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Breeding Performance and Foraging Plasticity of Purple Sunbird (*Cinnyris asiaticus*) in Crop fields of Northwestern India

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ABSTRACT

Fieldwork was conducted from February, 2022 to September, 2024 at four rural locations-Aittiana and Halwara in district Ludhiana, Punjab, and Ahmadpur and Mirpur in district Sirsa, Haryana, India representing heterogeneous crop fields interspersed with trees and human structures. The breeding performance and foraging plasticity of the Purple Sunbird (*Cinnyris asiaticus*) was studied in crop fields of northwestern India, emphasizing its ecological significance within agro-ecosystems. Breeding activities were monitored through point count and focal nest observations to document nesting chronology, site selection, clutch characteristics and breeding parameters. The species utilized a wide spectrum of nesting substrates, including *Acacia*, *Zizyphus*, *Morus*, *Punica* and artificial supports such as fencing wires, demonstrating strong adaptability to human-modified habitats. A pronounced dietary shift was observed during the breeding period, with adults relying heavily on insects-ants, bees, wasps, spiders, grasshoppers, and termites-for provisioning nestlings, while nectar remained a supplementary resource. Marked inter-annual and inter-site variation was recorded in the onset of nesting, egg-laying, and hatching at four locations. Clutch size varied from 2.00 to 4.00 eggs, with minimal variation in egg length and width, but greater variability in egg weight, volume, and specific gravity was observed across four locations. Hatching and fledging success rates were more at locations of Punjab state as compared to locations of Haryana state. These findings highlighted the role of agricultural landscapes in sustaining the reproductive and nutritional requirements of the Purple Sunbird and underline its potential contribution to natural pest regulation through insect consumption.

KEYWORDS: Breeding biology, crop fields, feeding, nesting, purple sunbird

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1. INTRODUCTION

Agroecosystems represent highly dynamic landscapes where biological communities interact with crops, influencing both ecological processes and agricultural productivity (Mehran et al., 2025). The beneficial organisms like predators and pollinators increase the yield of crops whereas the harmful pests and pathogens reduce the yield. Birds that feed on floral resources and arthropods occupy a pivotal functional niche in such environments, often providing ecosystem services that support sustainable agriculture (Mariyappan et al., 2023; Arya et al., 2024, and Bhoi et al., 2025). Nectarivorous passerines, including members of the family Nectariniidae, are adapted for extracting floral nectar with specialized morphology but frequently supplement their diet with insects and spiders, particularly during periods of increased protein demand such as the breeding season (Santos et al., 2023). The Purple Sunbird (*Cinnyri sasiaticus*) exemplifies this dual feeding strategy. While primarily nectar-feeding, especially outside reproductive periods, it shifts to greater insect consumption when provisioning nestlings, indicative of dietary plasticity that enables it to respond to the varying nutritional needs associated with reproduction (Ghadirian et al., 2007, Perera and Wijesundara, 2020, and Vyas, 2025). Insectivorous and mixed-diet birds can exert considerable control on arthropod populations in agricultural settings, with documented impacts on pest abundance and crop health (Sidhu et al., 2022). Research has shown that by foraging in crop fields the avian predators consume diverse pest taxa-such as caterpillars, beetles, grasshoppers and other herbivorous insects-reducing damage and contributing to trophic cascades that indirectly benefit plant productivity (Bhoi et al., 2025; Dand et al., 2025). These interactions underpin the rationale for integrating bird conservation into pest management frameworks, thereby promoting ecological intensification and reducing reliance on chemical pesticides besides lowering input costs and minimizing environmental contamination (Dand et al., 2025). In addition to pest suppression, nectarivorous and generalist birds often pollinate flowering crops, enhancing plant reproductive success as these birds move from flower to flower in search of nectar and they inadvertently transfer pollen between plants (Ayre et al., 2020). Species such as *C. asiaticus* visit a broad spectrum of floral resources and inadvertently facilitate pollen transfer, underscoring their importance in maintaining agroecosystem biodiversity (Mgimwa et al., 2025). Despite the recognized roles of birds in agroecosystems globally, comparatively few studies have quantitatively assessed how reproductive phenology, nesting ecology and foraging behavior of nectarivorous-insectivorous species vary within and among agricultural landscapes, particularly in the Indian subcontinent. Local habitat structure, cropping regimes, and seasonal resource fluctuations can influence bird community composition and functional performance, yet empirical documentation remains sparse, especially for site-specific breeding schedules and food resource use (Das et al., 2025). The Purple Sunbird is a widely distributed resident across South Asia and frequently occupies rural, urban, and cultivated habitats where floral resources and insect prey are abundant (Mazumdar and Kumar, 2014). It has ability to exploit both nectar and animal prey positions making it an ecologically adaptable species capable of persisting in heterogeneous agro-landscapes. *C. asiaticus* adjusts its breeding phenology, nesting substrate selection, and foraging tactics in response to local environmental conditions which provides insight into the mechanisms enabling its persistence in human-modified habitats and the potential ecosystem services provided by it (Kumar et al., 2021). Through systematic breeding season monitoring and detailed dietary observations across multiple agricultural locations, this study aimed to elucidate the breeding ecology and feeding plasticity of the Purple Sunbird in crop fields of northwestern India and inform conservation strategies that supported avian biodiversity within agricultural matrices.

