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ORIGINAL ARTICLE

Comparative ultrastructural observations of the Egyptian schistosomes: *Schistosoma mansoni* and *Schistosoma haematobium*

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Abstract An ultrastructural topography has been made to the tegumental architectures of two Egyptian schistosomes namely *S. mansoni* and *S. haematobium* hosted in a model animal namely *Cricentus auratus.* The distribution of sensory papillae on the oral sucker were arranged in one circle around the rim in addition to some papillae in upper part of inner zone in male, female *S. mansoni* and in male *S. haematobium.* The differences in the types of papillae, their distribution and shape of ridges on various parts of the body surface which are quite specific for each species was studied. Also, the ventral tegument of female's displays larger and more numerous sensory papillae. Both ciliated and non-ciliated papillae were observed in this work which makes a link with another species of schistosome *S. japonicum*. Another characteristic feature in this study is unique of male of *S. haematobium*, the extensive formation of ridges and transformation to microvilli in the posterior region in males. These finding may provoke further study of schistosomes hosted in animal model for more detailed investigation at the molecular level.

Keywords Tegument · Schistosomes · Animal model · SEM

Introduction

Scanning electron microscopy is a very important tool in studying the surface of parasites and documenting the alterations of the surface. Halton (1979) examined the surface topography of a monogenean *Diclidophora merlangi* using the SEM. In Egypt, Bayoumy et al. (2007) and Tadros et al. (2014) used the SEM to study the surface topography of *Paranaella diplodae* and *Lutianicola haifonensis*, respectively. Maldonad et al. (2003) examined the morphological character of *Echinostoma* species. Abdel-Haleem et al. (2014) studied the sensory organs of terrestrial flatworms *Biplaium kewense* by using SEM. Senft et al. (1961) examined the function and structure of the tegument of adult *S. mansoni*. Miller et al. (1972) studied the tegumental surface of adult *S. mansoni*, Kuntz et al. (1976) reported that there are differences between the surface structures of male and female as well as from one part of the same parasite to another of *S. haematobium* and Keiji and Yoichi (1977) studied the tegumental surface of adult *S. japonicum*. Both Chia-tung Pan (1980) and Hockely and Mclaren (1973) studied the fine structure of miracidium and cercariae of *S. mansoni.* Pereira et al. (2011) studied the SEM of the human low-density lipoprotein interaction with the tegument of *S. mansoni* and Reda et al. (2012) examined the tegument of *S. mansoni*. The present study aims to summarize all different fine

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surface structures of two Egyptian schistosomes namely *S. mansoni* and *S. haematobium*.

Materials and methods

Parasite and hamaster

Cercariae of *S. mansoni* and *S. haematobium* were obtained from *Biomphalaria alexandrina* and *Bulinus truncates* snails and two hamsters, 12 weeks-old, weighing ~ 100gm. They were provided by Schistosome Biological Production Unite (BPU) of Theodore Bilharz Research Institute (TBRI, Giza, Egypt).

Infection and recovering adult flukes

One hamster was infected with 350 cercariae of *Schistosoma mansoni* and the second infected with 400 cercariae of *S. haematobium*. Recovered worms were obtained in the Biological Production Unite (BPU) of Theodore Bilharz Research Institute (TBRI, Giza, Egypt). *Schistosoma mansoni* was perfused from the hepatic portal vessels and mesenteric veins of infected hamster, while *S. haematobium* was perfused from veins of urinary bladder using perfusion pumb containing phosphate -buffered saline (PBS) and rapidly placed in culture media (RPMI-1640).

Examination of adult worms by scanning Electron Microscope (SEM)

About 20 worms of each species gender were used. They were distend gently and fixed in buffered glutraldehyde 2.5%. Then, they were washed in 0.1 M sodium cacodylate buffer, at pH 7.2 for 5–10 min at room temperature. Post fixed in a solution of 1% osmium tetroxide at 37 °C for 2 h. Thereafter, the specimens were treated with 8 N hydrochloric acid at 60 for 30 min to remove any extracellular mucus for their surfaces. This procedure was followed by dehydration, critical point drying. The specimens were coated with a layer of gold in a sputtering diode coating unit. The samples were examined in an ISI-60 scanning electron microscope operating at 25–36 kv using the backscattered electron imaging (Electron Microscope Unite, Faculty of Science, Mansoura University).

Results

Adult male of *S. mansoni* & *S. haematobium* is cylindrical, shorter and thicker than the adult female. Male has a ventral longitudinal cleft; gynaecophoral canal (GC), where the female is embraced during copulation and during the journey off egg laying (Figs. 1, 30).

Body of male was divided into three regions; anterior region, comprise oral, ventral suckers and area linking them. The middle region (the gynaecophoral canal) and the posterior region; the area where female body was emerges from it.

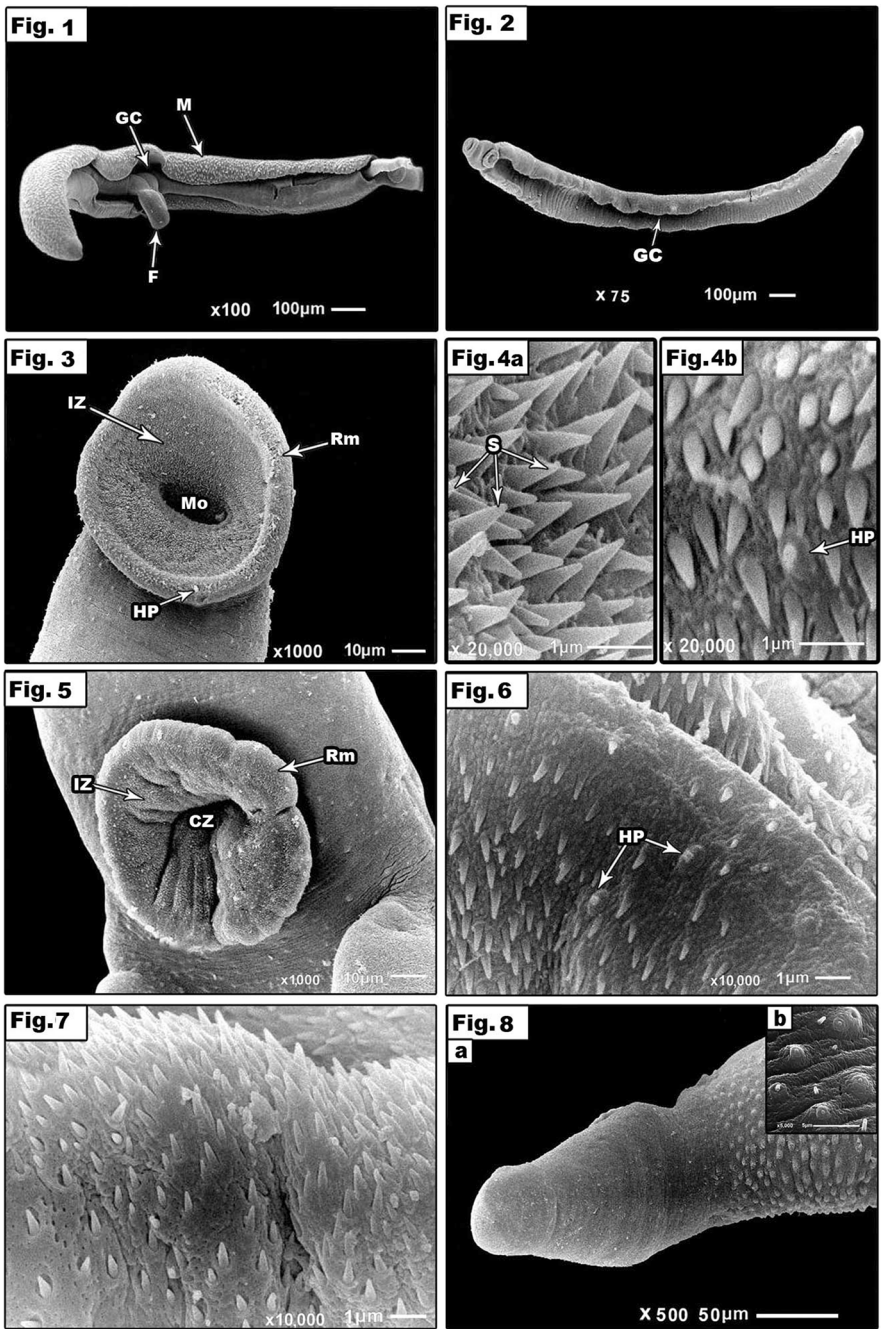
Ventrally, gynaecophoral canal started after the ventbral sucker region where the body increases in width (Fig. 2).

