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RESEARCH ARTICLE

Anatomical and histological characteristic of the tongue and tongue mucosa linguae in the cattle-yak (*Bos taurus* × *Bos grunniens*)

Yanping Ding[1], Shiyuan Yu[1], Baoping Shao (✉)[2]

[1] *School of Life Science, Northwest Normal University, Lanzhou 730000, China*
[2] *Institute of Zoology, School of Life Science, Lanzhou University, Lanzhou 730000, China*

Abstract **This study presents the first definitive anatomical description of the tongue and lingual papillae of the cattle-yak. Data on tongues from 12 healthy cattle-yaks were collected. The results show that five types of papillae were identifiable on the tongue surface of the cattle-yak. Among these, three types were mechanical papillae (filiform, conical, and lenticular), and two types were gustatory papillae (vallate and fungiform). Some morphological features of the cattle-yak tongue were similar to those of domestic ruminants, but the lingual prominence was higher and more developed. For example, more mechanical papillae were present and they were covered by a thicker, keratinized epithelium, the conical papillae possibly perform an immune function, the fungiform papillae have more mucus-secreting pores, and the sublingual glands were more developed. This research will provide a further and detailed source of morphological information about the cattle-yak that is currently lacking in species-specific studies on the morphology of the Bovidae family.**

Keywords cattle-yak, lingual papillae, morphology, anatomy, Qinghai-Tibetan Plateau, tongue

Introduction

The cattle-yak is a hybrid of the cattle (*Bos taurus*) and the yak (*B. grunniens*). A year-round grazing animal, it is the single most important hybrid species maintaining the alpine rangeland ecosystems in the Qinghai-Tibetan Plateau and its peripheral plateau area at 3000–5000 m above sea level. They can feed on grasslands at temperatures as low as –30°C to –40°C, or even lower during harsh winters. Moreover, the cattle-yak is considered an ideal model for plateau stock breeding studies as it is one of the largest hybrids and an important source of animal products in the Qinghai-Tibetan plateau.

In herbivores, the tongue, together with other organs within and near the oral cavity, play a major role in feeding (Iwasaki, 2002). The modification of the dorsal surface mucosa of the tongue into various shapes of lingual papillae facilitates mechanical and taste perception (Adnyane et al., 2011). The morphological characteristics of the tongue and lingual papillae vary among species in relation to the lifestyle, type of diet, adaptations, and taxonomic features of the animal, and this diversity has defined high-level systematic units, such as orders or families of species (Iwasaki, 2002; Jackowiak and Godynicki, 2004). In domestic animals, scanning electron microscope studies of the tongue papillae have been reported for the dog (Ojima, 2001), pig (Kumar and Bate, 2004), goat (Kumar et al., 1998), sheep (Emura et al., 2000a), cow (Steflik et al., 1983), buffalo (Emura and El Bakary, 2014), horse (Pfeiffer et al., 2000), camel (Eerdunchaolu et al., 2001; Qayyum et al., 1988), and yak (Shao et al., 2010).

To date, the morphological features of the cattle-yak tongue have not been studied. The present study aims to compare the macroscopic anatomical features of the tongue, scanning electron microscopic morphologies, and topographical distribution of the lingual papillae that occur on all of the lingual surfaces of the cattle-yak. The results of the present study provides essential data for studies on adaptation in this plateau animal.

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Correspondence: Baoping Shao
E-mail: shaobp@lzu.edu.cn

Materials and methods

The tongues of 12 healthy cattle-yak (7 males and 5 females, 3–6 years old) with a mean weight of 270 kg (S.D. 25 kg) were collected immediately after slaughter from the slaughter house, Maqu Tibetan Autonomous County, Gansu Province, China. Blocks were cut from various parts of 2 tongues and were fixed with 2.5% glutaraldehyde for scanning electron microscopy. Ten tongues were fixed with 4% paraformaldehyde (8 tongues for anatomy), shortly afterwards. Blocks were cut from various parts of the other tongues for light microscopy.

For light microscopy, the specimens were dehydrated through a graded series of alcohol concentrations, cleared and embedded in paraffin wax, and sectioned at 4 μm. Sections were stained with hematoxylin-eosin and the slides observed using bright-field light microscopy (BH-2, Olympus, Japan).