2. MATERIALS AND METHODS

2.1. Study areas

The present investigation on the breeding biology of the Purple Sunbird (*Cinnyris asiaticus*) in agricultural landscapes was conducted from February, 2022 to September, 2024 in four rural locations: village Aittiana (30°45'35''N, 75°36'42''E) and village Halwara (30°44'01''N, 75°38'33''E) of district Ludhiana, Punjab, and village Ahmadpur (29°34'17''N, 74°58'57''E) and village Mirpur (29°35'20''N, 75°01'13''E) of district Sirsa, Haryana. These study sites were designated as Location I, Location II, Location III, and Location IV, respectively.

Locations I and II were characterized predominantly by agricultural fields where wheat (*Triticum aestivum*) and rice (*Oryza sativa*) constituted the major cropping systems. Additional crops such as mustard (*Brassica juncea*), berseem (*Trifolium alexandrinum*), potato (*Solanum tuberosum*), and mint (*Mentha arvensis*) were cultivated in adjoining fields. The arboreal vegetation in these locations was largely confined to field bunds and around farm sheds, comprising mulberry (*Morus alba*), peepal (*Ficus religiosa*), dhek (*Melia azedarach*), and sheesham (*Dalbergia sissoo*). Fruit trees including mango (*Mangifera indica*), guava (*Psidium guajava*) and jamun (*Syzygium cumini*) were also present in scattered patches. Herbaceous weeds occurred in fallow lands, along field margins, and within crop fields, contributing to habitat heterogeneity. Similarly, locations III and IV were dominated by wheat and rice-based agro-ecosystems, with mustard (*Brassica juncea*) and berseem

(*Trifoliuma lexandrinum*) grown as subsidiary crops in nearby fields. The tree composition in these areas included mulberry (*Morus alba*), ber (*Ziziphus mauritiana*), dhek (*Melia azedarach*), kikar (*Vachellia nilotica*), eucalyptus (*Eucalyptus globulus*) and sheesham (*Dalbergia sissoo*). The presence of scattered trees, shrubs and seasonal weeds across field boundaries and uncultivated patches provided potential nesting substrates and foraging resources for the Purple Sunbird within the intensively managed crop matrix.

2.2. Nest monitoring, nesting site preferences and nest architecture

The breeding behavior of the Purple Sunbird was systematically documented across all selected study locations. Field observations were carried out using the point count and focal nest monitoring methods following the standardized approach outlined by Verner (1985) to ensure uniformity and replicability of data collection. Monitoring was conducted on a weekly basis over two consecutive breeding seasons from 2022–2023 to 2023–2024 in order to capture temporal variation in reproductive activities.

