

# Breeding behaviour of Purple Sunbird, *Cinnyris asiaticus* (Latham, 1790) in semiurban area of Punjab

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## Abstract

During the breeding seasons 2017-2020, breeding activities of the Purple Sun-Bird (PSB), *Cinnyris asiaticus* were studied in 16 nesting sites located in the northern rural and semi-urban outskirts of the Khanna city in Punjab. Observations on nest building, incubation, hatching, feeding, growth, fledging and other behavioural aspects of the parents/chicks were inferred from video-records, photographs and direct observations made on 11 clutches laid in 07 nests. In the study area the breeding season extended from March to July and the mean value of the nest structure parameters, namely, nest length, nest width and entrance diameter were  $15.2 \pm 0.63$  cm (range: 14-16 cm),  $6.61 \pm 0.36$  cm (range: 6.0-8.0 cm) and  $3.67 \pm 0.34$  cm (range: 3.0-4.0 cm) respectively. The clutch size was 2 eggs (n=6) or 3 eggs (n=4) and the egg (n=17) weight, length and breadth measured  $1.13 \pm 0.06$  gm,  $16.61 \pm 0.43$  mm and  $11.49 \pm 0.28$  mm, respectively. Most of the eggs were laid in morning hours between 6:30 am to 7:30 am (n=25) and the incubation period was recorded 12 days (n=3), 13 days (n=6) and 16 days (n=1). Video records of 80.62 hours diurnal observation time (OT) recorded over 07 consecutive days (between 6:30am – 6:30pm each day) of full incubation revealed that the PSB female spent 51.59 hours (64% OT) and 29.03 hours (36% OT) as attentive periods and un-attentive Periods respectively. Synchronous hatching was completed in one or two successive days (within 24 hours) except for a single three-egged clutch with its youngest chick hatching asynchronously on third successive day. During nestling phase of 13 – 16 days, eyes of the altricial chicks opened on 5th day after hatching and approaching the day-10, the chick appeared fully feathered. During the biparental food provisioning OT of 54 hours referable to 05 days of the second half on nestling life, male and female PSB contributed 173 (33.20%) and 348 (66.80%) feeding visits respectively at a rate of 9.44 visits per hour. During this OT, the male and female PSB were seen carrying faecal sacs of chicks away from nest on 03 and 79 occasions respectively. The review of video-records showed that the female Purple Sunbird made use of nest fibers from the inner lining of the nest, as a tool for removing the defective egg from the nest. One of the nests was used in two consecutive breeding seasons and 04 broods were successfully raised in the same nest. The Oriental Garden Lizard, *Calotes versicolor* was noticed as a nest predator.

**Keywords:** Breeding, *Cinnyris asiaticus*, Incubation, Punjab, Purple Sunbird, Tool Use

## Introduction

Sunbirds are small Passerine birds referable to Family Nectariniidae that primarily feed on nectar and insects (Cheke *et al.*, 2001). A total of 14 species of Sunbirds have been enlisted from the Indian region (Arlott, 2014) including 09 species from the Northern India out of which 02 species occur in Punjab (Grimmett and Inskipp, 2010). The Purple Sunbird (hereafter referred to as PSB), *Cinnyris asiaticus* is a small common resident bird in Punjab. In its breeding plumage male PSB is bright bluish-black above and the non-breeding eclipse plumage resembles female but with a broad purple-black stripe extending down the

center of the throat to belly. The female PSB is olive brown above, pale-yellow below with a faint supercilium and darker mask (Grimmett and Inskipp, 2010; Manakadan *et al.*, 2011).

Sunbirds play an important ecological role as pollinators of numerous species of plants, including those having economic value as crops (Dewar, 1911; Ali, 1941; Cheke *et al.*, 2001; Stone *et al.*, 2003; Solomon Raju, 2005; Janeček *et al.*, 2020). The PSB is an effective pollinator of freshly opened bright coloured flowers of *Butea monosperma* (Tandon *et al.*, 2003) and is also involved as a spreader of parasitic mistletoes on the economically

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important timber tree *Shorea robusta* (Davidson, 1945) and a pest of vineyards (Sharma and Kashyap, 1999) in India.

The seminal works during the pre-independence period (Jerdon, 1862; Dewar, 1911; Ali, 1941; Whistler, 1941) presented definitive morpho-ecological notes on PSB from the Indian region. During the post-independence period the unusual nesting sites, a toilet chain (George, 1957), clothline (Munidasa, 1969), telephone wire (Rahmani and Sankaran, 1990) and electric pole (Sangha, 1999) have been reported from different localities. In addition to some notes on nest structure (Srivastava, 2013; Tayade *et al.*, 2014; Mishra, 2014), studies on comparison of urban and rural nesting sites in New Delhi (Mazumdar and Kumar, 2014), provisioning of young ones by PSB parents in Haridwar (Sethi *et al.*, 2010), notes on feeding and breeding of PSB in Iran (Ghadirian *et al.*, 2007) and more recently an analysis of vocal signals of PSB (Manoj *et al.*, 2019) has been attempted by respective workers.

The information on the critical nesting parameters (clutch size, incubation period and nestling period) is available only about one third of the all extant species of the birds world over and the bird life history strategies often vary among habitat types (Xiao *et al.*, 2017). Studies on the breeding biology of birds are crucial for improving information about avian life-history theory and also for the implementation of effective management and conservation (Maurício *et al.*, 2013). Punjab is primarily an agrarian state with only 5.20 percent area under forest cover (Grover *et al.*, 2017). During the post independence period, the local environment scenario of Punjab has witnessed a sea change due to deforestation, industrialization, increased transportation network, modern agricultural practices, urbanization and other anthropogenic factors. As a result, the present day Punjab has lost much of its forest and dominant wildlife. Like other avian taxa, no specific study has been attempted to document its breeding, nesting, feeding and other behavioural aspects of PSB in the agricultural landscape of Punjab.

## Material and Methods

All the nesting sites were located in the northern rural and semi-urban outskirts of Khanna city in Punjab. In the study region PSB was most prevalent in thinly populated

residential areas with front/back yards; mixed vegetation in/around open unoccupied plots, community parks, institutions, village ponds and adjoining agricultural fields during the breeding season. The climate of study area is typical of Punjab plains, quite hot in summer and sufficiently cold in winter. The habitat provided a precise mixture of nesting sites and feeding sites (cultivated and natural vegetation) for successful breeding of PSB.

During the breeding seasons 2017 – 2020, following the clues given by female PSB behaviour, 10 nests were found in the beginning of nest building and 06 nests were found prior to onset of egg laying. Out of these 14 nests were closely monitored till the nest/clutch failure or fledging for making observation on nest building, egg laying, hatching, feeding and fledging of the chicks. Once recorded, a nest was visited at least once daily. During egg laying and hatching period different sites were visited at least thrice daily. Field photography was done using a Sony A-77 DSLR camera fitted with Tamron 70-300mm telephoto lens.