Oral sucker (OS) is oval in *S. mansoni* (Fig. 3), situated at the anterior extremity and has three distinguished regions; thin rim (Rm), inner large zone (IZ) and mouth (Mo) then oral cavity. Oral sucker is clothed with sharp spines (S) directed towards the oral cavitybb (Fig. 4a, b). Ventral sucker (VS) (Fig. 5) is circular and composed of rim (Rm), inner zone (IZ) and central zone (CZ); rim and central zone have hemispherical papillae (HP) and numerous spines (S) which differ in shape and size (Fig. 6). Inner zone bears numerous sharp spines directed towards the cavity and devoid of any sensory papillae (Fig. 7). Dorsally, the area opposite to the oral and ventral suckers area; is composed of rows of slight zig–zag ridges with finger-like projection named digtal form papillae (DiP) and hemispherical papillae (HP) (Figs. 8a, b, 9).

Dorsal tegumental surface composed of cytoplasmic ridges and characterized by the presence of profusely oval tubercles (T) each of which is a raised mound of spines that are directed towards its apex (Fig. 10). Tubercles extend all over the body except the anterior region. There are large tubercles (T), hemispherical papillae (HP), macule papillae (MaP) and dome-shaped papillae (DP) (Figs. 12, 14). Number of spines on each tubercle ranged from 70–95 (Fig. 13).

Right edge of the canal is overlapping the left one. The outer and inner surface of the left edge of the canal has very minute spines on the rim, hemispherical papillae (HP) before the presence of tubercles from outside (Fig. 11). While the right edge has large number of tubercles (Fig. 1). Inner surface of gynaecophoral canal appears as folds (Fig. 12). Spines could be seen along the canal and hemispherical papillae (HP). Number of short spines increased gradually in anterior part (Fig. 13), middle part (Fig. 14) and posterior part (Fig. 15). All portions have hemispherical papillae which increase in the last portion (Fig. 15).

Posterior region of body tegument composed of few number of tubercles, spines between tubercles, the excretory pore (EP) and cratered papillae (CrP) (Fig. 16a). Also, there are numerous hemispherical papillae (HP) (Fig. 16b). Moreover, there are four types of papillae in this area; hemispherical papillae (HP), macule papillae (MaP) digital form papillae (DiP), cratered papillae (CrP) which have ridges appear to radiate from it and dome-shaped papillae (DP) (Figs. 16, 17, 18).

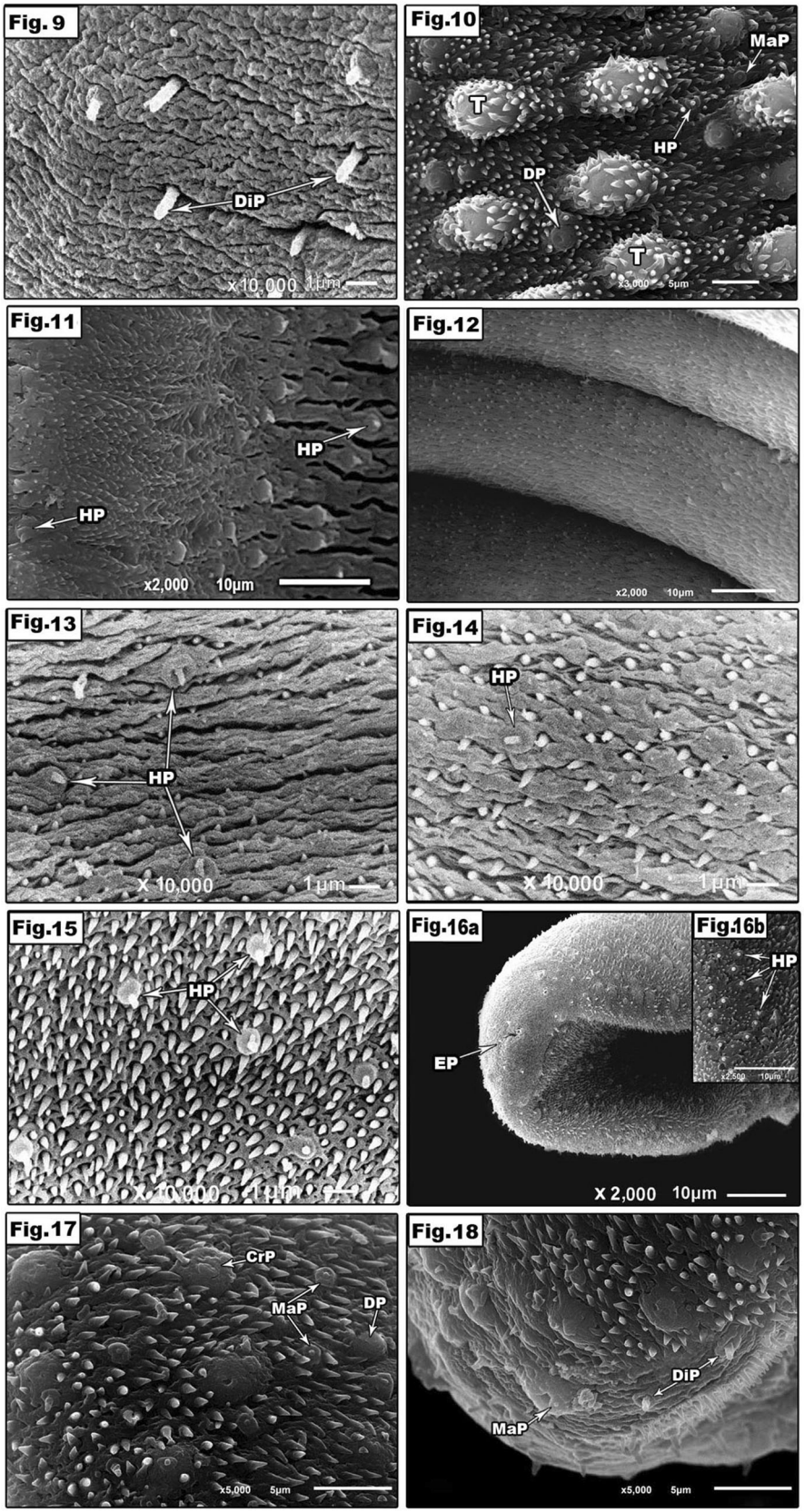


Figs. 1–8 Scanning electron micrographs of adult male *Schistosoma mansoni*. **1** Paired male (M) and female (F) showing the anterior and posterior ends of female emerge from the gynaecophoral canal (GC). **2** Whole mount of the male showing the gynaecophoral canal (GC). **3** Top view of oral sucker (OS) showing hemispherical papillae (HP), inner zone of oral sucker (IZ), mouth (Mo) and rim of oral sucker (Rm). **4a** Rim of the oral sucker showing sharp spines (S). **b** Inner zone (IZ) of oral sucker showing hemispherical papillae (HP) and spines (S). **5** Ventral sucker (VS) showing rim (Rm), inner zone (IZ) and central zone (CZ). **6** Edge of the ventral sucker with hemispherical papillae (HP) and spines. **7** Magnification of the ventral sucker surface with spines. **8a** Dorsal surface of area between two suckers. **b** Magnification of anterior dorsal area between the two suckers showing different sizes of hemispherical papillae