The number of nests and trees used by purple sunbird for building the nests were recorded at all locations. Nesting material used in nest building was recorded following standard descriptions of passerine nest structure as outlined by Hansell (2000). For each nest, detailed observations were recorded including nest type (enclosed or pendant), nesting substrate (identified to plant species or noted as artificial support such as fencing wire), and height above ground. The presence and type of anthropogenic materials incorporated into nest construction such as threads and plastic fibers and composition of the inner lining of the nests was observed. The entrance size was estimated visually to assess structural characteristics related to predator exclusion and microclimatic regulation. Wherever possible, fallen or naturally abandoned nests were carefully examined to verify material composition without disturbing active nests.

All field procedures were conducted with minimal disturbance to the birds and in accordance with accepted ethical guidelines for avian research. Data were recorded on standardized field datasheets to maintain consistency across observers and locations. The timing of visits was aligned with peak daily activity periods, which were identified through preliminary reconnaissance surveys and available literature on the species' breeding phenology. This approach ensured reliable assessment of the breeding ecology of *C. asiaticus* within the agricultural landscapes of Punjab and Haryana.

2.3. Foraging and feeding activity during breeding season

The purple sunbirds were observed for 5–10 min for recording the feeding attempts using binoculars during the breeding season. For each event, data were collected on foraging substrate (crops, weeds, trees, or artificial structures), prey type (nectar or arthropods) foraging movement (perching, hovering, short flights) and attack maneuver (gleaning, probing, hanging, aerial capture) following standardized classifications (Remsen and Robinson, 1990). Prey items were identified visually to the lowest possible taxonomic group. These observations were noted down across all the locations and consolidated to get insights into foraging plasticity during breeding activities.

2.4. Breeding parameters

The observations were taken to record the timing of key breeding events including nest initiation, egg-laying, incubation, hatching, and parental care at all locations. The various egg parameters were also recorded at all four locations. Breeding parameters like Hatching success and Fledging success rate were calculated after pooling data of locations I and II of Punjab State and locations III and IV of Haryana State to get comparative regional differences.

2.4.1. Egg parameters

To avoid disturbance to active breeding attempts, morphometric measurements of eggs were restricted exclusively to abandoned or naturally fallen eggs and nests. All handling procedures were conducted with utmost care to maintain sample integrity. Eggs were handled using wooden spoons to prevent direct contact, and hands were washed and rubbed with dry vegetation to minimize human scent. Each egg was held gently in the center of the palm with a partially closed grip to prevent accidental slipping. Measurements were taken using digital calipers and a precision electronic balance, ensuring minimal pressure on the eggshell. After examination, eggs were carefully returned to the nest cavity and placed in direct contact with the nest base while avoiding any rolling or mechanical damage, following the guidelines of Fierro-Calderon et al. (2021). The various egg parameters recorded were as follows:

2.4.2. Clutch size

The number of eggs laid by the breeding pair in a single nesting attempt was recorded as the clutch size.

2.4.3. Egg length and width

The dimensions of abandoned or naturally fallen eggs were measured using digital vernier calipers with an accuracy of 0.01 mm. Egg length was recorded as the maximum distance between the two poles, while egg width was measured at the widest equatorial region of the egg.

2.4.4. Egg weight

The weight of each abandoned or fallen egg was determined using a portable digital weighing balance with an accuracy of 0.01 g. Measurements were taken immediately after collection to avoid errors due to moisture loss.

2.4.5. Egg volume

Egg volume was estimated from egg length (L) and breadth (B) using the empirical equation proposed by Galbraith (1988):

Egg volume (ml)=$0.457 \times L \times B^2 \times 10^{-3}$

where *L* and *B* represented egg length and breadth in millimeters, respectively.

