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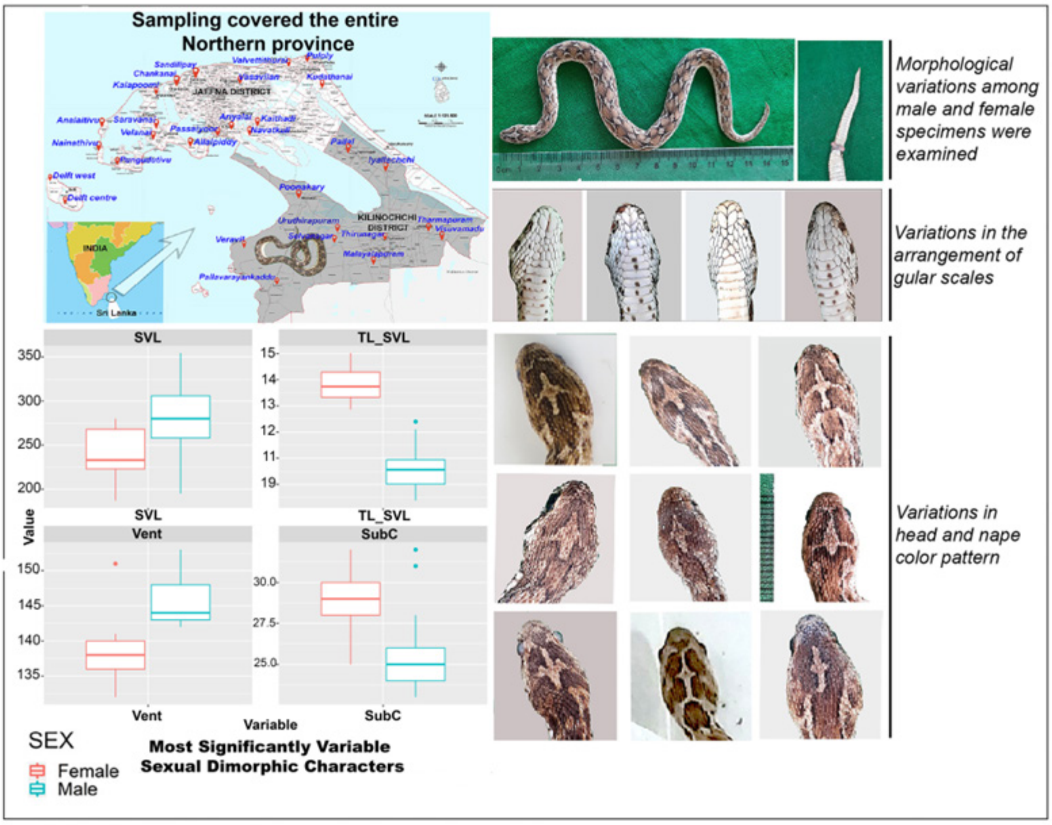

Highlights

- Research on *Echis carinatus* (Saw-scaled viper) in Sri Lanka was limited due to the 30- year civil war.
- Present detailed description of its morphology is after the initial reporting by Deraniyagala in 1951.
- Findings reveal greater variation in morphometric data, meristic measurements, and color patterns than previously described.
- Present research also marks the first report of sexual dimorphism in the Sri Lankan saw-scaled viper population.

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Morphological Characterization and Sexual Dimorphism of Saw-Scaled Viper (*Echis*: Viperidae: Ophidia) Population in Sri Lanka

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Abstract: The Saw-scaled vipers (SSV) of the genus *Echis* (Viperidae: Ophidia) primarily inhabit tropics. In Sri Lanka, *E. carinatus* is densely populated in the Northern Province where they account for over 50% of the local snakebites. Although it was initially reported as a unique Sri Lankan subspecies named *E. c. sinhaleyus*, its existence was later questioned, urging the need for more detail studies. The present study examined morphological characters and sexual dimorphism in 30 specimens (17 males and 13 females) collected from Kilinochchi and Jaffna Districts in the Northern Province, using 12 mensural and 17 meristic traits, updating Deraniyagala's report of 1951. Results showed that the adult females have longer snout to vent length (SVL) than that of males (280.34±43.32 vs. 240.88±27.03), revealing a positive sexual dimorphism index. Males had a greater TL/SVL ratio (x̄=13.89±0.68) than that of females (x̄=10.65±085). ANCOVA test retrieved most accurate and an independent significant effect of 'sex' on TL while SVL serving as the covariate. Males and females shared consistent meristic characters, except for number of dorsal scales at the lower part of the body, ventral and sub-caudal scales. There were more ventral scales in females (145.54±3.31) than that of males (138.41±4.08), and sub-caudal scales were higher in number in males (28.94±1.85) than that of females (25.85±2.82). Although, there were some colour pattern variations of the specimens, (head pattern and ventral pattern), they were not sex-associated and distributed evenly between males and females. This is the first study to illustrate the detail morphometric characters; mensural traits; meristic traits, and color patterns and to demonstrate the sexual dimorphism in the SSV from Sri Lanka, with noticeable differences in the snout-vent length (SVL), tail length (TL), ventral scales, and sub-caudal scales between male and female.

Keywords*:* *Echis carinatus sinhaleyus*; Morphology; Northern Province Sri Lanka; Sexual dimorphism; Snakes

INTRODUCTION

Sri Lanka is a tropical country with an agricultural economy having a significant burden of snakebites (Kasturiratne et al., 2005; Kularatne et al., 2009). Although snakebite hotspots were found in North-Central, North-West, South-West, and Eastern Sri Lanka, the overall incidence of envenoming is higher in the dry zone, which includes the North, North Central, and Eastern provinces (Ediriweera et al., 2016, 2021). Snake diversity in the island of Sri Lanka is extremely high, hosting at least 110 snake species in 11 families, of which at least 59 are endemic (Gower et al., 2024; Silva et al., 2023). However, only six of them are the medically important; the Russell's viper (*Daboia russelli russelli*), Cobra (*Naja naja*), the Kraits (*Bungarus caeruleus* and *Bungarus ceylonicus*), Saw-scaled viper (*Echis carinatus*) and Hump-nosed viper (*Hypnale hypnale*) (Kasturiratne et al., 2005). The Saw-scaled vipers of the genus *Echis* (Merrem, 1820) are members of the Viperidae family found in the tropical regions extending from West Africa to India and Sri Lanka (Cherlin, 1990). In Sri Lanka, it is distributed only in the dry and sandy coastal plains of North-western, Northern and in the Eastern Provinces. In the Northern Province it is widely distributed in the districts of Jaffna, Kilinochchi, Mullaitivu and Mannar and contribute to more than 50% of the snakebites in the Jaffna district (Kularatne et al., 2011; Sivansuthan, 2011).