For scanning electron microscopy, the fixed tissues were taken from apex, body, and root sections and post-fixed in a 1% solution of osmium tetroxide in a phosphate buffer for 4 h at room temperature. Subsequently, they were immersed in a solution of 3.5 N HCl for 3 weeks at room temperature (22–25°C) to remove mucus and sloughed cells. The samples were then washed thoroughly in water and dehydrated through a graded series of ethanol concentrations to 100%. The dehydrated tissues were freeze-dried in a hyperbaric chamber (Balzers) of CO_2 and coated with gold in an argon (18 mV) vacuum chamber for 3 min. The samples were observed using a scanning electron microscope (JSM-6380LV, Japan) with a 20-kV acceleration voltage. Description of morphology was according to the methods described by the Hunan Research Group (Hunan Research Group, 1984).

Anatomical data were measured using Vernier calipers, and the histological data were observed using Motic Images Plus 3.0 Data were presented as median±standard error.

All research protocols used in the current experiments were approved by the Animal Ethics Committee of the Gansu Province, China.

Results

The tongue of the cattle-yak was composed of apex, body, and root sections (Fig. 1A). Macroscopic measurements of the tongue are presented in Table 1. The tongue measured (from the tip to the glossoepiglottic fold) a mean of 30.0 cm in total length, 7.5 cm at its maximum width, and 3.5 cm at its maximum depth. The lingual was developed and lingual prominence was observed on the lingual body. Papillae were distributed not only on the dorsal surface of the tongue, but also on the anterior and ventral surfaces. Three types of mechanical papillae (filiform, conical, and lenticular) and two types of gustatory papillae (vallate and fungiform) were observed on the surface of the tongue.

Table 1 Macroscopic measurements of the cattle-yak tongue (mean± SE, n = 12)

Total length of tongue (cm)	30.0±1.6
Maximum width of tongue (cm)	7.0±0.9
Maximum thickness of tongue (cm)	3.5±0.7
Length of lingual apex (cm)	10.0±0.6
Maximum width of lingual apex (cm)	7.5±0.4
Filiform papillae	
Number per cm^2 (anterior dorsal surface)	28±2
Conical papillae	
Total number	160±10
Diameter (mm)	1.6±0.7
Height (mm)	3.2±0.3
Thickness of keratinized epithelium (μm) (papilla surface)	260±13
Lenticular papillae	
Total number	200±15
Diameter (mm)	2.0±0.4
Height (mm)	3.0±0.4
Thickness of keratinized epithelium (μm) (papilla surface)	220±16
Fungiform papillae	
Total number	280±8
Diameter (mm)	1.5±0.2
Height (mm)	1.2±0.5
Thickness of keratinized epithelium (μm) (papilla surface)	110±12
Number per cm^2 (anterior dorsal surface)	1.8±0.5
Number of mucus-secreting pores per papilla	13±0.2
Vallate papillae	
Total number	28±1
Diameter (mm)	2.5±0.4
Height (mm)	1.5±0.5
Thickness of keratinized epithelium (μm) (papilla surface)	440±40
Number of taste buds per papilla	32±8

Filiform papillae

Filiform papillae, which were the most numerous type of lingual papillae (Fig. 1D: 5), were cylindrical with a short, convex-point shape. All papillae lay pointing in the direction of the lingual root (Figs. 1D, 2D, and 2E), and were densely distributed on the dorsal surface of the anterior tongue. The mean number (per cm^2) of filiform papillae on the anterior, dorsal surface of the anterior tongue was 28±2, and papillae were variable both in their base diameter and height. Filiform papillae on the dorsal surface were larger and more numerous than those on the ventral surface. The entire lingual apex area (Fig. 1A: c) was pigmented, but there was only slight pigmentation; all of the papillae were white with no pigmentation on their surface (Figs. 1D: 4 and 5). In the apex region, the main protrusion was covered by a continuous