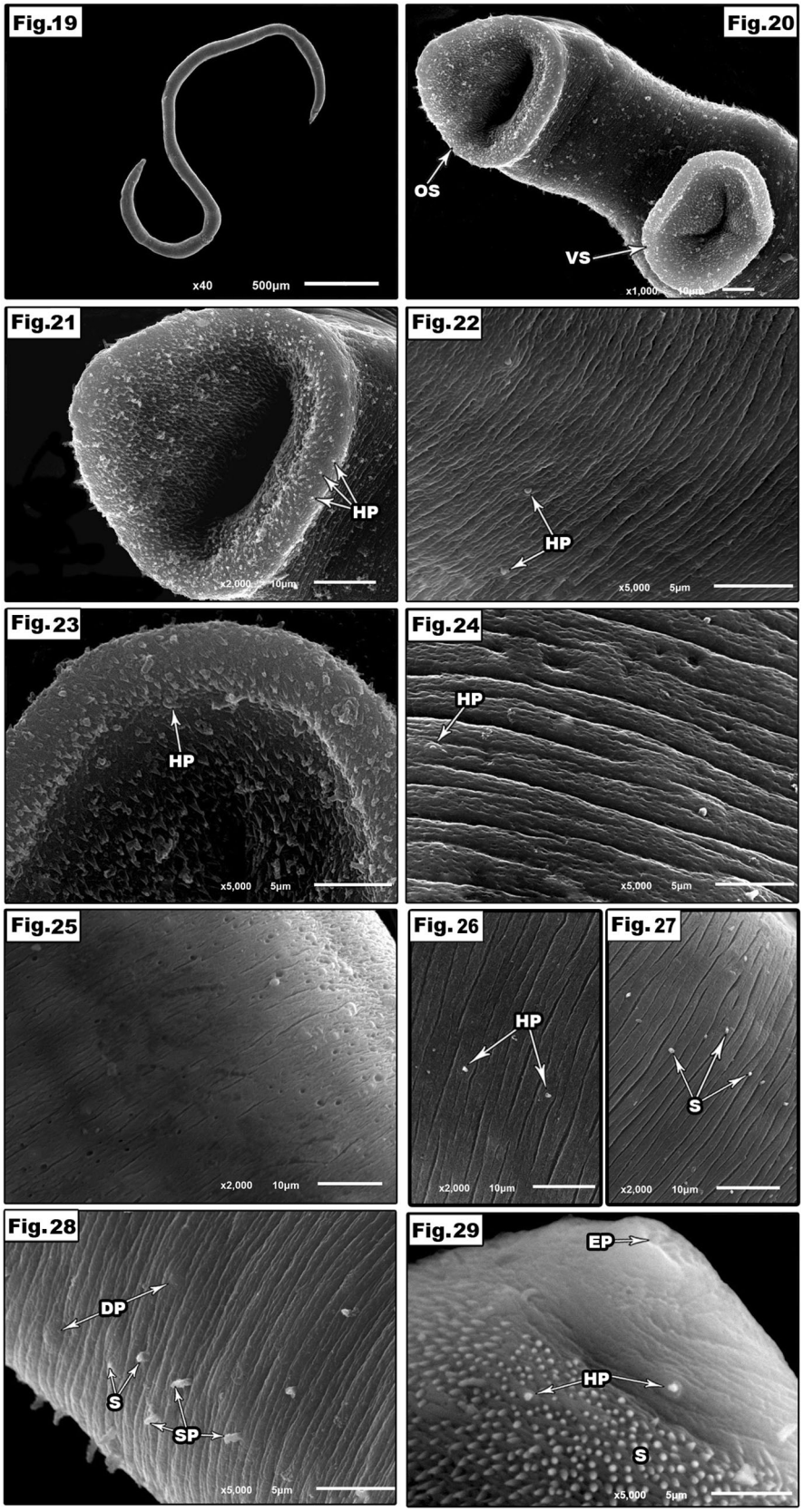
SEM of adult female *S. mansoni* & *S. haematobium* revealed that its body is cylindrical and elongated. The surface of adult female also is divided into three parts as in male.

Anterior region (Fig. 19, 20) consists of oral sucker (OS), ventral sucker (VS) and the linking area. Oral sucker in *S. mansoni*is triangular and possess numerous spines (S) directed towards the cavity (Fig. 21), it also has hemispherical papillae (HP). The area linking between oral and ventral suckers consists of cytoplasmic ridges and devoid of spines (S) but has hemispherical papillae (HP) (Fig. 22). Ventral sucker is circular and have numerous spines (S) with uniform shape and size and directed towards the cavity (Fig. 23).

The ventral surface composed of cytoplasmic ridges, hemispherical papillae (HP) and free of spines (Fig. 24) while, the lateral surface appeared pitted (Fig. 25). The dorsal surface composed of cytoplasmic ridges and hemispherical papillae (HP) (Fig. 26). In middle region (Fig. 27); spines (S) have begun to appear. In posterior region (Figs. 28, 29); number of spines (S), dome-shaped papillae (DP) and spikes (Sp) appeared. These spines are



Figs. 9–18 Scanning electron micrographs of adult male *S. mansoni.* **9** Magnification of the posterior dorsal surface of area between two suckers showing rows of low wavy ridges with hemispherical papillae (HP) and digtal form papillae (DiP). **10** Last portion of the body showing tubercles (T), dome papillae (DP), hemispherical papillae (HP) and macule papillae (MaP). **11** Inner surface of left edge of the canal with minute spines and hemispherical papillae (HP). **12** Inner surface of the canal; well-developed folds. **13** Magnification of anterior inner surface of the canal; hemispherical papillae (HP) and little number of minute spines. Note many clefts. **14** Middle inner surface of the canal with hemispherical papillae (HP) and moderate number of spines. **15** Posterior inner surface of the canal; hemispherical papillae (HP) and numerous spines. **16a** Dorsal view of posterior region of the male. Note few numbers of tubercles, spines between tuberclesand the excretory pore (EP). **b** Ventral view of posterior region of the male showing hemispherical papillae (HP). **17** The most extremely posterior region of the male showing macule papillae (MaP) and cratered papillae (CrP). **18** The most extremely posterior region of the male. Note the presence of digital-form papillae (DiP) and macule papillae (MaP)



Figs. 19–29 Scanning electron micrographs of adult female *S. mansoni*. **19** Whole mount of female showing anterior part (An), middle proximal (MP) region, middle distal (MD) region and posterior part (Po). **20** Anterior region of female showing the oral sucker (OS) and ventral sucker (VS). **21** Magnification of the oral sucker. Note the hemisphericalpapillae (HP) and spines. **22** The surface between the suckers. Note the hemispherical papillae (HP). **23** Magnification of the ventral sucker. Note spines and hemispherical papillae (HP). **24** Magnification of dorsal surface; hemispherical papillae (HP) and some pores. **25** The lateral surface of middle proximal region. Note pitted tegument. **26** The dorsal surface of middle proximal region showing hemispherical papillae (HP). **27** The dorsal surface of middle distal region. Note presence of few spines (S). **28** Magnification of dorsolateral surface. Note presence of spines (S), spikes (Sp) and dome-shape papillae (DP). **29** Posterior extremely showing hemispherical papillae (HP), excretory pore (EP) and profusely spines (S). Note spines directed anteriorly

arised between cytoplasmic ridges (Fig. 28). The area around excretory pore (EP) has numerous spines raised between cytoplasmic ridges that directed anteriorly and have few hemispherical papillae (HP) (Fig. 29).