2.4.6. Specific gravity

Egg specific gravity was calculated following the method of Stadelman and Cotterill (1995) using the formula:

Specific gravity (g cm^{-3})=Egg weight (g)/(Egg volume (cm^3)

2.4.7. Egg shape index

Egg shape index was determined as per Stadelman and Cotterill (1995) using the following equation:

Egg shape index=(Egg breadth/Egg length)×100

2.4.8. Hatching success

Hatching success was calculated according to Murray (1994) as:

Hatching success (%)=(Number of eggs hatched/Total number of eggs laid)×100

2.4.9. Fledging success

Fledging success was estimated following Horak (1993) using the formula:

Fledging success (%)=(Number of nestlings fledged/ Number of eggs hatched)×100

2.5. Statistical analysis

The collected data were subjected to statistical analysis to compute descriptive parameters including mean clutch size, egg morphometric traits and hatching and fledging success rates. Spatial and temporal comparisons were based on descriptive analysis of the coefficient of variation (CV%) which was calculated for all egg parameters for both years across all locations.

3. RESULTS AND DISCUSSION

3.1. Nesting site preferences and nest architecture

The Purple Sunbird had demonstrated consistent nesting behavior across all studied locations during the 2022–23 and 2023–24 breeding seasons, selecting a variety of nesting substrates within crop fields adjacent to airfield and roadside habitats. The species had preferred Kikar (*Acacia nilotica*) and Beri (*Zizyphus mauritiana*) at locations I and II, while at location III it had utilized Kikar, Beri, Pomegranate (*Punica granatum*) and fencing wire and at location IV it had selected Kikar, Beri, Mulberry (*Morus alba*) and fencing wire as nesting supports. This spatial variability had suggested considerable ecological plasticity, likely shaped by differences in local vegetation structure and the availability of anthropogenic features. A total of 18 nests had been recorded from the selected sites in Punjab and Haryana. There were observed 1 and 2 nests at location I, 2 and 3 nests at location II, 3 and 3 nests at location III and 2 and 2 nests at location IV during 2022–23 and 2023–24 respectively. This observation had indicated that the Purple Sunbird had effectively exploited both natural vegetation and artificial structures within agricultural landscapes, reflecting a high degree of adaptability in its breeding ecology.

The Purple Sunbird made enclosed nests and had shown notable resourcefulness in the selection of nesting materials, utilizing a combination of natural and anthropogenic substances for nest construction. The nests were built by utilizing long grass strands collected from the surrounding vegetation, indicating a strong dependence on locally available plant resources. In addition, synthetic materials such as threads and plastic fibers had been incorporated into the outer nest layers, reflecting the species' ability to exploit human-derived materials and adapt to modified agricultural landscapes. The inner lining of the nests had been carefully prepared with soft materials including cotton, cattle hair, human hair and fine fibers, which had likely contributed to the creation of a thermally insulated microenvironment suitable for incubation and chick development. A characteristic feature of the nest architecture had been the presence of a single, very small entrance that allowed access only to adult sunbirds. This restricted opening had suggested an adaptive strategy to reduce predator entry and to maintain favorable internal microclimatic conditions essential for reproductive success. The Rufous Treepie (*Dendrocitta vagabunda*) had been identified as a major predator responsible for nest damage and destruction, indicating persistent predation pressure on the species. The enclosed nest design and narrow entrance had therefore appeared to represent evolutionary responses aimed at enhancing nest security, although the effectiveness of these structural defenses against determined predators had remained uncertain and merited further investigation.

The observed variability in nest site selection-including native vegetation (e.g., *Acacia nilotica*, *Zizyphus mauritiana*, *Morusalba*) and artificial substrates such as fencing wires-reflects strong adaptability to human-modified habitats. Studies on other small passerine species have similarly documented the use of both natural and anthropogenic structures for nesting in agroecosystems, often as a response to altered landscape features and vegetation composition (Benton et al., 2003, and Sekercioglu, 2002). This adaptability in nesting behavior suggests that *C. asiaticus* can persist and reproduce in environments heavily influenced by agriculture and human activity.

