and width were measured by utilizing a meter scale. Nest opening area was measured by ¼*π* (average diameter)^2.

This behavior was documented by observing the bird with cameras and binoculars as other researchers. Overall, 16 Indian roller active nests were noted. The nests were tagged with numbers and the area was marked with alphabet letters. Observation was done after the 3 days intervals. Abandonment risks were removed by visits for the minimum time of surveillance and it was made sure that no dead end-tails had leave (Martin *et al*., 2013). The date of 1st egg laid, 1st egg hatching and fledging of each nest was noted in a data sheet. The data regarding total number of eggs laid total number of eggs hatched, incubation period, hatching and fledging success and survival rate with respect to tree species, tree status, area (habitat), tree height, nest cavity height and diameter at breast height was recorded and analyzed.

The success was noted by utilizing the formulae;

$$\text{Hatching success (\%)} = \frac{\text{No. of eggs hatched}}{\text{Total no. of egg layed}} \times 100$$

$$\text{Fledging success (\%)} = \frac{\text{No. of nestling fledged}}{\text{Total no. of egg layed}} \times 100$$

This rate was documented by adopting Mayfield (1975) method.

$$\text{Daily survival probability} = \frac{1 - \text{no. of failed nests}}{\text{Total no. of exposure days}}$$

Nest survival is daily survival probability nesting period. Exposure days were counted. Exposure days are total days while a nest remains active and is at risk of failure. Exposure days were matched for all the active nests and tally up those nests which were observed failed.

RESULTS

Population density

The population density of Indian roller (*Coracias benghalensis*) in agricultural area with high pesticide usage was significantly less in all 3 months as compared to forest and agricultural area with less pesticide usage. Overall, the population density of Indian roller across the studied areas ranged from 34.27 ± 7.46 birds/ km^2 to 100.10 ± 15.33 birds/ km^2. The maximum population density was computed in the month of May (42.86±5 birds/ km^2 and 116.72±7.7 birds/ km^2) for both agricultural areas with high pesticide usage and low pesticide usage respectively, while for forest area, the maximum population density was observed in March (85.44±8.5 birds/ km^2). However, the minimum population density was observed in the month of January (29.41±4.5 birds/ km^2, 80.23±2.9 birds/ km^2&65.51±5 birds/ km^2) for agricultural area with high pesticide usage, agricultural area with low pesticide usage and forest area, respectively (Fig. 3).

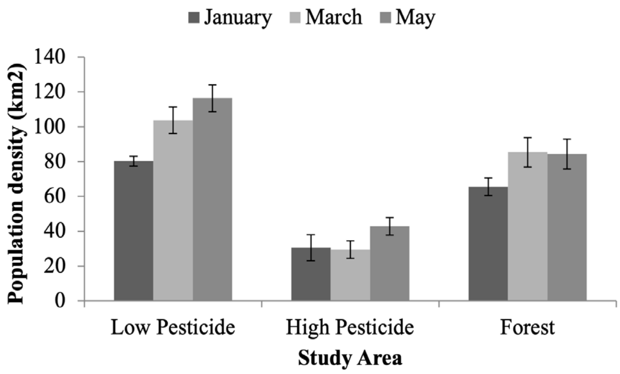

Fig. 3. Population density of Indian roller in different study areas during different months.

Fig. 4. Physical appearance of nest of Indian roller (*Coracias banghalensis*), (A) eggs, (B) Altricial chicks immediately after hatching, (C) Partially feathered youngs 2-3 weeks after hatching and (D) fully feathered youngs.

Overall, sixteen nests of Indian roller were found in the selected study site and were monitored on regular basis throughout the year. The bird is a secondary cavity nester and do not use any nesting material for making its nests (Fig. 4). Figure 5 indicated that more than half of the nests (56.25%) were found on dead trees.