One of the nests, build on chain of a swing placed under fiber-shed of a house (Latitude: 30°43'18.36" N & Longitude: 76°13'9.69" E) that hosted 03 consecutive clutches was intensively video monitored as a focal nest. The interiors of the nest were monitored and photographed using an endoscope hidden in the nest and operated indoors through a Dell laptop. The endoscope was secretly secured in the nest without causing any damage to the nest and disturbance to the incubating female bird as it was on a foraging visit at the time of camera installation. The attentive and inattentive periods (Podulka *et al.*, 2004; Wang and Beissinger, 2011; Liang *et al.*, 2018) during incubation and feeding visits conducted by parents during nestling period were video recorded using a Hikvision IR Network Camera with inbuilt-SD Card (64GB) installed at a distance of about 1m from the nest. Video-monitoring of nests has become a very useful tool for documenting behavioural data without causing any damage and disruption at the nest (Sabine *et al.*, 2005; Cox *et al.*, 2012; Jiang *et al.*, 2016). In comparison to direct observations, the technique records detailed, continuous and natural behaviour as the birds are oblivious to the camera and data can be reviewed as desired.

Nest and egg parameters were measured with SF-400C Digital Weighing Scale (Least Count 0.01 mg), Digital Vernier Caliper (Range 01-15 cm, Least Count 0.01 mm),

a 12" ruler and a Magnetic Compass. Observations on PSB behaviour were also made using Olympus 10×50 DPS Binoculars. Eggs were weighed after completion of the clutch, Egg volume was estimated using the equation (Volume = 0.51. LB<sup>2</sup>, where L is the length and B is the breadth) given by Hoyt (1979) and Egg Shape Index [ESI= (B/L) ×100] was determined as per Stadelman and Cotterill (1995). Nest locations were recorded by a GPS. In the present study, Incubation Period (IP) was taken as the number of days between laying to hatching of the last egg in a clutch (Kendeigh, 1963; Wesley, 2004) and Nestling Period (NP) as the number of days between hatching and fledging for each individual nestling in a brood (Vyas, 2010; Kouba *et al.*, 2015). We defined the Egg Laying Period (ELP), Hatching Period (HP) and Fledging Period (FP) as the number of successive days for completion of the respective event. The Nesting Period was the interval from laying of the first egg to fledging of the last chick of a brood (Vyas, 2010). Details about nest building, incubation, hatching, feeding, growth, fledging and other behavioural activities of the parents/chicks were inferred from video-records, photographs and direct observations.

## Observations and Results

### Nest Sites and Nest Building

The nesting sites observed during the present study include the sites/structures both in the residential premises (08 nests) and the adjoining open habitat around water bodies, agricultural fields and unoccupied vacant plots (08 nests). In the residential premises the cloth-line, electricity supply wire, swing chain, bicycle brake cable, air-conditioner support-frame and garden shrubs planted near the boundary walls were used as nesting sites, whereas, in the open habitat the lower bushy growth of plants viz. Indian Jujube (*Zizyphus mauritiana*), Sheesham (*Dalbergia sisso*), Garden Quinine (*Clerodendrum emerme*), Pointed Gourd (*Trichosanthes dioica*), Lemon (*Citrus limon*), Punjab Fig (*Ficus palmata*), White Mulberry (*Morus alba*) and False Mallow (*Malvastrum coromandelianum*) were preferred for nest building.

Hanging pouch-shaped nests were constructed solely by the female individual over a period of 6-7 days (n=10). The mean value of the nest structure parameters namely, nest length, nest width and entrance diameter are 15.2±0.63 cm (range: 14-16 cm), 6.61±0.36 cm

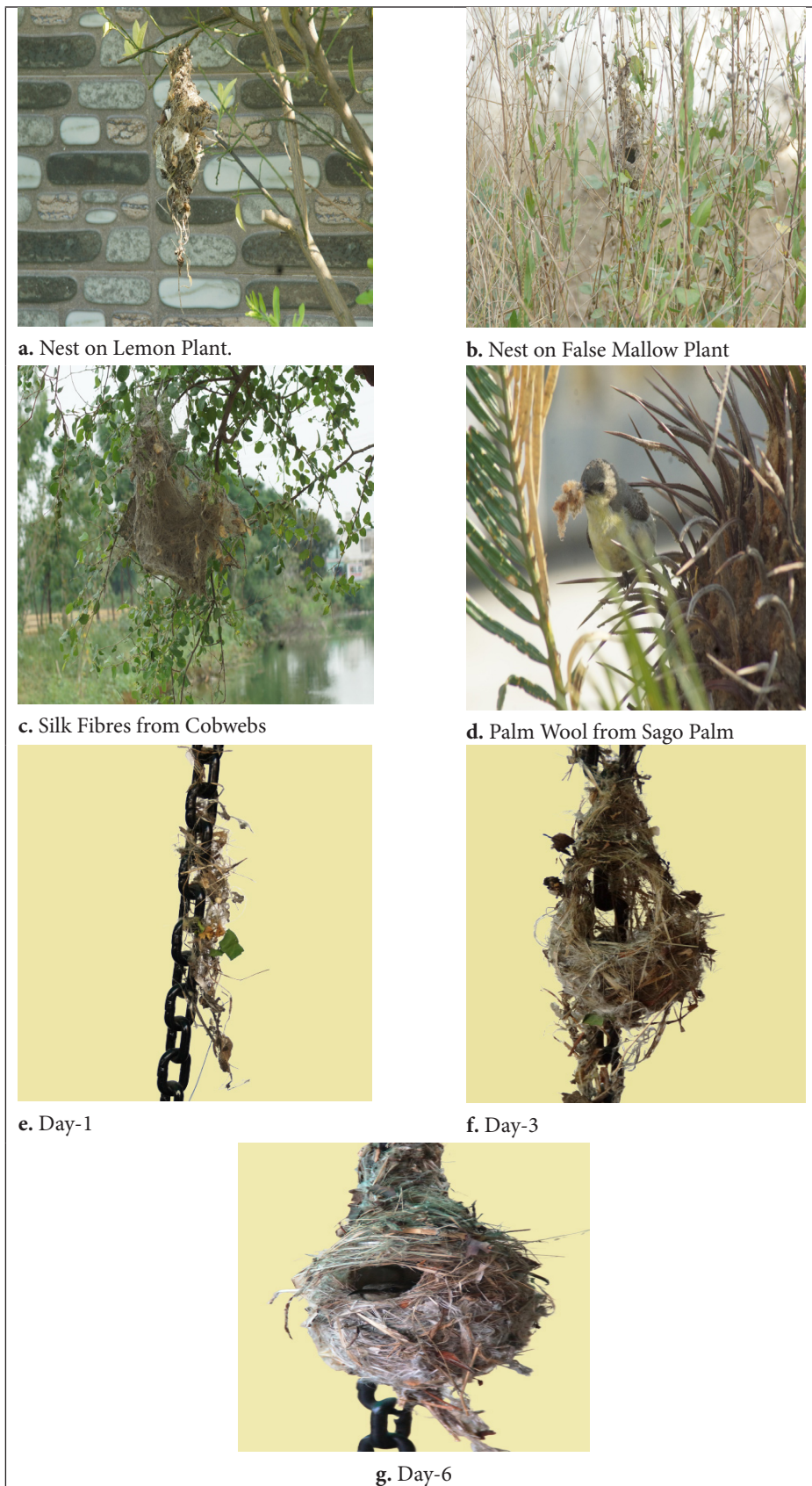
(range: 6.0-8.0 cm) and 3.67±0.34 cm (range: 3.0-4.0 cm) respectively. The weight of an empty PSB nest is 7.44 gm (n=1). The entrance hole of the nest was not oriented towards a specific direction (n=19) and it generally faced the open entry side of the nest (Figure 1).