Although the taxonomy of *Echis* has been revised many times in the past two decades, it remains complicated and poorly understood due to its highly diverse nature (Rogalski et al., 2017; Wüster et al., 1997). As per the recent taxonomy supported by molecular phylogenetics, researchers have classified the genus *Echis* into four major clades: (A) *E. ocellatus* group, distributed in Western Africa; (B) *E. pyramidum* group, which occur in the eastern and western edges of the Sahel, including Somalia; (C) *E. coloratus* group, distributed in the western, eastern and southern Arabian Peninsula, including eastern Egypt and the Sinai Peninsula; and the (D) *E. carinatus* group, distributed in south-western Asia where the range extends from, Northern India northwards Uzbekistan, including Oman and the United Arab Emirates (UAE) in the Arabian Peninsula (Arnold et al., 2009).

Echis carinatus is composed of four subspecies: *E. carinatus carinatus* (Schneider, 1801) distributed in the peninsular India, *E. c. astolae* (Mertens, 1970) distributed in the Astola Island and Pakistan, *E. c. sochureki* (Stemmler, 1969) ranging from Afghanistan, Pakistan, northern India, south and central Iran, Iraq, Oman and to U.A.E and *Echis carinatus sinhaleyus* (Deraniyagala 1951) restricted to Sri

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Lanka (Amr & Disi, 2011; Auffenberg & Rehman, 1993a; Mallow & Ludwig, 2003; Deraniyagala, 1955a; Rhadi, 2015).

Taxonomic studies related to snakes, widely use morphological features of the external body, such as measurements of body regions, pholidosis, and patterns of coloration (López & Giraudo, 2008). Morphological studies are also important in distinguishing the variation between males and females and also the sexually dimorphic characters. Study on sexual size dimorphism (SSD) provides valuable insights into the evolutionary biology, ecological adaptations, and reproductive strategies of the studied species. Since the origins of evolutionary biology, SSD has been a major focus of research, with numerous potential hypotheses for its ecological and evolutionary origins being proposed (Cox et al., 2003; Stephens & Wiens, 2009). There are three proposed mechanisms to explain the evolution of sexual dimorphism; (i) sexual selection on male size through mechanisms such as male–male combat (Cox et al., 2003; Bovero et al., 2003), (ii) selection related to fecundity in females, driven by the relationship between reproductive capacity and size (Kuo et al., 2009), and (iii) ecological divergence in size mediated by intraspecific competition and niche partitioning through prey divergence (Vincent et al., 2004). Sexual dimorphism in body size, shape, and coloration has evolved in many animal groups, with the most common pattern in tetrapod species being that females are larger and heavier than males (Shine, 2002). Although most studies on the evolution of sexual dimorphism focus on SSD (Cox et al., 2006), shape analysis is considered the most efficient and comprehensive method for quantifying sexual dimorphism (Kaliontzopoulou et al., 2007). Sexual dimorphism in body shape expressed as differences in body proportions and skull shape across various taxa, including snakes (Sanger et al., 2013; Vincent et al., 2004). In reptiles, sexual dimorphism may result from factors operating prior to maturity which is typically highly correlated with the degree of SSD at mean adult size (Shine, 1990). In snakes, female-biased sexual size dimorphism (SSD) is commonly observed in many snake families (Cox et al., 2007). However members of the family Viperidae commonly display the male biased SSD, (Duvall & Beaupre, 1998; Taylor & DeNardo, 2005).

Taxonomic status of Sri Lankan saw-scaled viper was initially examined by Deraniyagala using 8 museum specimens collected from Chavakachcheri (Jaffna District of Northern Sri Lanka) (Deraniyagala, 1955). Based on his observations on the morphometric features, he recognised the Sri Lankan saw-scaled viper as a sub species of *Echis carinatus* endemic to Sri Lanka and named it *Echis carinatus sinhaleyus* (Deraniyagala, 1955). Although some authors were in agreement with the taxonomic status of Sri Lankan saw-scaled viper originally described by Deraniyagala (Golay et al., 1993), the later studies synonymized *E. c. sinhaleyus* under *E.c. carinatus* in their revision of the genus *Echis* (Viperidae) (Auffenberg & Rehman, 1993a; Pook et al., 2009). Although, previous studies have revised the taxonomic status of the saw-scaled viper from other geographical areas over the time, there has been no detailed study of the complete morphological data analysis of Sri Lankan saw-scaled viper since its initial reporting by Deraniyagala in 1955. Therefore, the present study was conducted to investigate the morphological variations and sexual dimorphism of Sri Lankan saw-scaled viper in detail with a larger number of specimens collected from the multiple locations of Northern Sri Lanka where the saw scaled viper is densely populated.

MATERIALS AND METHODS

For the present study, a total of 39 specimens were collected from two districts, Kilinochchi and Jaffna, in Northern Sri Lanka during the period from 2019 to 2021. Of the 39 saw-scaled vipers, only 30 fresh specimens with a total body length greater than 200 mm were selected to ensure they were not juveniles. Because the total body length of the juvenile range from 115 to152 mm (Daniel, 2002). Specimens with the evidences of any physical damage or decomposition were not included in the study. Details of sampling localities are presented on a map in (Figure 1). The Institutional Animal Ethics Review Committee of University of Jaffna approved the animal study protocol (Ethics approval reference code AERC/2019/ approved on July 2019).