It was observed that the Indian roller (*Coracias benghalensis*) is conscious in choosing cavity direction in trees (Fig. 6). The data showed that 12 (75%) nests were found in the cavities opening towards southern directions [SE=5 (31.25%), SW=5 (31.25%) and S=2 (12.5%)] and only 4 cavity nests (25%) in other directions [NW=2 (12.5%) and W=2 (12.5%)] (Fig. 7A). Figure 7B clearly showed that the mostly wind rose from northern direction in the study area (Bahawalpur district) but as depicted in Figure 7A most of the nest have cavity openings towards southern directions (opposite to the direction of wind). It showed that the choice of cavity opening depend upon wind direction to protect their nests from storms, heavy winds and precipitation.

Fig. 5. Nesting preference of Indian roller on dead or live trees.

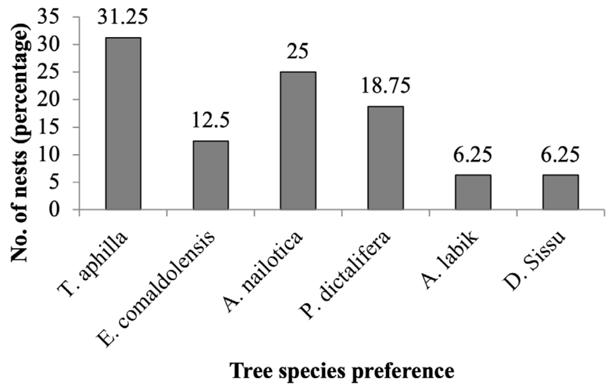

Fig. 6. Nesting tree preference.

Table II shows that the nests of Indian roller are found on different trees having an average height and DBH (Diameter at breast height) of (8.94±2.18 m and 52.98±13.36 cm), respectively. However, the bird preferred to make its nest on a height of 5.45±2.06m with maximum height of 9.12 m and minimum of 2.74 m. The average cavity area was found to be 284.42± 84.25cm^2 while the mean value of cavity depth was of 46±6.94cm with maximum 68cm and minimum 30cm.

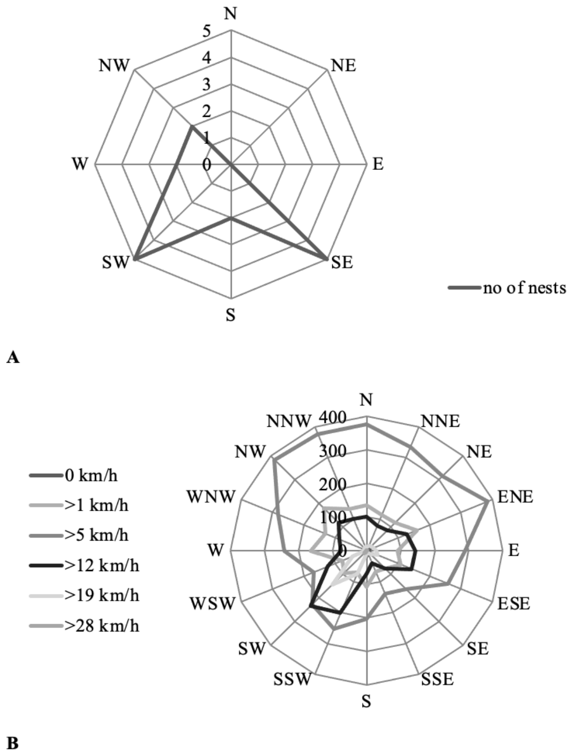

Fig. 7. Orientations of nesting cavities of Indian roller (A), and direction of wind of different velocity classes (B). The scale shows h per year.

Table II. Nesting preferences of Indian roller (*Coracian benghalensis*).

Variables	Mean±SD (Range)
Nest height (m)	5.45±2.06 (2.74-9.12)
Tree height (m)	8.94±2.18 (5.68 -13.30)
DBH (cm)	52.98±13.36 (38.54-76.43)
Cavity length (cm)	17.50±6.18 (11.0-32.0)
Cavity width (cm)	19.00±5.39 (14.0-32.0)
Cavity area (cm^2)	284.42±197.25 (132.7-754.4)
Cavity depth (cm)	46.00±10.94 (30.0-68.0)

DBH, diameter at breast height.