Adult male of *S. haematobium* has circular oral sucker (OS), situated at the anterior extremely (Figs. 30, 31, 32) and have two distinguished regions (Fig. 33); thin rim (Rm) and large inner zone (IZ). Tegument of rim is corrugated and invaginated by minute pores (Po). Small hemispherical papillae (HP) are few in number while, other type of papillae is also found namely cratered papillae (CrP). These papillae are small, numerous and have ridges appear to radiate from it (Fig. 34). Rim and inner zone contain numerous, rough and blunt spines (Fig. 35) that arised from holes. The outside and inside teguments of inner zones are corrugated and have numerous sharp, rough and centrally-directed spines. Also, there are many pores (Po) were observed and rough spines (Fig. 36).

In the ventral sucker; there are four zones. The first is thick rim (Rm) and the second is a narrow zone (NZ) (path running circumferentially). While the third is wider inner zone and the fourth is round central zone (Fig. 37). Tegument of ventral sucker rim is highly folded and many pores (Po) were observed. Hemispherical papillae (HP) have ridges which appeared to radiate from it was seen. Also, few short, rough and sparse spines (S) were observed (Fig. 38). The tegument of narrow zone is flat sheet which appeared highly pitted. Many hemispherical papillae (HP) and spines were not seen on this zone (Fig. 39). Tegument of wider inner zone is corrugated and contains very numerous centrally-directed long sharp spines and very few hemispherical papillae (HP) (Fig. 40). Tegument of central zone of ventral sucker composed of wavy and branching ridges (Ri). Most ridges appear to branch radially from cratered papillae (CrP), this papillae characterized by its thick and pitted rim with central opening (Fig. 41). This zone is free of spines but has a large numbers of digital papillae (DiP).

Also, the anterior part of tegument after suckers is free of spines. On the ventral and lateral sides, (Fig. 42) the tegument composed of transversal rows of wavy unbranching ridges. There are three types of papillae also observed (Fig. 43). The first namely, larger size ciliated fungiform papillae (FP) that have pitted rims and ridges radiating a way from bulbous bases. These papillae found in two longitudinal rows (Fig. 42) and extend from the end of oral sucker to the end of ventral sucker. The second type; smaller size, ciliated, numerous is namely hemispherical papillae (HP). Third type; large size called squarish papillae (SP). Also, there are spikes with finger-like projection (Sp) and distributed laterally (Fig. 43). On the dorsal aspect (Fig. 44) the tegument of this region composed of wavy branching ridges (Ri) (Fig. 45). These ridges are more complex than those of ventral aspect. Minute pores (Po) were seen in areas between invaginated ridges. Small hemispherical papillae (HP) with radiating ridges from it and branches are observed. Also, many spikes in high concentration were seen on the dorsal sides as well as there are squarish papillae (SP), digtal papillae (DiP) and many cratered papillae (CrP) (Fig. 46).

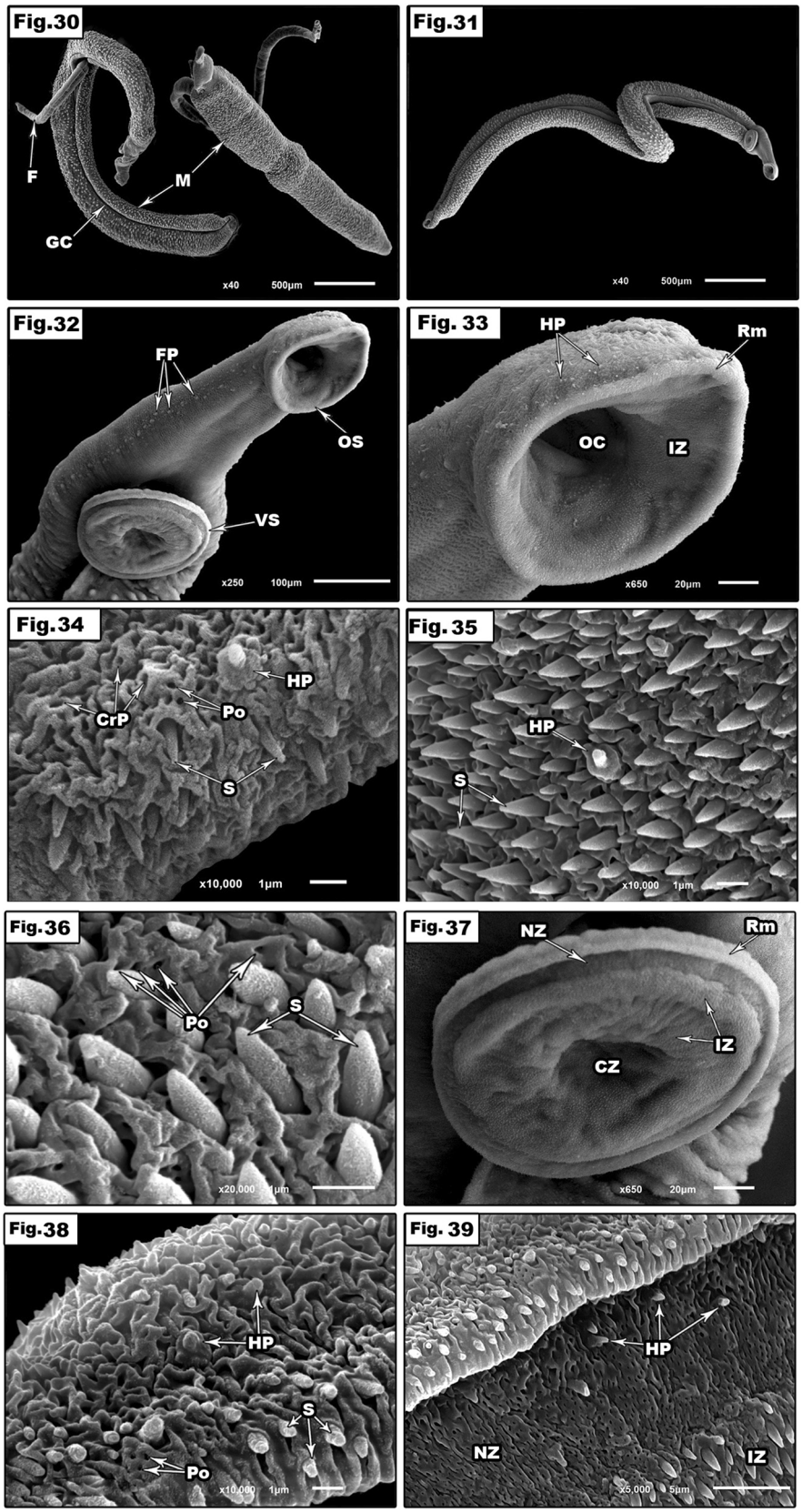
There is a regional differentiation of the male dorsal surface. The tubercles in the anterior region seemed to be few in number (Fig. 49), small in size and have less number of spines than the middle, lateral and posterior regions (Fig. 47a–c), respectively. The tegument is deeply folded and provided by many spines.

In general, the entire external surface of the male is characterized by unique tegumental tuberculations that increase gradually in number and size from anterior to posterior aspect.