The nest material used included cobwebs (Figure 1c); bark fibers from wild weeds; chips of tree bark; thin dried grass twigs; palm wool (Figure 1d); nylon threads from discarded fertilizer bags; white cotton pieces and threads; dried crumpled leaves of Blue Gum (*Eucalyptus globulus*); soft and dried colorless leaves of the Paper Flower (*Bougainvillea glabra*); soft and small feathers; white silky hair from the seeds of Sodom's Apple; soft white flakes from the leaves of Banyan tree; bits of candy wrappers, newspaper and polythene bags, etc. Using its curved bill, the female PSB was seen removing the bark fibers from the stalk of wild weeds available in the nesting territory.

The cobwebs were mainly available on the Gum Arabic tree (*Acacia nilotica*), Indian Banyan (*Ficus benghalensis*), Indian Jujube (*Zizyphus mauritiana*) and Sheesham (*Dalbergia sisso*) within a range of 70-90 m from the nesting site. Spider silk threads and fine bark fibers formed the bulk of nest structures at all the sites whereas the quality and quantity of other material varied from site to site in view of its availability in the immediate surroundings.

At two of the nesting sites, the PSB pairs were seen inspecting the respective nest sites about three days prior to start the nest building at those sites.

After selecting a potential nest site, the female PSB alone completed the solitary nest building in 6-7 days. In the first phase, silk fibers from cobwebs, and thin bark fibers were placed round the down-sloping branch or other man-made structure to form a secure holdfast (Figure 1e) for the hanging nest. Spider silk fibers were used as a glue to form a structural frame to hold the bits of other nest items used. By the end of the second day, the female bird first extended the holdfast into a flat perforated sheet and then made the future entrance hole in this sheet. During continuous visits conducted for collection of silk fibers from cobwebs, the Female PSB quickly deposited the material staying only for 5-7 seconds at the nest and the bulk of the silk fibers were collected from the same cobweb tree, once located. In the second phase, the female worked from this future entrance hole and added nest material from inside, thus broadening the nest in the form of a pouch (Figure 1f). The female was seen entering the



**Figure 1.** Nest Construction.

nest cavity and pushing the nest wall out from inside. On the fourth day, it completed the filling of perforations on the rear side of the pouch and deepened the nest interior. Female PSB invested alternate bouts for collection of silk fibers and other items required for nest building. A bout comprising 7-8 visits for silk fibers was followed by a bout comprising 4-5 visits for other items. It took an average of 68 seconds to conduct a single complete visit for bringing silk fibers from cobwebs available on a tree located at a distance of 70-80 m from the nest site. In the last phase of nest building on fifth and sixth day (Figure 1g), the female was noticed carrying soft feathers, thin bark fibers and silken threads for preparing the inner lining of the nest. It even performed springing movements inside the nest so as to expand the nest interiors and close pack the contents. A small porch like extension consisting of thin bark fibers was also made above the entrance hole. The lower end of the nest continued as a long dangling beard. Depending upon the weather conditions and availability of the raw material for nest building it took 6-7 days for completion of the nest by female PSB.

Nest building was more pronounced in the morning hours than in the evening, and was kept continued even during windy days. The entire nest building was carried out silently and secretively. It never directly perched on the nest twig, rather always followed an indirect route first perching on some other branch of the nest tree and then moved towards the nest twig for delivery of material.

The female PSB broke her silence in the last phase of nest building and produced loud calls on its arrival and departure from the nest while adding soft material for interior lining of the nest. During the nest building period of 6-7 days, the male PSB was infrequently seen perching atop the nest tree and the trees visited by female PSB for picking spider fibers.

During the nest building period, the other resident birds like Sindh Sparrow, Oriental Magpie Robin, Indian Tailor Bird and Common Myna were seen visiting the nest tree intermittently, but neither had they interfered with the nest building nor the PSB adults showed any aggressive response to these intruders. Adult PSB always made a downward flight whenever they leave the nest.

### Egg Laying and Incubation

In the study area the breeding season of PSB extended from March to July. During the breeding seasons 2017 – 2020, a total of 11 clutches laid in 07 nests (Table 1) were monitored for making an observation on egg laying, hatching, feeding and fledging of the chicks. Egg laying generally began two days after completion of the nest by female PSB. Out of these, eggs of 10 clutches (06 clutches of 02 eggs each and 04 clutches of 03 eggs each) were laid at a rate of one egg per day (24 hours apart) and 02 eggs of 01 clutch were laid on first and third successive day in morning hours between 6:30 am to 7:30 am.

**Table 1.** Egg-laying, hatching, incubation and fledging period of purple sunbird

Nest	Egg Laying				Hatching				Fledging			Nest- ing Cycle (Days)
	Clutch	Egg/s	Date	ELP (Days)	Chick	Dt.	H.P (Days)	I.P (Days)	Date	N.P (Days)	F.P (Days)	
Old Well 2017	First	E-1	24.03. 2017	03	C-1	07.04. 2017	02	13	21.04. 2017	14x14	02	29
		E-2	25.03. 2017		C-2	07.04. 2017			21.04. 2017	14		
		E-3	26.03. 2017		C-3	08.04. 2017			22.04. 2017	14		
Garden Quinine 2017	First	E-1	15.04. 2017	03	C-1	29.04. 2017	01	12	Nocturnal Predation of Nest on 07.05.2017			
		E-2	17.04. 2017		C-2	29.04. 2017						

Table 1. (Continued)