3.2. Feeding and foraging activity during breeding season

The feeding and foraging observations of the Purple Sunbird during the 2022–2024 breeding seasons revealed a diverse diet and varied foraging strategies. The birds commonly utilized crops, weeds, trees, and even artificial structures such as wires as foraging sites. This demonstrated their adaptability to both natural and human-modified environments.In terms of foraging movements, flying was prominently associated with capturing ants, wasps, and bees, suggesting active aerial or short-distance pursuit during feeding. Other prey categories did not show specific movement patterns in the recorded observations.Different attack maneuvers were documented depending on prey type. Gleaning behavior was used primarily when feeding on ants, wasps, and bees, while hanging behavior was observed during spider predation. Probing was associated with beetle capture. No specific attack maneuvers were recorded for termites or plant-based food items. Nectarivorous birds often supplement their diets with insects to meet the high protein and nutrient demands of raising young (Gartrell, 2000). The studies on sunbirds (*Nectarinia* spp.) have documented increased insectivory during breeding, suggesting this flexible foraging strategy is widespread among nectar-feeding taxa (Cheke and Mann, 2001). By actively consuming a broad spectrum of crop-associated arthropods, the Purple Sunbird had potentially contributed to the natural regulation of insect populations, thereby offering valuable biological control services within agro-ecosystems. This function was comparable to that of strictly insectivorous birds which have been shown to significantly reduce pest insect populations in farmlands, with measurable benefits to crop yield and health (Garrett et al., 2022).

3.3. Sequence of nesting events during breeding season at different locations

Nesting activity generally commenced between March and May, with subsequent nesting events progressing sequentially from nest initiation to parental care. At location I, initiation of the first nest occurred earlier in 2022–2023 (1st fortnight of March) compared to 2023–2024 (2nd fortnight of March) (Table 1). Egg laying and incubation began during the 2nd fortnight of March in 2022–2023, whereas both activities were delayed to the 1st fortnight of April in 2023–2024. First hatchlings were recorded in the 2nd fortnight of April in both years. Initiation of parenting coincided with first hatching and remained consistent across years, occurring during the 2nd fortnight of April. At location II, nesting activities were generally delayed compared to location I. The first nest was initiated in the 1st fortnight of

Table 1: Sequence of nesting events recorded at different locations

Sl. No.	Location	Nesting events	2022–2023	2023–2024
1.	I	Initiation of first nest	1st fortnight of March	2nd fortnight of March
2.		Initiation of egg laying	2nd fortnight of March	1st fortnight of April
3.		Initiation of incubation	2nd fortnight of March	1st fortnight of April
4.		First hatchling	2nd fortnight of April	2nd fortnight of April
5.		Initiation of parenting	2nd fortnight of April	2nd fortnight of April
1.	II	Initiation of first nest	1st fortnight of April	2nd fortnight of May
2.	III	Initiation of egg laying	2nd fortnight of April	1st fortnight of June
3.		Initiation of incubation	2nd fortnight of April	1st fortnight of June
4.		First hatchling	1st fortnight of May	2nd fortnight of June
5.		Initiation of parenting	1st fortnight of May	2nd fortnight of June
1.	III	Initiation of first nest	2nd fortnight of March	1st fortnight of March
2.	IV	Initiation of egg laying	1st fortnight of April	2nd fortnight of March
3.		Initiation of incubation	1st fortnight of April	2nd fortnight of March
4.		First hatchling	1st fortnight of May	2nd fortnight of April
5.		Initiation of parenting	1st fortnight of May	2nd fortnight of April
1.	IV	Initiation of first nest	2nd fortnight of April	1st fortnight of May
2.		Initiation of egg laying	1st fortnight of May	2nd fortnight of June
3.		Initiation of incubation	1st fortnight of May	2nd fortnight of June
4.		First hatchling	2nd fortnight of May	1st fortnight of July
5.		Initiation of parenting	2nd fortnight of May	1st fortnight of July