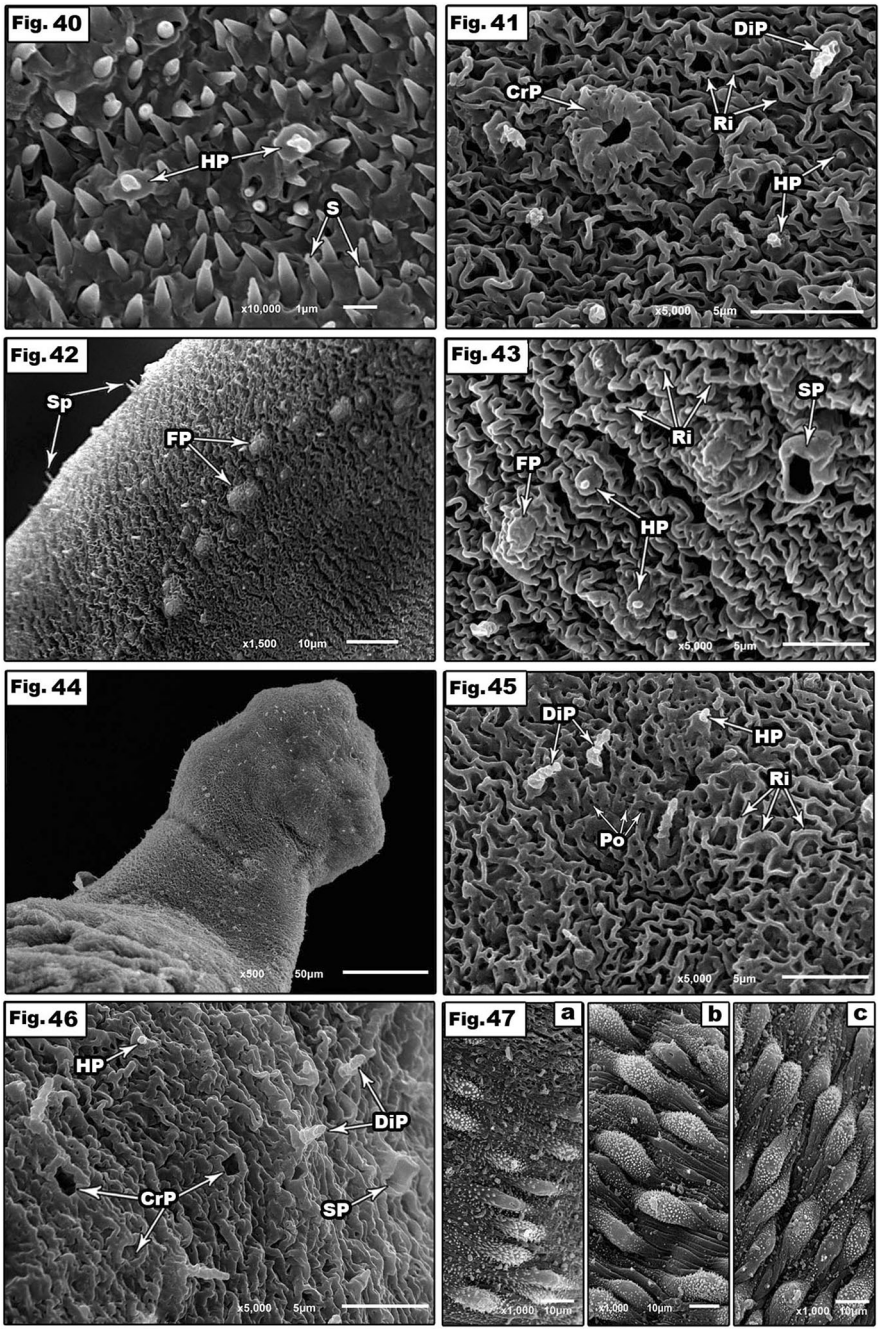
The tegument of right edge is composed of pitted folds but lower than the tegument of left edge which composed of wavy ridges. Tegument of right edges is provided with many spines and is richest in hemispherical papillae, flattened low macules ciliated papillae (MaP), cratered papillae (CrP) with its pitted rim and volcano-opening which seemed to be with secretory function (Figs. 48, 49). There are different types of papillae in the tegument of outer left edge, fungiform papillae (FP), dome papillae (DP) having one spine, dome papillae having knob with appearance of bulls-eye (DP2), dome-papillae having few spines (DP1) (Fig. 50). These papillae appear to be interspersed among the dorsal tubercles. The spines of the inner parts of gynaecophoral canal were decreased in size gradually until the posterior part of gynaecophoral canal (Figs. 51a, b).

The tegument of the posterior part is well developed pitted undulating folds similar to that of gynaecophoral canal. Moreover, in the dorsal side and around the excretory pore ridges appeared as leaf-like structure with microvillus-like projections (MV) (Fig. 52). Fungiform papillae (FP) were highly concentrated around the excretory pore and dorso-lateral aspect also, the tegument composed of wavy branching ridges (Ri) (Fig. 52).

SEM of adult female *S. haematobium* tegument of the anterior part appears perforated by many small pores. Hemispherical papillae (HP) are numerous and found in two circles around the oral sucker as well as along the latero-dorsal aspect. There are many spikes (Sp). Spines are also numerous than those of male (Fig. 53a, b). The tegumental surface here looks like a flat sheet and is naviginated by many minute pores and numerous small hemispherical papillae (HP) (Fig. 54). In another specimen tegument between two suckers composed of wavy, taller and branching ridges. Some sensory papillae with blunt finger-like projection (DiP) and few spines (S) were present (Fig. 55). The majority of worms were conjugated so, a



Figs. 30–39 Scanning electron micrographs of adult male *S. haematobium*. **30**. Ventral and dorsal view of conjugating male (M) and female (F) *S. haematobium* showing complete closed gynaecophoral canal (GC). **31** Ventral view of whole mount of male showing closed gynaecophoral canal. **32** Ventral view of anterior region showing oral (OS) and ventral (VS) suckers. Note two rows of fungiform papillae (FP). **33** Ventral view of oral sucker (OS) showing some thin rim (Rm), large inner zone (IZ) and oral cavity (OC). Note numerous hemispherical papillae (HP) outside the inner zone. **34** Rim of the oral sucker showing corrugated tegument, small cratered papillae (CrP) with radiating ridges, some pores (Po), few number of hemispherical papillae (HP). Note sharp and sparse spines (S). **35** Magnification of rim showing rough, long and sharp spines (S) and hemispherical papillae (HP). **36** High magnification of Fig. 32. Note rough, sharp and fungi form spines (S), corrugated tegument with many pores (Po). **37** Ventral sucker showing four zones; rim (Rm), narrow zone (NZ), large inner zone (IZ) and central zone (CZ). **38** Rim of ventral sucker showing highly folded tegument, few hemispherical papillae (HP), pores (Po) and short and sparse spines (S). **39** Sector of ventral sucker showing narrow zone (NZ) with pitted sheet tegument and hemispherical papillae (HP) only between two spinous zones



Figs. 40–47 Scanning electron micrographs of adult male *S. haematobium*. **40** Magnification of inner zone of ventral sucker. Note some hemispherical papillae (HP) and sharp spines (S). **41** Central zone of ventral sucker; a more extensive development branching ridges, (Ri), digital papillae (DiP), hemispherical papillae (HP) and non-ciliated cratered papillae (CrP). Note pitted rim and ridges radiate from CrP. **42** Ventral surface of anterior region showing a row of fungi form papillae (FP) and lateral spikes (Sp). Note transverse wavy ridges. **43** Magnification of Fig. 42. Note wavy ridges (Ri), fungi form papillae (FP), hemispherical papillae (HP) and squarish papillae (SP). **44** Dorsal surface of anterior region. **45** Magnification of Fig. 44. Note numerous digital papillae (DiP), pores (Po) and hemispherical papillae (HP). Note well development branching ridges (Ri). **46** Anterior part of dorsal surface showing numerous cratered papillae (CrP), digital papillae (DiP), hemispherical papillae (HP) and squarish papillae (SP). **47** Tegument of dorsal surface showing distribution of tubercles (T); anterior part (**a**) with few number of tubercles, middle part (**b**) with moderate number and posterior part (**c**) with numerous tubercles (T)

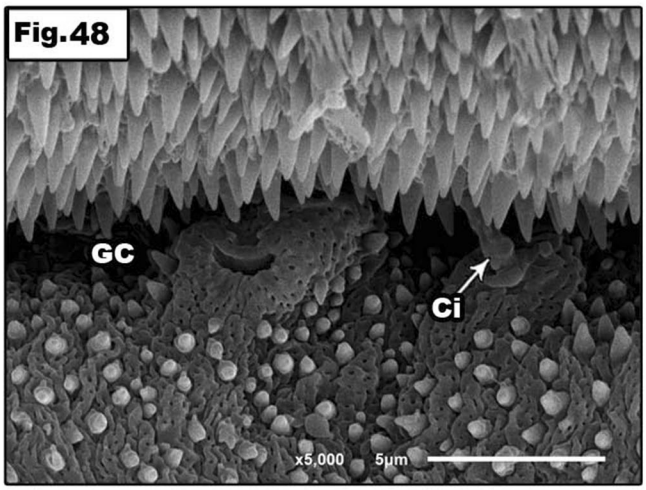
part of ventral sucker was observed and it has minute spines and hemispherical papillae (HP) (Fig. 56).