Nest	Egg Laying				Hatching				Fledging			Nest- ing Cycle (Days)
	Clutch	Egg/s	Date	ELP (Days)	Chick	Dt.	H.P (Days)	I.P (Days)	Date	N.P (Days)	F.P (Days)	
Swing Chain 2017	First	E-1	20.04. 2017	03	C-1	03.05. 2017	03	13	17.05. 2017	14	01	27
		E-2	21.04. 2017		C-2	03.05. 2017			17.05. 2017	14		
		E-3	22.04. 2017		C-3	05.05. 2017			C-3 Died & Female PSB removed it on 09.05.2017			
	Second	E-1	05.06. 2017	02	E-1	Un- hatched	Incubated for 17 days and then removed it from nest on 23.06.2017					
		E-2	06.06. 2017		E-2	Breakage during measurements						
	Third	E-1	27.06. 2017	03	C-1	11.07. 2017	01	12	24.07. 2017	13	02	28
		E-2	28.06. 2017		C-2	11.07. 2017			25.07. 2017	13		
		E-3	29.06. 2017		Egg disappeared from Nest on 03.07.2017							
	Lemon Plant 2017	First	E-1	22.04. 2017	03	C-1	05.05. 2017	02	11	19.05. 2017	14	02
E-2			23.04. 2017	C-2		06.05. 2017	20.05. 2017			14		
E-3		24.04. 2017	Egg disappeared from Nest on 27.04.2017									
Bicycle Brake Cable 2018	First	E-1	20.03. 2018	02	C-1	02.04. 2018	02	13	17.04. 2018	15	02	27
		E-2	21.03. 2018		C-2	03.04. 2018			17.04. 2018	14		
	Second	E-1	30.04. 2018	01	C-1	14.05. 2018	01	13	28.05. 2018	14	01	27
		E-2	01.05. 2018		C-2	14.05. 2018			28.05.2018	14		
	Third	E-1	23.06. 2018	02	C-1	06.07. 2018	02	13	21.07. 2018	15	01	28
		E-2	24.06. 2018		C-2	07.07. 218			21.07. 2018	14		

Table 1. (Continued)

Nest	Egg Laying				Hatching				Fledging			Nest- ing Cycle (Days)
	Clutch	Egg/s	Date	ELP (Days)	Chick	Dt.	H.P (Days)	I.P (Days)	Date	N.P (Days)	F.P (Days)	
Bicycle Brake Cable 2019	First	E-1	20.03. 2019	02	C-1	02.04. 2019	02	13	18.04. 2019	16	02	30
		E-2	21.03.2019		C-2	03.04. 2019			19.04. 2019			
AC Support Frame 2020	First	E-1	25.03. 2020	02	C-1	09.04. 2020	01	14	24.04. 2020	15	01	30
		E-2	26.03. 2020		Defective Egg did not hatch							

ELP: Egg-laying Period; H.P: Hatching Period; I.P: Incubation Period; N.P: Nestling Period; F.P: Fledging Period.

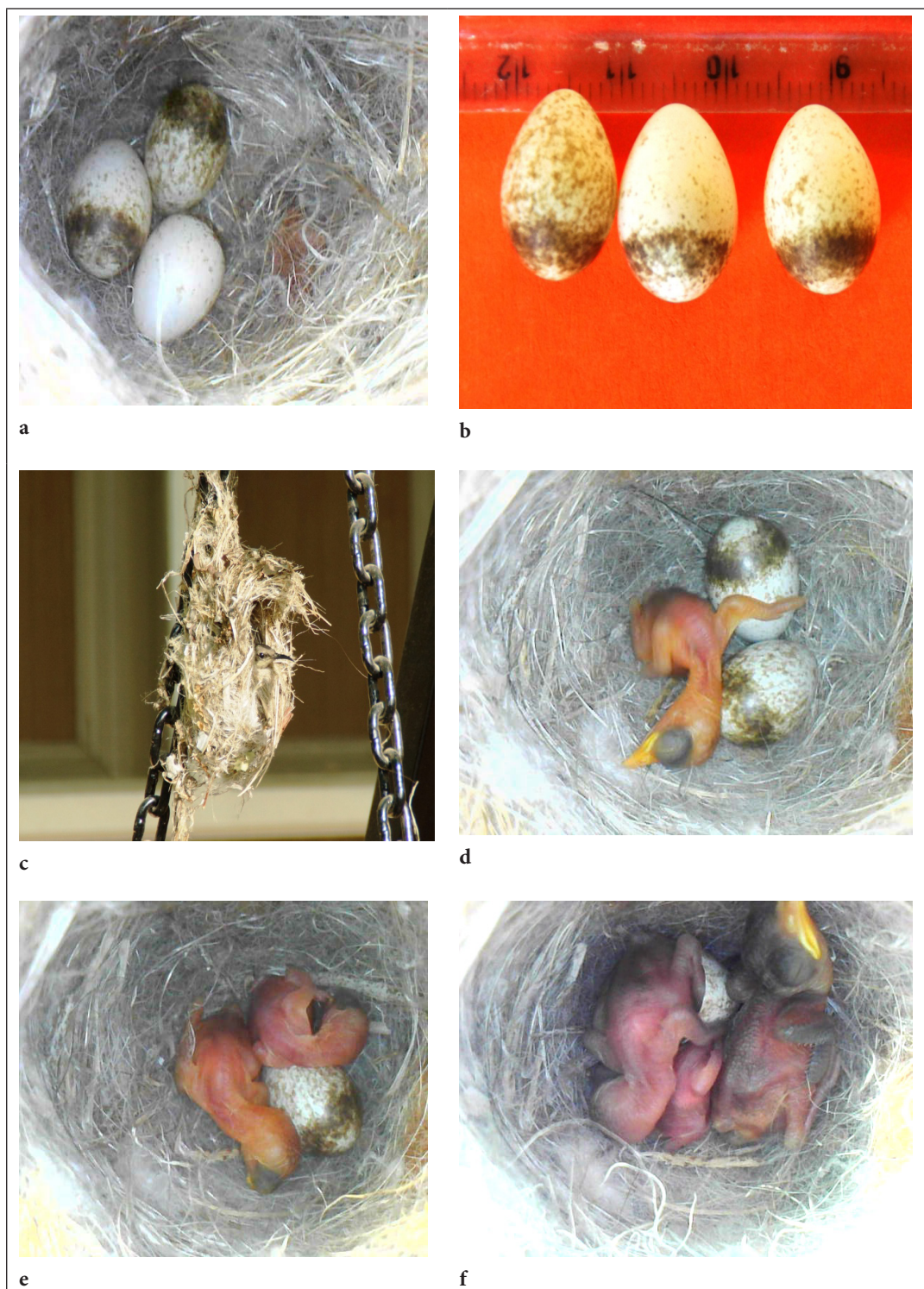
The eggs were oval with somewhat pointed narrower end, ground colour dull white and surface variably marked with ill-defined brown freckles. In some of the eggs the markings were uniformly present all over the egg surface while in others the markings were densely confined to the broader end of the egg and the narrower end may be rounded (Figure 2a & b). The eggs (n=17) weighed  $1.13 \pm 0.06$  gm (range: 1.03-1.25 gm), and length and breadth measured  $16.61 \pm 0.43$  mm (range: 16.10-17.55 mm) and  $11.49 \pm 0.28$  mm (range: 10.94-12.06 mm) respectively. The mean values of the egg shape index (Stadelman and Cotterill, 1995) and volume (Hoyt, 1979) were calculated  $69.35 \pm 2.55$  (range: 64-75) and  $1.12 \pm 0.06$  cm<sup>3</sup> (range: 0.99-1.21 cm<sup>3</sup>) respectively.