Majority of specimens were received from the patients bitten by saw-scaled vipers and admitted either to Teaching Hospital Jaffna or to the District General Hospital Kilinochchi except the three specimens captured directly from the field. Among them, 30 specimens (n=30) were selected for morphological analysis and sexual dimorphism investigations of saw-scaled viper. The sex of the individual specimens was determined by hemipenal eversion (Figure 2).

Mensural Characters

Snout-Vent length (SVL) and the tail length (TL) of the specimens were measured using a measuring tape to the nearest 1mm. The following measurements which were less than 2 cm were assessed under the dissection microscope using the vernier calliper to the nearest 0.1 mm; head length (HL); head width (HW); eye diameter (EyeD); rostrum height (RostH); rostrum width (RostW); eye-nostril distance (EyNoD), Eye-rostrum distance (EyRostD); nostril-nostril distance (NoNoD) and inter orbital length (IntOL).

Meristic Characters

The current study recorded the following 17 meristic characters of all the specimens as per the scale count method described previously by Babocsay (2004), with minor modifications. Number of dorsal scale rows at three points; forepart of the body (Dors1); Mid part of the body (Dors2); lower part of the body (Dors3); number of lateral oblique scales (Lat); number of ventral scales (Vent); number of subcaudal scales (excluding the apical spine and the first divided scale, SubC); number of supralabial scales (SupraL); number of infralabial scales (InfL); number of infralabial scales in contact with the chin-shield (InfL2); number of slightly enlarged gular scales between preventrals and the small elongated gular scales along the ventral midline of the head (G1); number of small

Figure 1: Sampling localities of saw-scaled viper in Jaffna peninsula and in the islands adjacent to the Jaffna peninsula and Kilinochchi district of Sri Lanka.

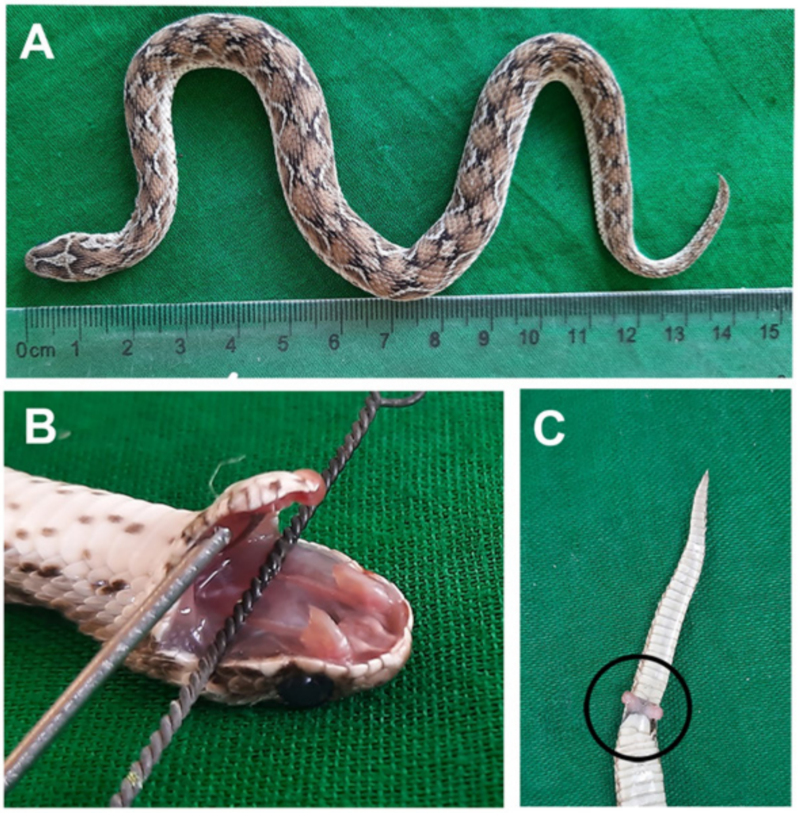

Figure 2: Adult female specimen of Saw scaled viper (A), Head and fangs (B), Everted hemipenis of an adult male (C).

elongated or round gular scales between preventrals and the posterior chin shield (G2); number of gular scales other than chin-shield in contact with infralabial scales (Gul); number of gular scales in contact with the chin- shield (Gul2); number of scales in the inner circumocular ring (scales in contact with the eye, (CircO-); number of scales in the outer circumocular ring (scales in contact with and distal to the scales in the inner circumocular ring (CircO2); number of scales between the eyes over the smallest inter-ocular distance (ScBE); number of scales between the anterior edge of the eye and the nasal (PreO).

Colour Pattern

The head and nape color patterns, dorsal and lateral body coloration, ventral color patterns, number of dorsal patches, and the number of supra-labials and infra-labials with pigmented patches were recorded for all specimens.

Sexual Size Dimorphism

Sexual size dimorphism was estimated using the sexual dimorphism index (SDI) developed by (Gibbons & Lovich, 1990). Accordingly, the mean SVL of the larger sex was divided by the mean SVL of the smaller sex; a positive value is obtained if females are the larger sex, and a negative value is assigned if males are the larger sex.

Statistical Analysis

All morphometric analyses were carried out using the R programming language ver. 4.2.2 (Team, 2020) and statistical analyses were considered to be significant at $P<0.05$. In addition, all the statistical analyses were conducted separately for males and females. For statistical analysis, the data of mensural traits (11), meristic traits (17) and colour pattern (06) of 30 specimens were compiled and performed descriptive statistical analysis for all the mensural and meristic trait data to obtain (Max., Min., Mean, and SD), using "favstats" function of "mosaic" package in R. In this study, the body measurements, head length and head width as percent of Snout-Vent length (SVL); and subunits of the head were expressed as percent of head length (HL) (Babocsay, 2004). Shapiro-Wilk test was also executed for a total of 28 variables (11 mensural and 17 meristic characters) to identify parametric and non-parametric variables prior to analyzing the sexual dimorphism. In order to compare the mean differences between two sexes, parametric variables were analyzed using independent t-test or Welch's t-test based on the outcome of the Levene's test; and non-parametric variables using the Wilcoxon rank-sum Test.