Breeding aspects

The breading season of Indian roller starts from mid March when the male bird used to make Arial acrobatics to attract the female. The female starts laying eggs from mid to late April. The average incubation period was observed to be 18.27±1.03 days and both male and female took part in incubation. Altricial nestlings (helpless, naked, week and immobile nestlings with eyes closed) were found after hatching as indicated in Figure 4. The average fledged days were found to be 35.18±2.56 days. However, the maximum exposure days for nest were 57 with an average value of 53.18±2.56 (Table III).

Table III. Durations of different phases of active nests of Indian roller (*Coracias benghalensis*).

Nesting period (days)	Mean±SD (Range)
Incubation period	18.27±1.03 (17-20)
Fledging days	35.18±1.94 (31-38)
Exposure days	53.18±2.56 (48-57)

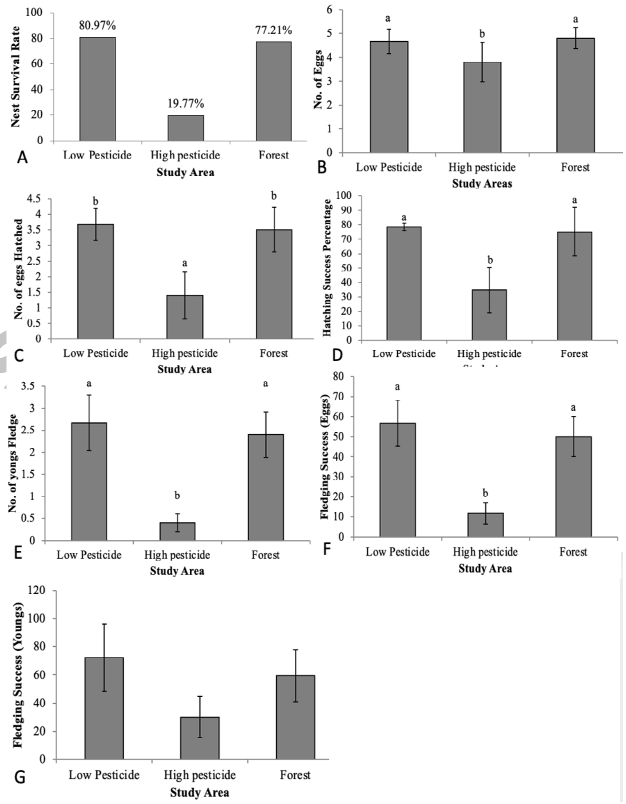

Fig. 8. Nest survival rate (A), clutch size (B), no. of eggs hatched (C), hatching success percentage (D), successfully fledged nestlings (E), fledging success-eggs (F) and fledging success-youngs (G) of Indian roller in different study areas.

The calculated survival rate indicated to be significantly affected ($p \leq 0.05$) that overall, 61.31 % chances of nest to produce at least one young till fledging successfully. Figure 8A shows that the survival rate in agricultural area where high pesticide usage was minimum (19.77%) as compared to agricultural area with less pesticide usage (80.97%) and forests (77.21%). The results clearly show that the high usage of pesticide on agricultural land is a significant threat for the survival of this farmer friendly bird (Fig. 8A). The clutch size was found to be significantly affected ($p \leq 0.05$) in area with high usage of pesticide having minimum mean value (3.8±0.84 eggs/nest) as compared to agricultural area with less pesticide (4.67±0.52 eggs/nest). However, the maximum clutch size (4.8±0.45 eggs/nest) was computed for forest area as depicted in Figure 8B. The number of eggs hatched significantly ($p \leq 0.05$) differed across the studied areas with maximum number of hatched eggs (3.67 eggs/nest) in agricultural area with less pesticide usage while minimum number of hatched eggs (1.4 eggs/nest) in agricultural area with high pesticide usage as depicted in Figure 8C. Similar to number of hatched eggs, hatching success also varied significantly ($p \leq 0.05$) across all study areas. The hatching success in agriculture area with less pesticide was slightly higher as compared to forest area. The range of hatching success was found to be 34.67 ± 15.63% to 75 ± 16.8% with minimum for agriculture area with high pesticide usage (Fig. 8D).