Incubation was uniparental and synchronous. It started after completion of the clutch and the female PSB solely performed this task through day and night. The incubation period (Kendeigh, 1963) varied from 11 to 14 days (n=11). However, in case of a defective clutch, the incubation continued for 17 days till the bird deserted the unhatched egg and removed it from the nest. The female stayed in the nest during nights throughout the incubation period. During full incubation days (Wang and Beissinger, 2011), the incubating female PSB adopted a diurnal rhythm of attentive periods (in the nest) and inattentive periods (off the nest). The review of continuous day time video records of 80.62 hours total observation time (TOT) recorded over 07 consecutive days (between

6:30 am – 6:30 pm each day) of full incubation revealed that the PSB female spent 51.59 hours (64% TOT) and 29.03 hours (36% TOT) as attentive periods and inattentive periods respectively (Table 2). During this TOT, the female left the nest 111 times, each inattentive period averaging 15.69 minutes, whereas, each attentive period lasted for 26.92 minutes.

It used to keep its bill projecting out of the entrance hole with its chin resting on the lower rim of the hole. On observer's approach near the nest, it acquired a more crouched posture thus concealing its presence in the nest. In the month of April, the incubating female was seen panting occasionally with widely open upwardly directed bill. In case of nests built in residential premises, the incubating bird got quickly adapted to the routine disturbances near the nest. The male PSB was seen defending the territory and never seen visiting the nest during incubation period.

One of the eggs from a 07 day old clutch laid in a nest built on an electric supply wire under a shed disappeared from the nest (on 23.05.2017) while the second one was lying broken on the floor below the nest. The nest was fully intact and had witnessed no damage at all. The next day, an Oriental Garden Lizard (*Calotes versicolor*) was observed unexpectedly approaching the nest on the wire, thus indicating the presumable predation on the PSB eggs. Two of the nests were mutilated by unknown nocturnal predators during the following night just after their completion.



**Figure 2.** Egg laying and hatching in purple sunbird. **a.** A Clutch in Nest, **b.** Egg Size & Shape, **c.** Female PSB Incubating the Eggs, **d.** Hatching of Chick-1 (Day-1), **e.** Hatching of Chick-2 (Day-1), **f.** Hatching of Chick-3 (Day-3).



**Table 2.** Incubation time budgeting by female PSB diurnal Observation Time (OT): 06:30 am to 6:30 pm

Day	OT (hours)	Duration of Periods (hours)		No. of Alternate Periods		Average Duration of Periods (minutes)	
		Attentive	Inattentive	Attentive	Inattentive	Attentive	Inattentive
1	12	7.13 (59.41% OT)	4.87 (40.59% OT)	17	17	25.16	17.19
2	12	8.83 (73.63% OT)	3.17 (26.37% OT)	16	15	33.11	12.66
3	12	7.99 (66.58% OT)	4.01 (33.42% OT)	20	19	23.97	12.66
4	12	6.97 (58.09% OT)	5.03 (41.91% OT)	22	21	19	14.37
5	12	7.79 (64.92% OT)	4.21 (35.08% OT)	15	14	31.16	18.04
6	12	7.79 (64.92% OT)	4.21 (35.08% OT)	16	16	29.21	15.79
7	8.62	5.09 (59.05% OT)	3.53 (40.95% OT)	9	9	33.93	23.51
<b>Total 7 Days</b>	<b>80.62</b>	<b>51.59 (64% TOT)</b>	<b>29.03 (36% TOT)</b>	<b>115</b>	<b>111</b>	<b>26.92</b>	<b>15.69</b>

## Hatching and Feeding of Nestlings

Out of the 11 clutches, only one was defective and 10 clutches hatched successfully (Table 1) over a hatching period ranging 1-3 days. Amongst the 08 successful clutches (containing 02 eggs each), both the eggs in 03 clutches hatched on the same day (3-6 hours apart on 20.04.2017; 11.07.2017 & 14.05.2018); in case of 04 clutches, the two eggs of a particular clutch hatched on two successive days (within 24 hours: 05.06.2017 & 06.06.2017; 02.04.2018 & 03.04.2018; 06.07.2018 & 07.07.2018; 02.04.2019 & 03.04.2019) and in case of 01 clutch only one egg hatched (09.04.2020). In case of 02 successful clutches (containing 3 eggs each), the first 02 eggs of a particular clutch hatched on the same day (3-6 hours apart on; 07.04.2017 & 03.05.2017) whereas, the third egg of these clutches hatched on second and third successive day respectively (on 08.04.2017 & 05.05.2017). Typical asynchronous hatching (Clark and Wilson, 1981; Podulka *et al.*, 2004) occurred in case of the egg that hatched on a third successive day (05.05.2017). During the hatching period, the female PSB continued the short attentive periods in the nest ensuring partial incubation (Wang and Beissinger, 2011) of the 'yet to hatch egg/s' and

brooding of hatchling/simultaneously. In the beginning of each such attentive period maintained between the feeding visits, the female PSB also performed egg turning movements using its curved bill. Egg shell pieces are removed from the nest by the female immediately after hatching before they get broken into smaller pieces due to erratic body movements of the hatchlings.

With the start of hatching, the incubating female PSB was no more an occupant of the nest, rather it became a visitor to the nest and started performing the coupled tasks of feeding the hatchlings, turning the 'yet to hatch egg/s' and providing warmth to the both. During the repeated nest visits, it frequently stayed in the nest for short intervals (30 seconds to one minute duration) providing warmth to the nest contents. All chick feeding and egg turning actions were carried out by perching on the rim of the nest entrance. After feeding the chick/s, it swiftly turned the egg/s with curved bill and then entered the nest to cover the egg/chicks under her body. During hatching of a clutch containing 03 eggs that delivered 02 hatchlings on the first day, over an observation time of 04 hours (2:16 pm to 6:16 pm) the female PSB visited the nest 17 times (4.25 visits/hour) ensuring feeding 11 times,

egg turning 12 times and warming of the nest contents 07 times. A day after the start of hatching, the male PSB also started assisting the female in feeding the chicks. It never entered inside the nest and performed no 'egg turning'. About 02 days after completion of hatching (n=7), the Female PSB was also never seen entering/staying inside the nest during day time. All the feeding and nest sanitation activities were performed by perching at the entrance rim of the nest. However, the female continued its night stay inside the nest till 08-10 nights since the beginning of the hatching (n=4).