The statistical method, analysis of covariance (ANCOVA), was used to explore how mensural and meristic characters are related to the sex of the saw-scaled viper. Morphometric traits (mensural and meristic) were checked for the significant effect of 'sex' on each trait as the outcome variable, SVL (snout-vent length) served as a covariate in the following syntax: (morphometric trait ~ SEX + SVL). Type III summary function was used to obtain the F-statistics. A significant interaction of 'sex' on a trait may suggest that particular traits are significantly sexually dimorphic within the species. The total variation in the ANCOVA model was to examine as adjusted R^2 value using "adj.r.squared" function in R. Further the VIF (variance inflation factor) was measured to check for multicollinearity in predictor variables in the best-fit ANCOVA model.

RESULTS

Of the 30 specimens selected for the morphological study, 17 were male and 13 were female. A total of 34 characters were meticulously analyzed and tabulated, which included mensural, meristic and morphological features. In order to identify any sexually dimorphic characters, male and female specimens were analyzed separately.

General Description

The body slender to moderately stout and slightly flattened dorso-ventrally. The head was short, distinctly wide posteriorly to eyes and distinct from the narrow neck and covered with small scales, which may be either keeled or smooth. The snout was short, rounded, and the eyes were relatively large with vertically elliptical pupils. Tail was short, tapered abruptly and the anal plate was not divided.

Pre-nasal and sub-nasal scales fused with nasal scale and in contact with the supralabial and the rostrum scales on both sides; lower prenasal was absent; postnasal separated by one slightly enlarged scale from the supralabial; a pair of contiguous internasals scales on either side. A few lateral scale rows on either side of the body were smaller in size than other body scales and were serrated and oblique in orientation. This oblique scale rows starting from two or three lateral scale rows from the ventral and continue caudo-dorsally. Counting of this oblique scale rows at the mid body revealed an average of five scales in most of the specimens (range 4 – 6). All other meristic characters of the *Echis carinatus* population previously reported from South Asia (India, Bangladesh, Pakistan) and presently reported from Sri Lanka are summarised in Table 1.

Analysis of Morphometric and Meristic Characters

The results obtained from the descriptive analysis of the mensural characters (11) is summarised in (Table 2). Body measurements and head lengths are given as percentage of SVL and subunits of the head as percentage of HL, to avoid size related bias (Babocsy, 2003). Similarly, Table 3

Table 1: A comparison of meristic characters of the *Echis carinatus* population previously reported from South Asia (India, Bangladesh, Pakistan,) and presently reported from Sri Lanka

	Trait	Previously reported South Asian population *.	Presently reported Sri Lanka population
1	Number of supralabials (SupraL)	10-12	9-10
2	Number of infra labials (InfL)	10-13	9-11
3	Circumocular scale (CircO)	14-21	12-16
4	Scale raw separate the eye and the supralabials	01-03	01
5	Body scales in the mid body (Dors2)	25-39	23-27
6	Ventrals (Vent)	143-189	132-152
7	Subcaudals (SubC)	21-52	23-32
8	Number of lateral oblique scale rows (Lat)	4-7	4-6

*(Auffenberg & Rehman, 1993; Mallow & Ludwig, 2003)

summarizes the descriptive data of the meristic characters (17).

The analysis of sexual dimorphism using independent t-test showed significant differences in the following characters between the males and females: TL/SVL (p<0.001, t=11.53), HW/SVL (p=,0.03, t=2.23), NoNoD/HL (p=0.031, t=2.27), Vent (p= <0.001, t=5.13) and SubC (p=0.001, t=-3.62). The Wilcoxon rank-sum test showed significant differences only in Dors3 (p=<0.001, W=182.5) between males and females.

The adult females had a longer SVL (x̄=280.34±43.32) compared to adult males (x̄=240.88±27.03), and the adult males had a greater TL/SVL (x̄=13.89±0.68) than adult females (x̄=10.65±085). This results in a positive sexual size dimorphism (SSD) index of 1.163, indicating that females were larger than males. Additionally, the HW/SVL of the males (x̄=4.19±0.33) were larger than that of females (x̄=3.90±0.37).

The meristic characters, with the exception of Dors3, Vent, and SubC, appeared to show less variability between males and females. The mean Dors3 was slightly higher in females (x̄=18.46±0.66) compared to males (x̄=17.59±0.51). Conversely, females had a higher number of Ventral scales (x̄=145.54±3.31) than males (x̄=138.41±4.08) and males had a higher number of SubC (x̄=28.94±1.85) than females (x̄=25.85±2.82). However, body length of the Sri Lankan saw-scaled viper is female biased and tail length is male biased. Figure 3 illustrates the comparison of snout-vent length (SVL) and most prominent mensural and meristic traits poses significant variations between males and females.

Specially, six of 29 traits retrieved an independent statistically significant effect of 'sex' in the ANCOVA test (Table 4 and Supplementary table 1). Contrary to the results received from independent t-test or Wilcoxon rank-sum test, ANCOVA showed significant effect of 'sex' on number of scales in outer circumocular ring (CircO2) but not on head width (HW). However, based on the calculated adjusted R^2 value for ANCOVA, tail length (TL) demonstrated a highly accurate and an independent statistically significant effect of 'sex' (R^2=0.78, F=78.62, *P*=<0.001) while SVL serving as the covariate (Table 4).

Head and Nape Color Pattern

A distinctive pattern always marked the top of the head and nape, ranging from a bird footprint/trident shape to a wider or shorter arrow shape. An average of 6.3 ± 0.92 pigmented scales on either side of the head forming a dark strip that runs from the eye towards the angle of the jaw (Figure 4).

Table 2: Descriptive statistics and comparison of mensural traits in males and females of *Echis carinatus* population from Sri Lanka.