April during 2022–2023 but shifted later to the 2nd fortnight of May in 2023–2024. Egg laying and incubation began in the 2nd fortnight of April during 2022–2023 and were delayed to the 1st fortnight of June in 2023–2024. First hatching and initiation of parenting occurred in the 1st fortnight of May during 2022–2023, while both events were observed in the 2nd fortnight of June during 2023–2024. At location III, the initiation of the first nest occurred during the 2nd fortnight of March in 2022–2023 but earlier, in the 1st fortnight of March, during 2023–2024. Egg laying and incubation commenced in the 1st fortnight of April during 2022–2023 but advanced to the 2nd fortnight of March in 2023–2024. First hatching and parenting initiation were observed in the 1st fortnight of May during 2022–2023 and in the 2nd fortnight of April during 2023–2024, indicating an overall advancement of the breeding cycle in the latter year. At location IV, nesting began in the 2nd fortnight of April in 2022–2023 and shifted earlier to the 1st fortnight of May in 2023–2024. Egg laying and incubation occurred in the 1st fortnight of May during 2022–2023 and were delayed to the 2nd fortnight of June in 2023–2024. First hatching and initiation of parenting were recorded during the 2nd fortnight of May in 2022–2023 and the 1st fortnight of July in 2023–2024. Locations I and III exhibited earlier nesting activity compared to locations II and IV, suggesting more favorable local conditions. These inter-annual and inter-site differences had indicated considerable flexibility in the breeding schedule of the Purple Sunbird, suggesting that local environmental conditions and habitat characteristics had likely influenced the timing of reproductive activities (Wingfield, 2008). The breeding flexibility might be advantageous in fluctuating environments; however, continued shifts or mismatches between breeding timing and peak food availability could have implications for reproductive success (Visser et al., 2006).

3.4. Egg parameters at different locations

Egg parameters of the Purple Sunbird varied across locations (I–IV) and between the two breeding seasons (2022–2023 and 2023–2024), indicating spatial and temporal variation in reproductive traits (Table 2).

The clutch size was highest at location IV (4.00±0.00, 3.50±0.55) and lowest at location III (2.00±0.00, 2.33±0.22). Coefficient of variation (CV) values were variable at different locations during both the years with maximum variability recorded at location 1(20.05) during 2022–23 and no variability (0%) recorded at location II and III during 2023–24.

Table 2: Egg parameters of purple sunbird observed (fallen eggs/abandoned nest) at different locations

Location	Year	Clutch size		Egg length (mm)		Egg width (mm)		Egg weight (gm)	
		Mean± SD	C.V. (%)	Mean± SD	C.V. (%)	Mean± SD	C.V. (%)	Mean± SD	C.V. (%)
I	2022–23	2.50±0.50	20.0	16.32±0.23	1.41	11.27±0.29	2.57	1.46±0.22	15.07
	2023–24	3.00±0.00	0.00	16.55±0.31	1.87	11.11±0.13	1.17	1.36±0.12	8.82
II	2022–23	3.00±0.58	19.33	14.98±0.08	0.53	11.53±0.21	1.82	1.56±0.06	3.85
	2023–24	3.00±0.00	0.00	14.61±0.17	1.16	11.11±0.13	1.17	1.73±0.06	3.47
III	2022–23	2.00±0.01	0.50	15.92±0.34	2.14	10.83±0.31	2.86	1.18±0.33	27.97
	2023–24	2.33±0.22	9.44	15.75±0.08	0.51	10.73±0.12	1.12	1.29±0.06	4.65
IV	2022–23	4.00±0.00	0.00	16.01±0.66	4.12	10.87±0.36	3.31	1.20±0.78	65.00
	2023–24	3.50±0.55	15.71	16.18±0.12	0.74	11.07±0.03	0.27	1.41±0.00	0.00