While feeding the chicks, the PSB parent used to thrust its bill deep into the buccal cavity of the chicks. The hatchlings were provided no solid food item during the first two days and over these feeding bouts the PSB parents frequently maintained simultaneous feeding of the synchronously hatched chicks. However, a differential feeding in terms of food quality was seen in case of asynchronously hatched third chick. It was observed that whenever a parent reached the nest with some solid food item, the feeding parent did not offer it to the youngest chick (< 2 days old) in spite of its repeated begging attempts (n=3). Afterwards, the parents were observed feeding all the three chicks in a single bout.

In diet of nestlings included nectar, fragments of the tubular part of China rose flowers, small insects and spiders. Small arthropods presumably the spiders brought through a single feeding sortie by the female PSB were repeatedly regurgitated and fed to the chicks. The adults were seen foraging on a wide range of plants including the ornamental flowers (*Dianthus caryophyllus* and

*Delphinium ajacis*), wild/cultivated shrubs (*Calotropis procera*, *Citrus limon* and *Hemelia patens*) and trees (*Campis grandiflora*, *Bauhinia variegata*, *Cascabela thevetia*, *Ceiba speciosa*, *Albizia julibrissin*, *Hibiscus rosa sinensis* and *Moringa oleifera*). A review of the video records spanning 54 hours OT referable to 05 nestling days in the second half of the nestling life, revealed a total of 521 feeding visits conducted by the PSB parents (Table 3). The food provisioning was biparental and male and female PSB conducted 173 (33.20%) and 348 (66.80%) nest visits respectively at a rate of 9.44 feeding visits per hour. In evening, the female PSB was observed capturing flying insects presumably the mosquitoes, killing them by striking its bill against bark and then feeding it to the juveniles accompanying her (n=1).

As in case of other Passerines, the PSB chicks also discharged their waste enveloped in the form of whitish mucosal sacs. These fecal sacs (were discharged by the chick/s only when the parent was present at the nest entrance and attending them. As a rule, most of the fecal sacs followed the act of feeding by the parents. The voiding chick raised its cloacal end upwards and the parent directly grasped the fecal sac on its bill not allowing any littering of the nest interiors. The fecal sacs discharged by the chicks during the first 2-3 days were swallowed by the female. As recorded during the first 02 days, in an observation time of 07 hours, 02 chicks produced 09 fecal sacs and all were consumed by the female PSB. These fecal sacs resembled thin non-sticky translucent bubbles or some were exactly like honeydew consumed immediately by the female PSB. Very rarely, any fecal sac was discharged by the chick/s

**Table 3.** Parental provisioning by PSB (See Table 1, Nest: Swing Chain, Clutch: First, Fledged on 17.05.2017)

Observation Day	OT (hours)	No. of Feeding Visits			Provisioning Rate Feeding Visits/ hour
		Total	Male PSB	Female PSB	
Day 1 (11.04.2017)	07	67	25	42	9.57
Day 2 (12.04.2017)	12	123	45	78	10.25
Day 3 (13.04.2017)	12	117	40	77	9.75
Day 4 (14.04.2017)	11	110	30	80	10
Day 5 (16.04.2017)	12	104	33	71	8.66
<b>Total 5 Days</b>	<b>54</b>	<b>521</b>	<b>173 (33.20% visits)</b>	<b>348 (66.80% visits)</b>	<b>9.44</b>

in the absence of the parent and that too was removed by the parents during their subsequent visits. The nest was kept free from any contamination due to food or faeces. As per observations made from outside the nest, the appearance and consistency of the fecal sacs changed with the growth of chicks. The fecal sacs from one week old chicks were more opaque and viscous, and the parents carried most of these sacs away from the nest rather than swallowing. During the second half of the nestling life, in the video OT of 54 hours male and female PSB were seen carrying faecal sacs of chicks away from nest on 03 and 79 occasions respectively (1.5 faecal sacs per hour). The chicks intending to discharge the fecal sac used to turn inside the nest, raise and bring its cloaca nearer the nest entrance so that the parent may easily grasp the sac. In one of the broods where the entrance rim of the nest was damaged by wind and rain, making it unfit for perching by the parent/s, the chicks were seen trying to defecate directly out of the nest, apposing their cloacae near the entrance rim.

## Growth and Fledging of Chicks

A newly hatched PSB chick was fully altricial having its eyes large, dark, closed and bulging against eyelids; skin totally naked, thin, pinkish and transparent; bill flat, triangular, broader at the base and tapering towards tip; mouth marked with whitish yellow flanges and bright orange interior lining (Figure 2d). A whitish egg-tooth was present at the tip of the bill. In between the feeding visits by the parents, the chicks remain sleepy. Stimulated by parent's arrival at the nest entrance or subsequent probing by the parent, it used to lift its large head with wobbly neck and opened its mouth to receive food from the parents. The gape flanges and bright orange interior lining of the mouth served as delivery targets for the parents. No feather pins are visible. Neither the feeding parent nor the chicks produce any call during feeding bouts.

On 3rd day a faint split line between eyelids; dark feather papillae of capital, humeral and dorsal tracts, and the alar pins made their appearance (Figure 2f). On day-4 the eyes began to open partly, the alar pins had grown all along the wing edge and their unsheathing was in fast progress. Dorsal surface of the body also gained an ashy metallic gloss due to the developing feather pins in head and trunk tracts (Figure 3a). The day 5 witnessed

partial unsheathing of feathers in dorsal, caudal and femoral tracts whereas the unsheathing of ventral tract was yet to start. The eyes were now fully opened and the chick started occupying a leading position near the nest entrance favouring a better food supply from the parents. Approaching the day-10, the chick appeared feathered due to extensive unsheathing and growth of feathers in different tracts of the body. The ventral surface of body acquired a yellow coloration. They were quite alert to their surroundings and acquired a more crouched posture whenever they sensed any disturbance near the nest. During subsequent days till fledging (on day-14-16), chicks were seen peeping out through the nest entrance as if waiting for parental visits and they used to produce calls as the parent arrived to feed them. The fledglings were having a plumage similar to the female parent. However, the tail was still stubby with white trailing to edges and a yellow supercilium was present above the eye. A day before fledging the nestling weighed 7.55 gm (n=2).

On the day of fledging, the chicks were very active and seemed less intended to be fed by parents and more eager to leave the nest. Feeling a sort of unrest in the nest, the chicks were repeatedly extending their heads out and looking around. They promptly responded to the parents' calls produced from a distance of about 10m. The fledging chick did not fly directly out of the nest. It came out then moved to one side of the nest as if selecting the nearest approachable perch. The fledglings left the nest same day (n=3) or on successive days (n=5). Three weeks (21 days) after fledging, one of the juveniles was seen perching in dense foliage of Black Plum (*Syzygium cumini*) in the same territory, at a distance of about 12 m from the nest. The parents were still accompanying it and the female was capturing the flying insects and feeding the juvenile. Though the birds were not ringed but in view of the territory and the nesting site most likely it was the same family. The young ones of Sunbirds remain in their natal area until leaving parents' territory and the parents continue to feed for up to two weeks after fledging (Cheke & Mann, 2008).