Trait	Sex (n)	Mean ± SD (range)	*P*- value
Snout-vent length (SVL in mm)	♂ (17)	240.88± 27.02 (187 – 280)	N/A
	♀ (13)	280.35±43.32 (195 – 354)	
As a percentage of snout-vent length			
Tail length (TL)	♂ (17)	13.89±0.68 (13 – 15)	**<0.001****
	♀ (13)	10.65± 0.86 (10 – 12)	
Head length (HL)	♂ (17)	6.55± 0.55 (6 – 8)	0.224
	♀ (13)	6.29±0.59 (5 – 7)	
Head width (HW)	♂ (17)	4.19±0.33 (3 – 5)	**0.033***
	♀ (13)	3.90±0.37 (3 – 4)	
As a percentage of head length			
Eye diameter (ED)	♂ (17)	17.22±1.9 (14 – 20)	0.309
	♀ (13)	16.43± 2.30 (12 – 20)	
Rostrum height (RostH)	♂ (17)	7.81±0.93 (6 – 10)	0.587
	♀ (13)	7.59± 1.26 (5 – 10)	
Rostrum width (RostW)	♂ (17)	15.72±1.70 (13 – 19)	0.554
	♀ (13)	15.32±1.93 (12 – 20)	
Eye-nostril distance (EyNosD)	♂ (17)	13.98±1.4 (12 – 16)	0.378
	♀ (13)	13.38±2.24 (9 – 19)	
Eye rostrum distance (EyRostD)	♂ (17)	20.78±3.07 (13 – 27)	0.754
	♀ (13)	21.18±3.86 (13 – 29)	
Inter-narial distance (NoNoD)	♂ (17)	18.81±1.62 (16 – 21)	**0.031***
	♀ (13)	17.17±2.33 (13 – 21)	
Inter-orbital length (IntOL)	♂ (17)	44.62±5.09 (37 – 53)	0.417
	♀ (13)	43.06±5.22 (37 – 53)	

*, *P*-value<0.05; **, *P*-value<0.001; SD, Standard deviation

Table 3: Descriptive statistics and comparison of Meristic traits in males and females of *Echis carinatus* population from Sri Lanka

Trait	Sex (n)	Mean ± SD (range)	*P*- value
Number of dorsal scales counting across the forepart of the body (Dors1)	♂ (17)	21.29±0.47 (21-22)	0.1832
	♀ (13)	21.54±0.52 (21-22)	
Number of dorsal scales counted across mid-body (Dors2)	♂ (17)	24.82±1.19 (23-27)	0.9473
	♀ (13)	24.77±1.48 (23-27)	
Number of dorsal scales, counted across the lower body (Dors3)	♂ (17)	17.59±0.51(17-18)	**<0.001****
	♀ (13)	18.46±0.66 (17-19)	
Number of lateral oblique scales (Lat)	♂ (17)	5.00±0.009 (5-5)	1.00
	♀ (13)	5.00±0.41 (4-6)	
Number of ventral scales (Vent)	♂ (17)	138.41±4.1(132-151)	**<0.001****
	♀ (13)	145.54±3.31 (142-152)	
Number of sub-caudal scales (SubC)	♂ (17)	28.94±1.85 (25-32)	**0.001***
	♀ (13)	25.85±2.82 (23-32)	
Number of supra labial scales (SupraL)	♂ (17)	9.88±0.33 (9-10)	0.7763
	♀ (13)	9.85±0.38 (9-10)	
Number of infralabial scales (InfL)	♂ (17)	10.00±0.61(9-11)	1.00
	♀ (13)	10.00±0.41 (9-11)	
Number of infralabial scales in contact with the chin shield (InfL2)	♂ (17)	3.88±0.49 (3-5)	0.302
	♀ (13)	3.69±0.48 (3-4)	
Number of gular scales between preventrals and the small elongated gular scales along the ventral midline of the head (G1)	♂ (17)	6.41±1.23 (4-9)	0.2657
	♀ (13)	5.76±1.74 (2-9)	
Number of small elongated or round gular scales between preventrals and the posterior chin shield (G2)	♂ (17)	8.11±1.55 (4-12)	0.8488
	♀ (13)	8.38±2.06 (5-12)	
Number of scales, other than chin-shield, in contact with infralabials (Gul)	♂ (17)	6.54±0.66 (5-7)	0.2957
	♀ (13)	6.29±0.69(5-7)	
Number of gular scales in contact with the chin- shield (Gul2)	♂ (17)	2.79±0.36 (2-3)	0.6855
	♀ (13)	2.85±0.32 (2-3)	
Number of scales in inner circumocular ring (CircO)	♂ (17)	14.00±0.79 (13-16)	0.558
	♀ (13)	14.08±1.19 (12-16)	
Number of scales in outer circumocular ring (CircO2)	♂ (17)	15.29±1.05 (13-17)	0.698
	♀ (13)	15.23±1.36 (14-17)	
Number of scales between eyes (ScBE)	♂ (17)	9.35±0.93 (7-10)	0.167
	♀ (13)	9.08±0.64(8-10)	
Number of scales between the anterior edge of the eye and the nasal (PreO)	♂ (17)	3.18±0.39 (3-4)	0.4077
	♀ (13)	3.31±0.48 (3-4)	

*, *P*-value<0.05; **, *P*-value<0.001; SD, Standard deviation.

Table 4: The effect of snout-vent length (SVL) and sex on mensural and meristic traits of *Echis carinatus* from Sri Lanka

Trait	F-value	*P*-value	Adjusted R^2
Tail length (TL)	78.62	1.755e-09**	0.782
Nostril-nostril distance (NoNoD)	5.16	0.031*	0.461
Number of dorsal scales, counted across the lower body (Dors3)	6.88	0.014*	0.452
Number of ventral scales (Vent)	16.37	0.00039**	0.457
Number of sub-caudal scales (SubC)	7.82	0.0094*	0.278
Number of scales in outer circumocular ring (CircO2)	6.92	0.012*	0.433

*, *P*-value<0.05; **, *P*-value<0.001; Snout-vent length was used as a covariate for ANCOVA model