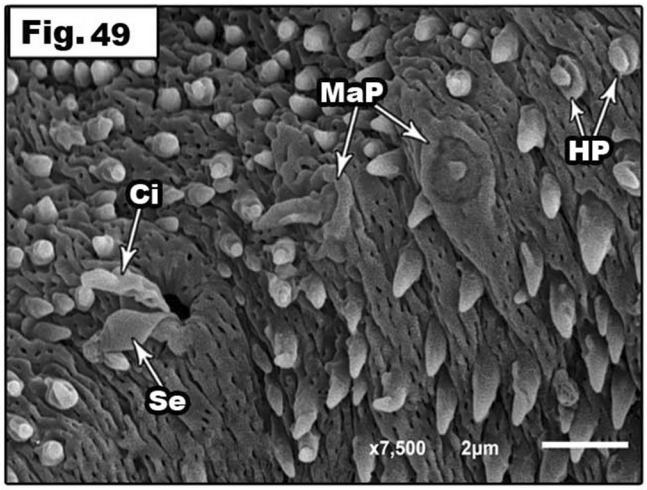
The tegument of the proximal middle part appears as parallel folds with fewer digital form papillae (DiP), few hemispherical papillae (HP), short and stubby spines (S). The folds appear as crisscrosses of low ridges (Figs. 57, 58). The tegument on the distal region seems as parallel folds with low pitted surface (Fig. 59).

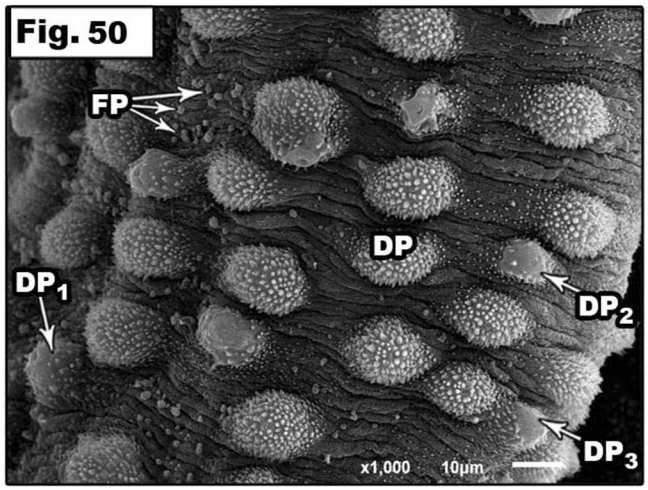
The tegument in the posterior part is less corrugated and the folds are highly pitted with large pores (Fig. 60). The numbers of spines are increased on all sides by comparing to other parts of female (Fig. 61). Closer to the excretory pore the hemispherical papillae (HP) are numerous. Spines (S) are more numerous, short, stubby and directed backward.

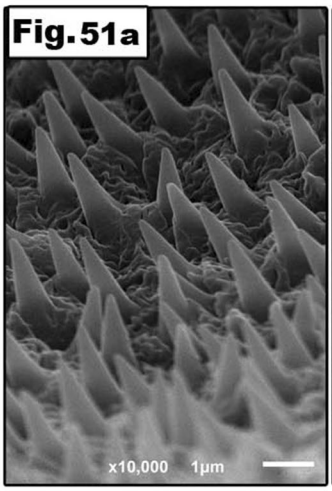
Discussion

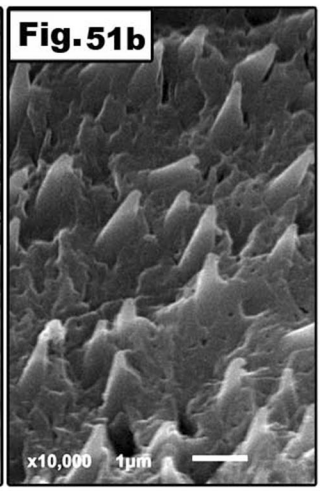
The *Schistosomes* are most successful human parasites by maintain themselves within the mammalian blood vessel and facilitate living in. SEM provides a high resolution