## Removal of Dead Chick and Defective Eggs from Nest

During breeding season 2017, three consecutive clutches (03 eggs, 02 eggs, 03 eggs respectively) laid in the same nest made on chain of a swing placed under fibre-shed of a house



**Figure 3.** Growth and fledging of chicks in purple sunbird. **a.** Chick-1 (Day-4), **b.** Chick-1 (Day-8), **c.** Chick-1 (Day-10), **d.** Chick-1 (Day-15), **e.** Use of Repaired Nest, **f.** Removal of Unhatched Egg by Female PSB.

(Latitude: 30°43'18.36" N & Longitude: 76°13'9.69" E) were closely monitored (Table 1). The third chick of the first clutch (hatched on 05.05.2017) died after 04 days and disappeared from the nest whereas the elder 02 chicks (hatched on 03.05.2017) were still inside the nest. These 02 chicks successfully fledged on 17.05.2017. Observations on this clutch were done using an endoscope hidden in the nest. However, the disappearance of the dead chick from the nest occurred out of the observation time when the camera was off. How did the dead chick disappear from the nest? Was it removed by the parent?

For monitoring the second clutch, a CCTV camera was installed since the beginning. One of the eggs of the clutch laid on (05.06.2017/06.06.2017) was regularly incubated for 17 days by the female PSB. As usual, the incubating female stayed in the nest during nights also but it stopped incubation on 22.06.2017. It was not in the nest during the intervening night of 22.06.2017 and 23.06.2017. On 23.06.17 and 24.06.17 it was seen adding fresh cushioning material to the interiors of the nest, as if preparing for the third clutch. The nest was examined using an endoscope and surprisingly the defective egg of the second clutch was not in the nest. The question was 'who had removed the egg and how'? Did some predator visit the nest? However, there was no damage to the nest. The earlier question of removal of the dead chick of first clutch was also still unanswered? This necessitated the review of CCTV footage of the nest recorded on 23.06.2017.

The review of the video records revealed that after discontinuing incubation, the female herself removed the defective unhatched egg from the nest, as the incubation exceeded the average incubation period of 12-13 days. The camera footage showed that the female removed the unhatched egg using the inner lining fibers (Figure 3f) of the nest as a tool for trapping the egg. It perched at the rim of the nest and then using its bill trapped the egg in the fibers making a thread net around the egg and then pulled the egg up to rim of the nest. The egg size was 16.72 mm (length) and 11.39 mm (width). Then it held the trapped egg between its legs supporting below with its tail. Next, it removed the excess fibers, placed these fibers back in nest and then picked the egg basket and flew away. It took about 5:30 minutes to complete the entire exercise. These thread like fibers and feathers are especially used for preparing the inner lining of the nests (n=11). This ability of female PSB to manoeuvre and use the fibers as

a tool for removing the defective egg from the nest also gives a clue to answer the disappearance of the dead chick of the first clutch. Certainly the chick was removed by the female either directly picking by bill or using lining fibers.

## Discussion

The present study on breeding behaviour of PSB brings to light information on nesting, egg laying, incubation, hatching, growth, food provisioning and some other behavioural activities on a regional scale, hitherto unrecorded. In our study area the PSB breeding extends from March to July and we have seen male PSB in their eclipse plumage during the months of October and December. In New Delhi it extends from February to May (Mazumdar and Kumar, 2014) and as per the earlier records (Ali, 1941) in India, nests may be found practically all the year but most general breeding months are March to May. It seems that the reproduction season depends on climate and availability of flowers in different regions (Ghadirian *et al.*, 2007).

Once a dweller of open habitat gardens, groves, cultivated and scrub country, and appreciated for its boldness to visit flowers lining 'varandahs' and growing over porches (Whistler, 1941), now seems well adapted to build nests under human trusteeship. The nesting sites like a toilet chain (George, 1957), clothline (Munidasa, 1969), telephone wire (Rahmani and Sankaran, 1990) and electric pole (Sangha, 1999) were reported as unusual nesting sites from different localities. Nesting sites and structures are often an important part of a species niche (Gould, 2008). In the present study, out of 16 nesting sites, only 06 nests were away from human trusteeship, whereas, 10 sites (05 man-made structures in porches in 05 shrubs in front-yards) involved the generous presence of man. Protection from predators seems to be the crucial factor determining selection of a promising nest site. Undoubtedly, the nests built in human presence were not camouflaged and concealed ones as those found in natural open habitat, but the human presence near the nest proved to be a savior against the predators. Chances of predation at human habitations are often much reduced (Adeyanju *et al.*, 2013) and hence nesting adaptations in/near residential premises apparently have survival value for the species.

The birds that reproduced successfully at a particular site are more likely to return at the same site (Powell

and Frasc, 2000). Both, the Swing Chain Nest (2017) and Bicycle Brake-cable Nest (2018 & 2019) were built at the same nesting site. The PSB showed nest fidelity for the successful nest built on bicycle brake-cable for two consecutive breeding seasons (2018 & 2019) and laid a total of 04 clutches in the same nest (Table 1). Similarly, another nest made on an electric supply wire was occupied for two consecutive seasons (2017 & 2018) and the birds continued to stay in these nests even after repair (Figure 3e). The PSB preferred to occupy nesting sites that were protected from above, behind and sides, thus ensuring protection from sun, wind, rain and predators. The entrance hole of the nests was not in any specific direction and was made towards the unprotected open side so that the incubating bird may keep a vigil on that site. There is anecdotal evidence that sunbirds build their nests to face particular directions (Cheke *et al.*, 2001) and nest entrance is rarely towards south or west (Ghadirian *et al.*, 2007). The task of nest building is solely performed by the female PSB and depending upon the weather breaks, it took 6-7 days (n=10) to complete the structure of a nest. The nest architecture plan and period followed by the female PSB was in consonance with that documented by George (1958). It is the same period (6-7 days) as documented for nests of *Nectarinia zeylonica*, Purple-rumped Sunbird, (Wesley, 2004; Kasambe, 2011) and *Cinnyris coccinigastrus*, Splendid Sunbird, (Adeyanju *et al.*, 2013).

Examination of the nest structure revealed that the interior cup of the nest is stuffed and lined with very soft feathers, fine bark threads and silky fibers from seeds of Sodom's Apple. Use of feathers in bird nests have been studied to play a role in thermoregulation (Mainwaring *et al.*, 2014), antimicrobial protection against pathogens (Peralta-Sánchez, 2010; Soler *et al.*, 2010) and protection of occupants from coarser material used in the outer structure of the nests (Lovette & Fitzpatrick, 2016). In the novel observation of tool use, the female PSB moulded this interior lining material as a tool for removing the defective egg from the nest so that the nest may be reused for the subsequent clutch.