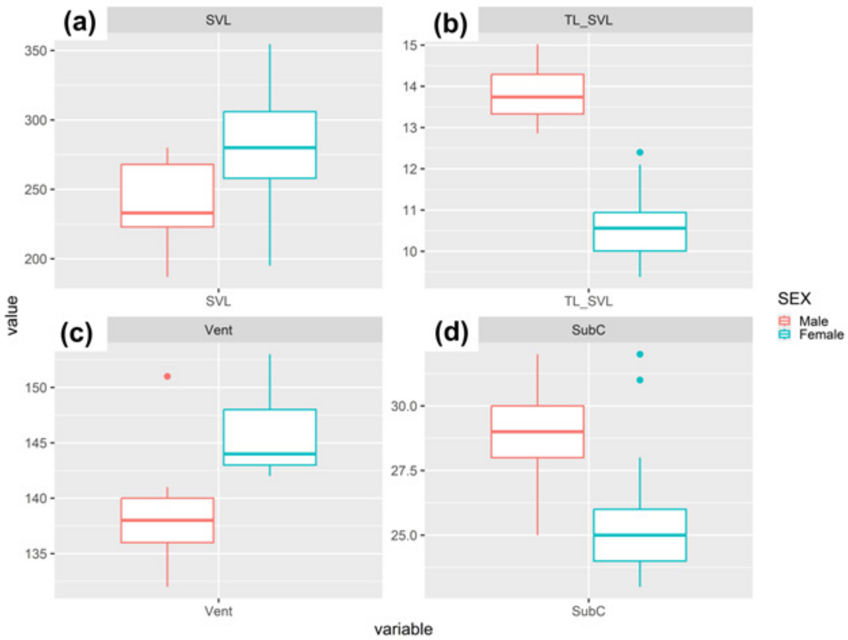

Figure 3: The comparison of snout-vent length (SVL) and most prominent mensural and meristic traits which possess significant variations between male and female *Echis carinatus*. a) snout-vent length, b) tail length as a percentage of snout-vent length, c) number of ventral scales, d) Number of subcaudal scales. Horizontal lines within the boxes indicate median values; box boundaries indicate the inter-quartile range (IQR). Whiskers imply minimum and maximum values within a quartile ± 1.5 times the IQR

Figure 4: Head and nape colour patterns of *Echis carinatus* population in Sri Lanka. (A-C), Broad arrow (D-F), Bow and arrow shape (G), Narrow cross (H, I)

Nasal Scale

Prenasal and subnasal fused with nasal and in contact with the supralabial and the rostrum on both sides; lower prenasal was absent; postnasal separated by one slightly enlarged scale from the supralabial; a pair of contiguous internasals on either side (Figure 5).

Circumocular Scales and Subocular Rows

There was an average of 14 circumocular scales, ranging from 12 to 16, around the inner margin of the ocular ring consistent with the previous reporting (Deraniyagala, 1955). Within the circumocular scales, the most dorsally located scale is larger than the other scales and differentiated as supra ocular shield. An average of 15 outer circumoccular scales surrounded the inner circumocular ring. These scales did not completely intrude the scale rows between the eye and the supralabial scales, leaving only a single row of subocular rows between the eye and the supralabial shields (Figure 5).

Gular Scales

The analysis of the ventral side of the head revealed a pair of enlarged chin shields (CS) bounded anteriorly by the mental (M), laterally by the extended first infralabials (IL) followed by an average of 3.8 ± 0.48 infralabials and ventrally by an average of 2.8±0.3 gular scales on either sides. The gular scales between the chin shields and the preventral scale along the ventral midline were sharply enlarged, rounded and forming longitudinal rows. The enlarged scales were arranged either opposite to each other in 1 to 3 pairs or arranged alternatively (G1) which is comparable to the South Indian population. The average number of gular scale row among the Indian population range from 2.2 to 3.0 and the more Northern population including Pakistan range from 3.2 to 5.0 (Auffenberg and Rehman, 1993). The rest of the gular scales were smaller and mostly elongated (G2), straddling on either side. The number of gular scales (G2) between chin shield and the preventral scale ranged from 4-12 (Figure 6).

Dorsal and Oblique Serrated Lateral Scale Rows

Counting the number of scale rows across the forepart of the body, mid body and the level of 5th ventral anterior to the anal plate are summarized in (Table 3). Among them, a few lateral scale rows on either side of the body were smaller in size, apparently serrated and oblique in orientation. This oblique scale rows starting from two or three lateral scale rows from the ventral and continue caudo-dorsally. Counting of this oblique scale rows at the mid body revealed five scales in most of the specimens with the range of four to six scales (Figure 7).

Body Colour Pattern

The body was tan, to wood brown or chocolate brown with dark-edged whitish spots along backbone. A series of white crescentic marks in association with the larger darker spots, and the crescent tips join to form a zigzag undulating white line which runs on either sides of the body. Longitudinal series of white or yellow rhomboid-shaped transverse blotches were present on the paravertebral area of the dorsal body. A dark frame more prominently surrounds the white/yellow blotches towards the tip, which were located on a ground color of intermediate density.

Counting from the first dark dorsal blotches immediately after the light-colored marking on the head and nape, contained the last one over the cloaca (or immediately