Location	Year	Egg volume (cm^3)		Egg specific gravity ($g\ cm^3$)		Egg shape index		Egg shell thickness (mm)	
		Mean± SD	C.V. (%)	Mean± SD	C.V. (%)	Mean±SD	C.V. (%)	Mean±SD	C.V. (%)
I	2022–23	0.94±0.06	6.38	1.53±0.13	5.07	69.02±0.78	1.13	0.03±0.00	0.00
	2023–24	0.93±0.04	4.30	1.45±0.06	4.14	67.13±0.47	0.70	0.04±0.01	25.00
II	2022–23	0.91±0.04	4.40	1.71±0.01	0.58	76.92±1.02	1.33	0.03±0.00	0.00
	2023–24	0.82±0.03	3.66	2.10±0.14	6.67	76.01±0.03	0.04	0.04±0.02	50.00
III	2022–23	0.85±0.18	21.18	1.38±0.20	14.49	68.05±0.27	0.40	0.03±0.00	0.00
	2023–24	0.82±0.01	1.22	1.56±0.22	14.10	68.11±0.09	0.13	0.04±0.01	25.00
IV	2022–23	0.86±0.08	9.30	1.38±0.04	2.9	67.87±0.23	0.34	0.04±0.02	50.00
	2023–24	0.90±0.06	6.67	1.56±0.01	0.64	68.44±0.62	0.91	0.03±0.00	0.00

Eggs from location I exhibited larger length (16.32±0.23 m, 16.55±0.31 m) and location II exhibited smaller length (14.98±0.08 m, 14.61±0.17 m) in both years. Egg length displayed minimal variation, with low CV values across all locations (ranging from 0.51% to 4.12%), indicating stability of this trait.

The egg width was observed to be maximum at location II (11.53±0.21 m) during 2022–23 and at location I and II (11.11±0.13) during 2023–24. The minimum egg width was recorded at location III (10.83±0.31, 10.73±0.12) during both the years. There was observed little variability in egg width during both the years at all for locations (0.27% to 3.31%).

The egg weight was found to be maximum at location II (1.56±0.06, 1.73±0.06) and minimum at location III (1.18±0.33, 1.29±0.06) during both the years. The egg weight showed wide range of variability and very low variability as well high variability (65%) recorded at location IV during 2023–24 and 2022–23 respectively.

The egg volume was found to be maximum at location I (0.94±0.06, 0.93±0.04) during both the years and minimum at location III (0.85±0.18) during 2022–23 and at location II and III (0.82±0.03, 0.82±0.01) during 2023–24. The egg volume was observed to show wide range of variability with very low variability (1.22%) during 2023–24 and high variability (21.18%) during 2022–23 both observed at location III.

The egg specific gravity was observed to be highest at location II (1.71±0.01 g cm^{-3}, 2.10±0.14 g cm^{-3}) and lowest at III and IV (1.38±0.20/0.04 g cm^{-3}, 1.56±0.22/0.01 g cm^{-3}) during both the years. The minimum variation with very low variability was observed at location IV (0.64%) and maximum variation with moderate variability was recorded at location III (14.49%).

The egg shape index was recorded to be maximum at location II (76.92±1.02 cm^3, 76.01±0.03 cm^3) and minimum at location IV (67.87±0.23 cm^3) during 2022–23 and at location I (67.13±0.47 cm^3) during 2023–24. There was observed with very low variability in values of egg shape index across all location during two years with minimum variation observed during 2023–24 (0.04%) and maximum variation(1.33%) during 2022–23 both observed at location II.

Egg shell thickness ranged from 0.03 to 0.04 mm. There was wide range of variability in egg shell thickness and no variability (0%) was recorded at location I , II and III during 2022–23 and at location IV during 2023–24. The egg shell thickness showed high variability at location I (25%), location II (50%) and location III (25%) during 2022–23 and at location IV (50%) during 2022–23.