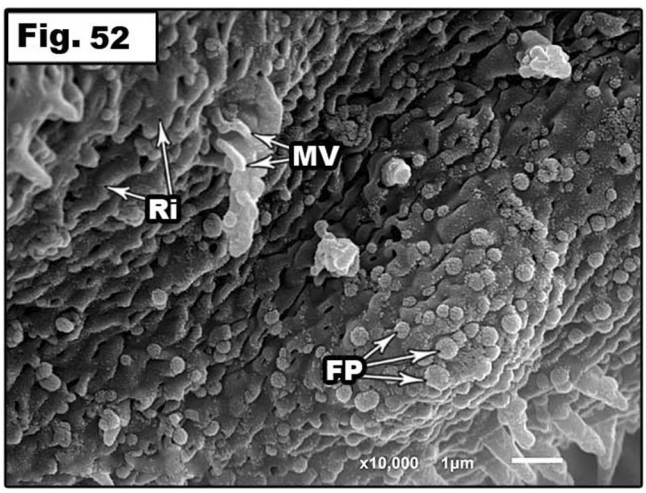




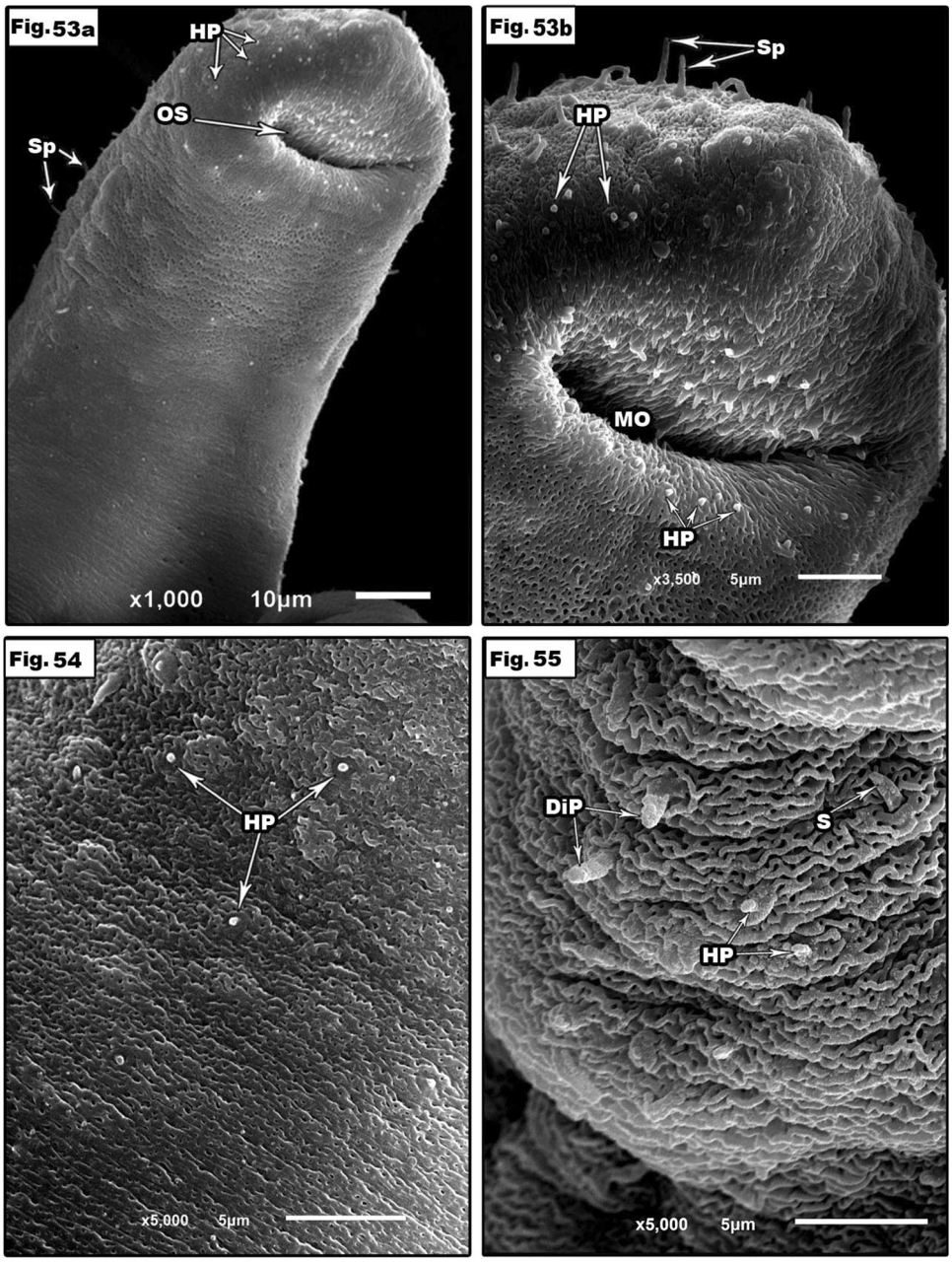








Figs. 48–52 Scanning electron micrographs of adult male *S. haematobium*. **48** Right edge of gynaecophoral canal (GC) provided by non-ciliated and ciliated cratered papillae. Note cilia (Ci). **49** Right edge of gynaecophoral canal showing highly pitted tegument with ciliated cratered papillae that seemed to be secretory, macules (MaP) and hemispherical (HP) papillae. Cilia (Ci) and secretion (Se). **50** View of middle third of the body showing numerous and small fungi form papillae (FP) interspersed among the dorsal tubercles, ciliated dome papillae (DP2), dome papillae (DP3) and dome papillae with knob (DP1). **51a** Inner surface of anterior and middle part of gynaecophoral canal showing long and sharp spines. **b** Inner surface of posterior part of gynaecophoral canal showing slightly pitted tegument seemed to be disrupted by short and stubby spines. **52** Magnification of Posterior extremely end showing ridges (Ri) transform to leaf-like and microvilli (MV) like projections. Note accumulation of very numerous fungi form papillae (FP)



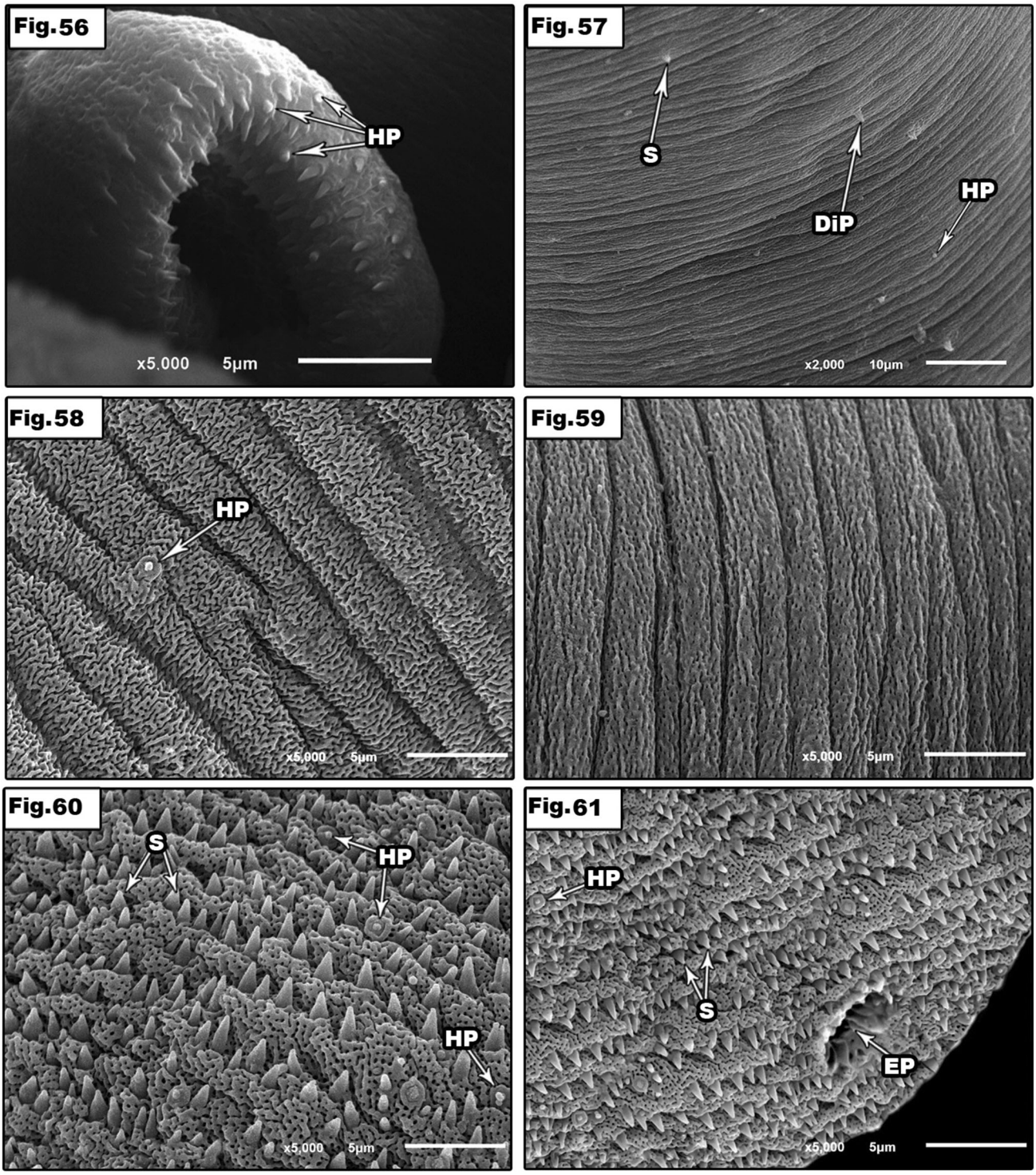
Figs. 53–55 Scanning electron micrographs of adult female *S. haematobium*. **53a** Ventral surface of anterior region showing oral sucker with mouth opening (MO). Note two circles of hemispherical papillae (HP) and spikes (Sp). **b** Magnification of the oral sucker showing spongy appearance tegument, mouth opening (MO), hemispherical papillae (HP) and spikes (Sp). Note spines directed inward. **54** Tegument of flat sheet ventral surface. Note invagination by numerous minute pores. Note numerous small hemispherical papillae (HP). **55** Magnification of lateroventral aspect of anterior region showing digital papillae (DiP), hemispherical papillae (HP) and spines (S). Note wavy branching ridges

method for examining the surface topography of the adult male and female of *S. mansoni* and *S. haematobium*. The gross topographical features include the oral and ventral suckers, the gynaecophoral canal and the entire external tegument of both *S. mansoni* and *S. haematobium* have the same with some differences is showed. Some authors studied the tegumental surface of both adult *S. mansoni* and *S. haematobium* using SEM (Senft et al. 1961; Hockley and McLaren 1973; Kuntz et al. 1976; Reda et al. 2012).