The number of youngs fledged was also significantly affected ($p \leq 0.05$) by high usage of pesticide agricultural area (0.4±0.2 youngs/nest) as compared to agricultural area with less pesticide usage (2.67±0.63 youngs/nest) and forest area (2.4±0.52youngs/nest) as shown in Figure 8E. Similar to numbers of young fledged the fledging success with respect to clutch size was also significantly affected ($p \leq 0.05$) by high usage of pesticide agricultural area (1.67 ± 5.24%) as compared to agricultural area with less pesticide usage (56.67 ± 11.4%) and forest area (50 ± 10%) as shown in Figure 8F. However, there was no significant difference ($P>0.05$) among all three study areas i.e., agricultural area where less or no pesticide was used (72.22 ±23.96%), agricultural area where high pesticide was used (30±14.72%) and in forest (59.33±18.5%) as shown in Figure 8G.

DISCUSSION

A pesticide is a mixture of chemical utilized for controlling, or lessening the pest damage. Even though pesticides compounds are simple to use and can be useful against pest species, they can also impact on human and it's environmental (Cech *et al*., 2022; Faiz, 2022). Lots of species of birds have shown huge decrease in diversity and richness (Ali *et al*., 2021; Mitra *et al*., 2021). These have been linked to modern agricultural usage, which has taken the form of changes in farmland work (Kamp *et al*., 2021). One of these is increased use of pesticides. These indirect effects act predominantly via reduction in food supplies (Youth, 2021). This is predominantly due to insecticide use causing decreased abundance of insect food, and insectivores birds are declined (Bright *et al*., 2008; Singh *et al*., 2019; Sigouin *et al*., 2021).

The current study was conducted in order to check the nesting and breeding biology of Indian roller (*Coracias benghalensis*) in District Bahawalpur, Punjab, Pakistan. The research revealed that the breeding season of Indian roller starts from mid-March when it starts laying eggs from mid to late April. Earlier, Asokan *et al*. (2009) had also shown that Indian roller start laying eggs from late April. Nithiyanandam and Asokan (2015) also recorded the breeding activities in similar months i.e. March to June. The current study about nesting preferences shows that six tree species were frequently preferred by Indian roller for nesting and among those six species; *Tamarix aphylla* with 31.25% of total nests was the most preferred nesting tree. It is mainly preferred due to its high abundance and presence of natural cavities. However, it is somehow contradictory with the previous findings when *Cocos nucifera* was found to be the most preferred tree for the India roller with 45.5% of nesting preference (Asokan *et al*., 2009). While according to our present study, 18.75% nests were found on *Phoenix dactylifera* which have somehow identical structure as *Cocus nucifera* and it is the 3rd most preferred tree for nesting by Indian roller. So, it is assumed that the adaptation in nesting depends upon the availability of cavities on relatively higher trees.

In the current study, it was revealed that high usage of pesticide has a worse effect on the birds population and it is clearly evident that there is a significant difference between the two areas. The population density of Indian roller was highest in agricultural areas with less pesticide usage (100.10 birds/km^2) and minimum in agricultural areas where pesticide usage (34.27 birds/ km^2) was much higher. Sivakumaran and Thiyagesan (2003) also reported similar results regarding the link of the population density of Indian roller with the usage of pesticide at the agricultural fields. Asokan *et al*. (2010a) also reported that after the usage of pesticide at a particular agriculture field, average highest population was 36±5.16 birds/km^2.

The current observations about nesting preferences showed that the Indian roller preferred a tree having an average of 8.94±2.18m in height while preferred nest height was 5.45±2.06m and the average diameter of 52.98±13.36cm was preferred. Where Nithiyanandam and Asokan (2015) have somewhat similar findings with the current study with very little variation in average height of preferred trees (10.7±4.25m), average height preferred for nesting was 6.5±0.50 m and they preferred the trees of average DBH 43.5±6.50 cm. However, in the current study, the cavity length, width, area and depth were 17.50±5.18cm, 19±5.39cm, 284.42±197.25cm^2 and 46±10.94cm respectively and the findings of Asokan *et al*.

(2009) regarding cavity length and cavity depth confirm our results as they are pretty similar to our findings; 14.3 ± 2.52cm and 68.6±6.41cm, respectively. In the current study it was also revealed that Indian roller mostly chose the tree cavity opening towards southern direction, opposite to the direction from which the wind rose i.e., northern directions.