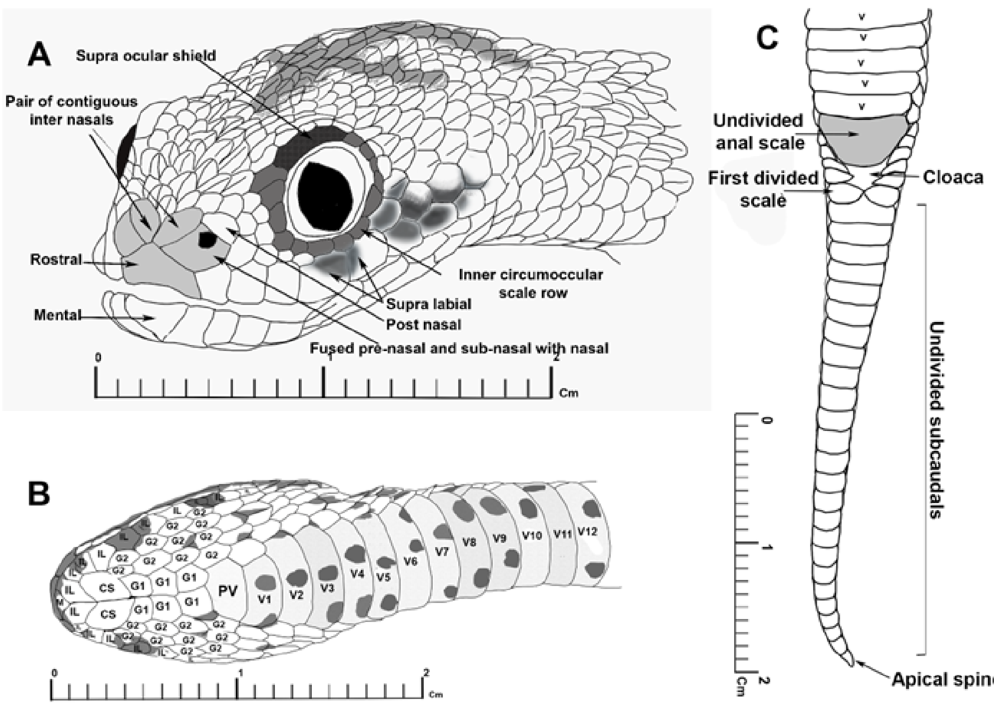

Figure 5: Dorsal side of the head (A), Ventral side of the head (B) and Ventral side of the tail (C) of *Echis carinatus*.

anterior of it if no spot above it) ranged from 28 to 31. The crescent tips of the zigzag undulating line are connected to the tips of these transverse blotches. The density and distribution of melanin in the dorsal blotch and ground color exhibits a fair degree of variation according to their respective geographic environment (Figure 7).

Belly was often white or yellowish white and blotched with dark dots. The ventral color pattern ranges from dim, small spots; medium intensity, large markings; darker, larger markings; dim, small, high intensity spots; and deeply pigmented, high intensity spots with whitish belly background (Figure 8).

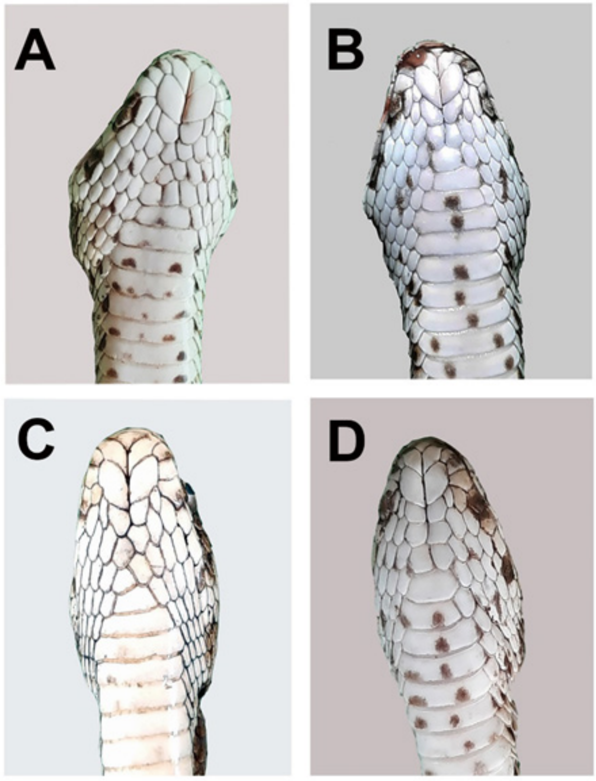

Figure 6: Variation in number and the arrangement of gular scale rows of *Echis carinatus*: the scales between the chin shields and the pre-ventral scale along the ventral midline are enlarged and rounded forming longitudinal rows. One row of enlarged scales (A), Two rows arranged oppositely (B), Three rows arranged alternatively (C), Three rows arranged oppositely (D)

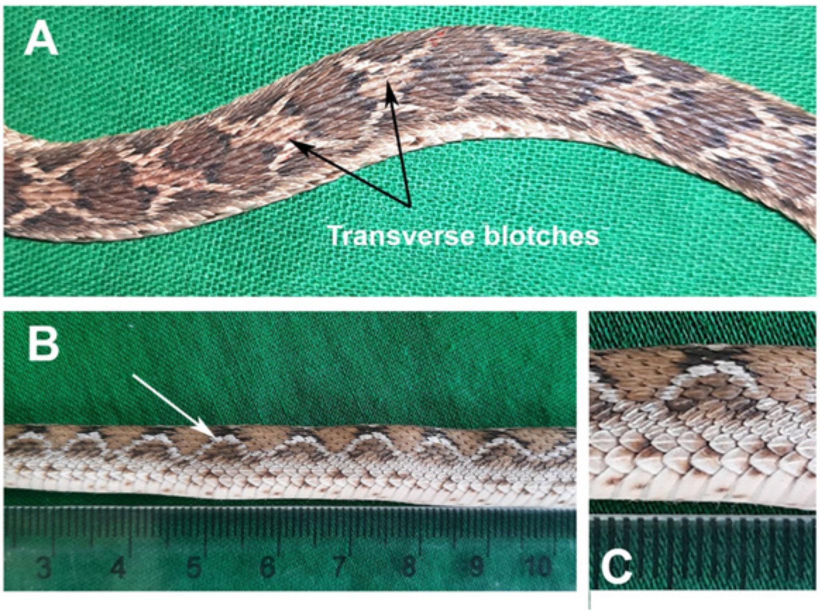

Figure 7: Lateral and the dorsal body colour pattern of *Echis carinatus*. Longitudinal series of white or yellow rhomboid shape transverse blotches (A), Series of white crescentic marks in association with the larger darker spots (B) and the crescent tips join to form a zigzag undulating line, obliquely disposed lateral scales (C)