Also, at the ultrastructural level, there is significant information suggesting that tegumental features of Schistosomes may provide to a better host-parasite and male–female relationship. By analyzing SEM observations we can demonstrate the remarkable specialization of the adult worm's tegument which has involved ability to survive within their host.

In the present study, spines are widely distributed on the oral sucker, ventral sucker, the gynaecophoral canal and the entire external tegument of males and some regions of females of both *S. mansoni* and *S. haematobium* (Kohn et al. 1982; Machado-Silva et al. 1997).

The functions of the spines on the oral sucker are responsible for attaching and scraping the blood vessel tissues for feeding. While sensory papillae enable oral sucker to select the appropriate attachment site to achieve a firm adheres during feeding (Reda and El-Shabasy 2016).



Figs. 56–61 Scanning electron micrographs of adult female *S. haematobium.* **56** Ventral sucker showing pitted tegument with short and stubby spines and some hemispherical papillae (HP). **57** Tegument of the ventral surface showing folds, digital papillae (DiP), hemispherical papillae (HP) and spines (S). **58** Magnification of the lateral region showing folds and hemisphericalpapillae (HP). Note corrugated folds tegument. **59** Magnification of the lateral region showing folds. Note corrugated folds tegument. **60** Dorsal surface showing tegument with corrugated pierced folds. **61** Posterior extremely showing excretory pore (EP), corrugated pierced tegument with sharp spines (S) and hemispherical papillae (HP)

The distribution of sensory papillae on the oral sucker was arranged in one circle around the rim in addition to some papillae in upper part of inner zone in male, female *S. mansoni* and in male *S. haematobium.* While in female *S. haematobium* there are two circles of sensory papillae as well as some papillae in upper part of the oral sucker. The basic structure of the oral sucker of *S. mansoni* and *S. haematobium* is remarkably similar to other species of *Schistosoma* described. There are differences in the types of papillae, their distribution and shape of ridges on various parts of the body surface which are quite specific for each species.

The tubercles and associated spines are seen to play an important role in adaption to life in the blood vessels. The presence of numerous spines suggests a protective role by anchoring the worm into the endothelial cells of the host blood vessel against the blood flow (Hockely 1973).

SEM has provided additional information on the tegumental characteristics of females of both species. The more irregular and regular of porous nature of the surface lead to increase the surface area and reflect a possible absorptive capacity of the tegument. The ventral tegument of female's displays larger and more numerous sensory papillae. These receptors may provide for more sensitive directional capabilities. Also at the ultrastructural level, there is significant information suggesting that tegumental features of Schistosomes may provide for male–female relationship. Rogers and Bueding (1975) mention the possibility of trans-tegumental absorption of nutrients by female *Schistosoma* from male. They also showed that female displayed only a limited uptake of glucose through the tegument when enclosed in the gynaecophoral canal. Hockley (1973) suggests that amino acids and other important substance may pass from male ventral tegument to female tegument.

The tegumental characteristics of dorsal surface of female of *S. mansoni* and *S. haematobium* are basically similar. In general, the posterior aspect of the gynaecophoral canal reveals that the furry investiture of spines directed inward. The heavy investiture of spines on the posterio-dorsal end of the female is similar to the arrangement on the gynaecophoral canal of the male. The two areas may interlock in some manner to help security of the female in the canal. The folds of gynaecophoral canal of male probably provided a mechanism for stabilizing the female within the grasp of the male deep within the canal.

Concerning to clefts which are seen in the ventral aspect of the male gynaecophoral canal; many of these clefts are provided with spines, while others are empty (pores). The fact that these clefts are particularly numerous in the gynaecophoral canal in male–female contact zone may serve to transfer small molecules (Senft 1968) and suggested opportunity for metabolites to enter or egress through these openings.

The most important gains from the topography are that schistosomes are well provided with numerous and varied tactile papillae. The appendages were seen also by SEM are spines and spikes.

On a morphological basis the present study, at least papillae "receptors" can recognize:

1. *Ciliated hemispherical papillae* Generally evenly spaced and best observed on the anterior region of the schistosomes. These papillae are numerous and have a cilium this suggests that their function may be tactile and/or tango receptors. These papillae are similar to those found in *S. japonicum* (Voce et al. 1978; Sobhon et al. 1986) and *S. mansoni* (Senft and Gibler 1977).
2. *Fungiform papillae* These appear to be restricted only in the ventral aspect of the anterior region in two rows extending from the ends of oral sucker to the end of ventral sucker. The non-ciliated type only was recorded in the present study and these characters similar to that of *S. japonicum* (McLaren 1980). The functions of these non-ciliated fungiform papillae may be presso-receptors. Voce et al. (1978) recognized fungiform papillae are more numerous, a few hemispherical papillae in *S. japonicum*in contrast to thisstudy.
3. *Cratered papillae* Both ciliated and non-ciliated types were observed in the present study, this in contracted to result of Senft and Gibler (1977); McLaren (1980) who reported non-ciliated type only in *S. mansoni* and *S. haematobium*. Presence of many pits, the cratered papillae may be involved in chemoreception. Also because of the presence of some substance seemed to be secretion from papillae opening, the cratered papillae may be involved to be secretary gland. So, more studies are needed.
4. *Squarish papillae* These papillae are rare in the specimens and found in the dorsal and ventral aspect of the anterior region of the body. It characterized by its square base, thin and smooth and large square opening. It seemed to be first record.
5. *Macules papillae* These flattened ciliated best seen between tubercles and in the posterior region.
6. *Digital papillae* These papillae typically with blunt tipped projections emerging from a low base and were numerous in dorsal and ventral aspect of anterior region of the body and central zone of ventral sucker, those papillae were observed by Senft and Gibler (1977) in *S. mansoni* in female also.
7. *Dome papillae* Appears as hillocks and devoid of spines and sometime have a knob.
8. *Ciliated dome papillae* These dome papillae showing nipple-like apices with a single central spine.

Concerning the spikes which were seen in the females particularly along the lateral region, its gross appearance with stiff structure, highly fragile and sheared off during movement may be exudates from surface pore like spines (Senft and Gibler 1977). Also it is probably analogous structure of spines in *S. mansoni* and *S. haematobium* (Sobhon et al. 1986).

Finally, the extraordinary high concentration of various sensory papillae throughout the surface of schistosomes is evidence of a strong dependence of parasites upon the tactile receptions and chemical stimuli from their environments. Another characteristic feature in this study is unique to male of *S. haematobium*, the extensive formation of ridges and transformation to microvilli in the posterior region in males. This leads greatly to increase the surface area of the male *S. haematobium* to absorb nutrient molecules in a greater proportion. Therefore, it is very likely that the tegument of *S. haematobium* may have a significant role in the uptake of nutrient molecules in addition to the gut.

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Author contributions statement Prof. ESR participated in the design of the study, in the photographing of the specimens and reviewed the final editing of the manuscript. Prof. AES carried out the final revision of the manuscript. MAS performed the preparation process of worms and participated in the photographing. Dr. EAE conceived of the study; participated in its design, getting the worms, preparation process and coordination; and helped to draft the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Ethical approval All deals with animals in this study were carried out according to international valid guidelines of experimental animal studies and research protocol was approved by the local ethical committee of the faculty of Science, Mansoura University with code number MZ18007.

Conflict of interest The authors declare that they have no conflict of interest.

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