Birds are physiologically constrained to laying just one egg per day (Clark & Wilson, 1981; Stoleson & Beissinger, 1999) and the Passerines are mostly considered to lay one egg every 24 hrs at dawn (Ali, 1935; Skutch, 1952; Perrins, 1979; Muma, 1986). Eggs in all the 11 clutches followed this general pattern of the Passerines (Table 1). Multiple

broods in same nest were observed. A nest built on a Swing Chain was reused for laying 03 successive clutches in the same breeding season (2017) with intervals of 13 days and 26 days between the fledging of one brood and start of egg laying of the successive brood. Another nest built on a Bicycle Brake-cable was reused for laying 04 clutches (03 in breeding season 2018 and 01 clutch in breeding season 2019) with an interval of 19 days between the first two successive clutches. In this nest the egg laying of third clutch started only 04 days after removal of the defective clutch (egg) of the second clutch that had failed to hatch after incubation for 17 days. Reuse of the same nest yielding three broods in single breeding season with intervals of 21 days and 42 days in case of *Chalcomitra senegalensis*, Scarlet-chested Sunbird (Molokwu *et al.*, 2006) and six broods in two successive breeding seasons with an average interval of 29 days in case of *Cinnyris coccinigastrus*, Splendid Sunbird (Adeyanju *et al.*, 2013) have been reported from Nigeria. However, a separate nest is built by *Nectarinia zeylonica*, the Purple-rumped Sunbird for all successive clutches in the same breeding season (Wesley, 2004).

The incubation period varied from 11-14 days. Though, the female PSB was the sole incubating parent, no incubation feeding (Matysiokova & Remes, 2010) was offered by male PSB. It appeared only twice at the nest during a TOT of 80.62 hours spanning over 07 full incubation days. Further, the nest attentiveness did not show any consistent trend of increase or decrease over the observation days (Table 2). In case of the Purple-rumped Sunbird, *Nectarinia zeylonica*, an increase in nest attentiveness over the incubation period has been recorded by Kasambe (2011). The female PSB continued the incubation of defective one egg clutch for 17 days and then removed it from the nest to start laying a fresh clutch after 04 days. After hatching, the presence of active nestlings in a nest provides a stimulus to the incubating parent to switch on its behaviour from 'incubation' to 'care of the young'. In case an entire clutch fails to hatch, the parent may continue to incubate the defective egg/s even three times the normal incubation period before finally deserting it (Lovette & Fitzpatrick, 2016).

In birds that begin incubation on completion of the clutch, hatching is synchronous (within 24 hours), whereas, in birds that begin incubation prior to clutch completion hatching is asynchronous, a minimum of 24 hours between the hatching of the first and last laid

eggs (Aldredge *et al.*, 2014). In this context, out of the 11 clutches, one clutch of 03 eggs with the youngest chick hatching on third successive day showed asynchronous hatching. If hatching asynchrony is large, the earliest hatched nestlings may be fed before their siblings hatch, leading to competitive size asymmetries among nestlings which could lead to brood reduction (Stoleson and Beissinger, 1997). In our study, the youngest chick was smaller in size, displayed relatively poor begging ability and it was always kept away from the nest entrance, as the elder ones used to position themselves near the nest entrance. It apparently died of starvation four days after its hatching.

Many passerines occasionally ingest their nestlings' faeces as a source of energy when the nestlings are young (Gluck, 1988; Hurd *et al.*, 1991; McKay *et al.*, 2009). As per endoscopic monitoring of the nest interiors, the female PSB swallowed all the faecal sacs produced by the hatchlings during the hatching period. As observed from outside the nest, the appearance and consistency of the fecal sacs changed with the growth of chicks. Video records of food provisioning made in the second half of the nestling life, revealed that male and female PSB carried away the faecal sacs of the chicks 03 (3.66%) and 79 (96.34%, n=82) times respectively (OT of 54 hours). The infrequent swallowing of fecal sacs was also on the 10<sup>th</sup> day after hatching. Undoubtedly, the female PSB was dominantly involved in swallowing or removal of faecal sacs. The high frequency of this behaviour in female PSB seems attributed to its sole parental effort during nest building and incubation, and higher contribution in brooding and feeding the chicks. Ingestion of faecal sacs of the nestlings apparently allowed the energetically or nutritionally deprived female PSB to regain some nutrients from the faecal sacs.

Tools are traditionally defined as objects that are used as an extension of the body and held directly in the hand or the mouth (Lefebvre *et al.*, 2002). Certain species of birds have been observed to use tools for diverse activities

such as food capture, food extraction and agonism. (Kenward *et al.*, 2006; Efe *et al.*, 2015; Uomini and Hunt, 2017). Given the lack of previous reports of tool use in PSB, the use of nest lining fibers for removal of a defective egg from the nest by female PSB gives the first description of tool use in this species.

In India plants like Paper Flower (*Bougainvillea sp.*), China Rose (*Hibiscus rosa*), Spunge Tree (*Prosopis cineraria*), Black Plum (*Syzygium cumini*), Babul (*Acacia sp.*), Date Palm (*Phoenix dactylifera*) and Sodom's Apple (*Calotropis procera*) have been reported as nesting sites of PSB (Ali, 1941; Srivastava, 2013; Mishra, 2014). Flowers of *Hibiscus rosa* and *Moringa oleifera* are its preferred foraging sites (Srivastava, 2013; Mishra, 2014; Tayade *et al.*, 2014). In our study, PSB selected the lower bushy growth of plants viz. Indian Jujube (*Zizyphus mauritiana*), Sheesham (*Dalbergia sisso*), Garden Quinine (*Clerodendrum emerme*), Pointed Gourd (*Trichosanthes dioica*), Lemon (*Citrus limon*), Punjab Fig (*Ficus palmata*), White Mulberry (*Morus alba*) and False Mallow (*Malvastrum coromandelianum*) for nest building. The female PSB collected the cobwebs mainly available on Gum Arabic (*Acacia nilotica*), Indian Banyan (*Ficus benghalensis*), Indian Jujube (*Zizyphus mauritiana*) and Sheesham (*Dalbergia sisso*) within a range of 70-90 m from the nesting site. Amongst other plants listed elsewhere, *Citrus limon*, *Hibiscus rosa* and *Moringa oleifera* were preferred for foraging purposes. Out of the total 16 nests, 04 nests were destroyed by nocturnal unknown predators and 01 nest was burnt in plot fire, 11 nests were used for laying clutches (nesting success of 68.75%), 42 eggs (19 clutches) were laid and 35 eggs hatched successfully (hatching success of 83%), with predation and death of 03 nestlings, 32 nestlings fledged successfully (fledging success of 91%). As none of the nests built in human proximity were attacked by any predator and the birds continued to stay in repaired nests, human trusteeship apparently have a survival value for this bird.

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