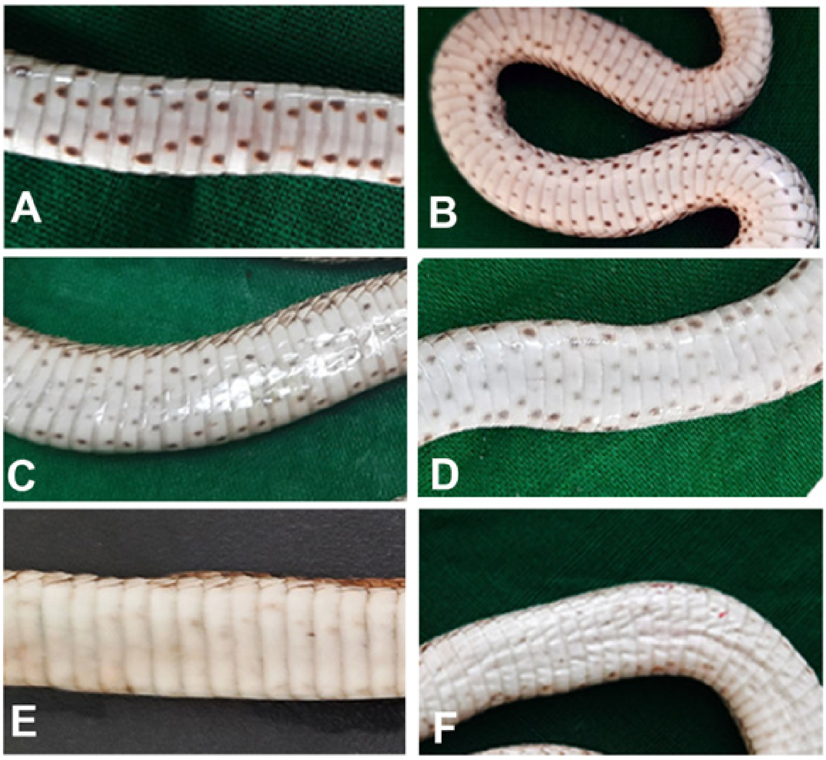

Figure 8: Ventral colour pattern categories of *Echis carinatus*. Deeply pigmented and high intensity dark large spots (A), deeply pigmented high intensity small spots (B), faint medium intensity small spots (C), faint large spots (D), uniform no obvious pattern (E), very faint small spots (F)

DISCUSSION

Saw scaled viper is one of the venomous snakes responsible for more than 50% of the snakebite in Northern Sri Lanka (Sivansuthan, 2011). However, research on Sri Lankan saw-scaled viper is very limited when compared with other studies related to venomous snakes in the country. One of the major reasons for the lack of studies on saw-scaled viper in Sri Lanka is the in-accessibility of the areas where the snake is mainly populated for more than 30 years due to the civil war that prevailed in those endemic areas in the past (Gnanathasan et al., 2012). Deraniyagala initially reported the taxonomy of saw scaled viper from Sri Lanka in 1955 by studying the general morphological characters such as the shape of head, eye, neck, snout, body and some selected meristic characters using only eight museum specimens (Deraniyagala, 1955). However, he did not study any mensural characters in detail except the total length and the tail length of only one specimen. Deraniyagala reported that the maximum length of the specimen was only 100 mm, including the tail length of 26mm. Despite the morphological observation, he also reported that the venom of the Ceylon race is seldom or never fatal to human based on his close observation of the effect of venom on a saw scaled viper bite victim (Deraniyagala, 1955). According to his observations on the morphological data, smaller body size and the relatively low potency of the venom, Deraniyagala elevated it as a subspecies endemic to Ceylon (Sri Lanka) and named it *E. c. sinhaleyes*. Deraniyagala did not report any sexual differences, which could be due to the low number of specimens or the possibility that the specimens were mostly juveniles. Because the maximum length of the specimen reported by Deraniyagala was 100 mm, which is less than 50% of the total body length of the specimens included in this study. Previous studies reported that the difference in the snout-vent length and the tail length between male and female are not clearly visible before their sexual maturity (Gouveia et al., 2017). The present study indicates a great variation in the total length of the adult specimens ranging from 215 mm to 390 mm. The tail length was ranging from 28 to 40 mm.

Previous studies on the taxonomy of the saw scaled viper, also confirmed the existence of sexual dimorphism among the different species of saw scaled viper that showed variation in the TL to SVL ratio (Cherlin, 1990). Although the saw-scaled viper from Sri Lanka is reported as a different subspecies, previous studies have not examined in detail, the morphological variation between male and the female saw-scaled vipers. The present study, which indicated a positive value of sexual dimorphism index (SDI) confirmed the existence of a female-biased sexual size dimorphism among the saw scaled viper population in Sri Lanka as well. Research on sexual dimorphism performed in several species of snakes has also reported the female-biased sexual dimorphism, in which females have a highest snout-vent length compared to males (Burbrink & Futterman, 2019; King, 1989; Rivas & Burghardt, 2001a; Shine, 1994) and males have a longer tail length than females which was proportional to the number of subcaudal scale counts. Similar observation in our study shows that the females have a greater number of ventral scales and the males have higher number of subcaudal scales.

Experts have described the phenomena of sexual dimorphism in different categories, such as sexual selection of larger size of females related to fecundity associated with reproductive biology (Bonnet et al., 1998; Burbrink & Futterman, 2019), selection on male size that possesses the behavior of competition for territory and females during reproductive period, and also intraspecific competition associated with the ecological divergence (Rivas & Burghardt, 2001).

Indeed, the larger body size and number of ventral scales (Vent.) in females suggest increased fecundity in reproductive potential in this species. *Echis carinatus* is an ovoviviparous species and therefore a greater body size in females may optimize their reproductive potential, as the females need a higher body volume to accommodate more number of young in a brood (Mebert, 2011). The positive value of sexual size dimorphism index (SSD) might also indicate the possible absence of territorial behaviour among the males.

Despite the illustrated differences in mensural characters and pholidosis between males and females, we also observed variation in color patterns, such as head pattern, ventral pattern, and color density, which were completely shared across both sexes and was therefore not associated with the sex of the specimens.

CONCLUSIONS

Deraniyagala named the saw-scaled viper from Sri Lanka as a sub species of *Echis carinatus*, *Echis carinatus sinhaleyes*, in 1955. However, no recent studies have investigated its detailed morphology since the initial report. Although this study largely aligns with previous reports, the morphometric data, meristic measurements, and color patterns exhibit a much broader range of variation than previously described. This is likely due to the examination of a larger number of specimens from diverse geographical locations and a wider range of specimen sizes. Additionally, this is the first study to demonstrate the detail mensural characters and the sexual dimorphism in the saw scaled viper from Sri Lanka, with noticeable differences in the snout-vent length (SVL), tail length (TL), ventral scales, and sub-caudal scales among male and female.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

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