The observed variation in egg parameters of the Purple Sunbird across locations and years reflected the influence of local environmental conditions on reproductive investment. Earlier studies have shown that egg size, clutch size, and shell characteristics were shaped by habitat quality, food availability, and female condition (Yosef et al., 2025). The comparatively larger clutch size at Location IV suggested more favorable conditions, such as better food resources or reduced nesting stress while smaller clutch sizes at Location III might reflect suboptimal habitat quality or higher energetic costs. Egg length, width, and weight showed relatively low variability, supporting earlier findings that egg dimensions were conservative traits under strong physiological control (Krist et al., 2004). Slight increases in egg size and weight during 2023–2024 at certain locations might indicate improved nutritional conditions for breeding females. Larger eggs were often associated with higher hatchling survival and improved early growth (Magrath, 1992). The higher egg volume observed at Location IV suggested greater maternal investment egg^{-1}, which might confer an advantage under favorable environmental conditions. However, higher CV values in egg weight at some locations indicated that individual females might respond differently to local constraints. Egg specific gravity and shape index values indicated structurally sound eggs across all locations. Higher shape index values at Location II suggested slightly rounder eggs, which has been associated with enhanced resistance to mechanical stress in some bird species (Stoddard et al., 2017). The limited variation in shell thickness aligned with earlier studies showing that shell thickness remained relatively stable unless influenced by nutritional deficiencies or environmental contaminants (Attard and Portugal, 2024). Overall, the results demonstrated moderate spatial and temporal variation in egg parameters of the Purple Sunbird, reflecting adaptive reproductive strategies in response to local environmental conditions. Such plasticity in egg characteristics might enhance reproductive success in heterogeneous habitats. Continued multi-year monitoring would help clarify long-term trends and the influence of climatic variability on reproductive investment.

3.5. Hatching and fledging success at different locations

The hatching success was higher at locations I and II of Punjab state (93.33%) during 2022–23 but declined to 66.67% in 2023–24. In contrast, pooled data of locations III and IV of Haryana showed consistently lower hatching success (40.00%) in both years (Figure 1). A similar pattern was observed in fledging success rate as pooled data of locations I and II of Punjab state recorded higher fledging success (83.33% in 2022–23; 66.67% in 2023–24), whereas pooled data of locations III and IV of Haryana maintained

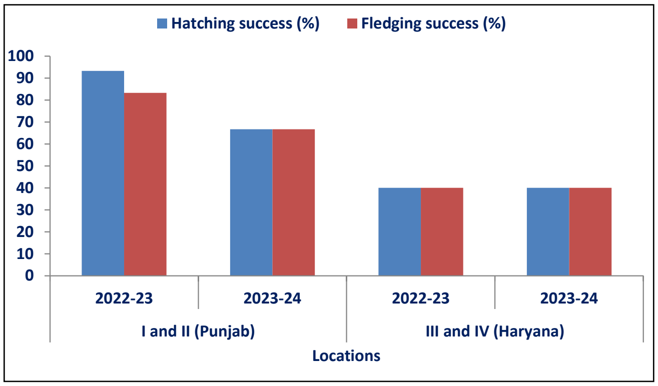

Figure 1: Breeding parameters of purple sunbird at different locations of Punjab state and Haryana state

a lower and constant fledging rate (40.00%) across both breeding seasons. Both the hatchling success and fledging success was higher as was evident from pooled data of locations of Punjab State in comparison to locations of Haryana State which might be due to local habitat features, anthropogenic disturbances and prey abundance or predator pressure (Laux et al., 2024).

4. CONCLUSION

The Purple Sunbird functioned as a highly adaptable and ecologically important species in agricultural landscapes of Punjab and Haryana. It exhibited flexibility in nesting ecology, utilized diverse natural vegetation and artificial substrates and showed a dietary shift toward insectivory during breeding which helped in insect pest regulation by this bird. It adjusted its breeding phenology across locations and years in response to environmental conditions. Higher hatching and fledging success in Punjab indicated better resource availability, highlighting its role as a bio-indicator and contributor to sustainable agriculture.

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