Present study revealed that the clutch size of Indian roller was maximum in forest area (4.8±0.45 eggs/nest) followed by agricultural area with low pesticide (4.67±0.52 eggs/nest) and whereas the clutch size was significantly ($p \leq 0.05$) minimum in areas with high usage of pesticides (3.8±0.84 eggs/nest). It can be assumed that the toxicity of chemicals used as pesticides in agricultural crops also affects its egg laying ability. However, Nithiyanandam and Asokan (2015) also reported the similar findings that the overall clutch size of Indian roller was 3.67±0.57 eggs/nest in areas with high pesticide usage. The hatchability in the areas with high usage of pesticide (34.67%) was also very low as compared to the hatching success in agricultural areas with low usage of pesticide (75%). While Asokan *et al*. (2009) findings of hatching success was also much nearer to our findings in agricultural areas with low usage of pesticide i.e. 78.9%. So, it can be assumed that hatching success is significantly affected ($p \leq 0.05$) by high usage of pesticides on crops. The current findings revealed that the fledging success with respect to number of eggs and number of young was lowest in agricultural areas with high usage of pesticide 11.67% and 30%, respectively while it was best in agricultural areas with less usage of pesticide 56.67% and 72.22%, respectively, followed by forests 50% and 59.33% respectively. Nithiyanandam and Asokan (2015) reported that overall fledging success was 66.6% in agricultural areas with less usage of pesticide and in forests and this result is quite similar to ours. While Asokan *et al*. (2009) reported a little higher percentage of fledging success 80.3% in such areas. So, it can be assumed that hatching success is significantly affected ($p \leq 0.05$) by high usage of pesticides on crops.

According to present study there is an average of 53.18±2.56 brooding days during which the nests remains active (18.27±1.03 days of incubation and 35.18±1.94 days chicks took to fly from nest). Asokan *et al*. (2009) had approximately similar findings for incubation period i.e., 17-20 but days taken for fledging were less than our findings (30-32 days). The difference may be due to the different kind of area or habitat. However Nithiyanandam and Asokan (2015) also reported the incubation period at same range i.e. 18-20 days. The present study also revealed that the nest survival rate was significantly less ($p \leq 0.05$) in area with high usage of pesticide (19.77%) whereas nest survival rate was relatively higher (80.97%) in areas with less usage of pesticide and was quite similar to nest survival rate in forest area (77.21%). Higher population density in agricultural area with less pesticide usage indicated that the bird mainly belongs to agricultural land but high usage of pesticide is effecting its population to great extent. Asokan *et al*. (2009) described coconut tree as the main preferred tree of Indian roller for nesting, however, in present study only 3 nests (18.75%) were found on a data palm tree (*Phoenix dactylifera*) having somewhat similar structure to coconut tree. Frash (*Tamarix aphylla*) was found to be the most preferred tree by the bird in the study area (5 nests) as it has more cavities as compared to other tree species. The minimum number of nests (6.25%) was observed on black seris (*Albizia lebbeck*) and sheshum (*Dalbergia sissoo*), respectively. There are ecological and economic reasons for conserving wildlife in agricultural areas. Few researches have documented that avian species may help in limiting insect pest populations at low densities, allowing decrease of pesticide utilize (Kirk *et al*., 1996; Garcia *et al*., 2020; Tela *et al*., 2021).

CONCLUSION

It was concluded that Indian roller is highly beneficial farmer friendly insectivores' bird. Mainly occur in agricultural areas but the high usage of pesticide on crops is significant threat for its population density, clutch size, hatching, fledging and for the nest survival rate. The farmer should be motivated to encourage this bird by fixing the environment according to habitat preferences as reveled in the current study. So that it might helpful in uplifting the economy. More researches should be done on economic benefits of biological control by the insectivorous birds like Indian roller (*Coracias benghalensis*) so that farmers could be motivated for the conservation of insectivorous birds.

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IRB approval

This study was based on a field survey rather than human or animal trials, therefore, IRB approval was not needed.

Statement of conflict of interest

The authors have declared no conflict of interest.

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