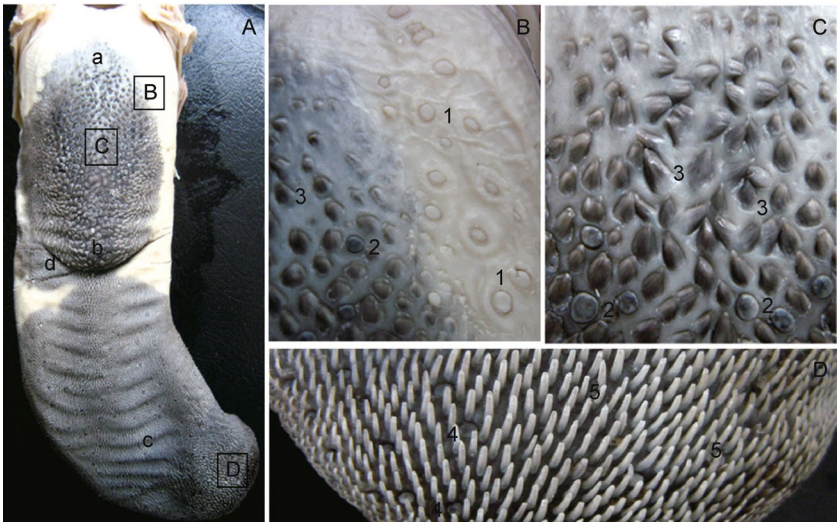

Figure 1 The tongue of the cattle-yak: a, lingual root; b, lingual body; c, lingual apex; d, transverse sulcus; B, C, and D are the enlarged view of areas B, C, and D in (A), respectively; 1, vallate papillae; 2, lenticular papillae; 3, conical papillae; 4, fungiform papillae; 5, filiform papillae.

and tough, aculeate-serrate, keratinized epithelium (Fig. 2F). The central region of the papillae was flat and the surface showed scales of cornified epithelial cells (Fig. 2D). On the remaining basal region, there were 5–10 secondary papillae and pseudo-papillae that emerged as delicate projections from the surface of the central papillary body and adhered to the central papillae (Fig. 2D).

In light microscopy observations, loss of nuclei, weakly stained by eosin, was observed in the most superficial layer of the epithelium on the anterior side of each filiform papilla (Figs. 2B: * and 2C: *). In contrast, nuclei remained in the most superficial layer on the posterior side, despite the same degree of eosin staining. The interpapillary epithelium of filiform papillae had flattened nuclei and concentrated cytoplasm. However, the epithelium exhibited weak keratinization, similar in appearance to parakeratinization. Furthermore, keratohyalin granules were observed in the granular layer of the epithelium located on the anterior side of each filiform papilla (Figs. 2A and 2B). There were some lingual gland ducts in the lamina propria (Figs. 2A: GD and 2B: GD).

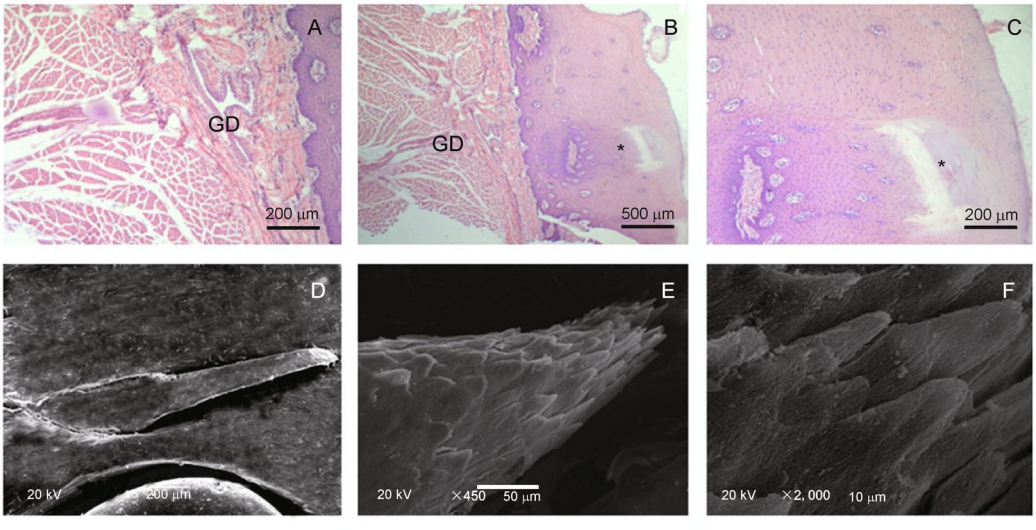

Figure 2 The filiform papillae of the cattle-yak: (A), (B), and (C) light micrographs of a sagittal section of the base of filiform papillae distributed on the anterior part of the tongue. There were some lingual gland ducts (GD) in the lamina propria, but no nuclear area (*) in the epithelium; (D) SEM micrograph of the external surface of a filiform papilla distributed on the anterior part of the tongue. The filiform papilla was spearhead-like in shape; (E) SEM micrograph of the external surface of the papillae apex; (F) SEM micrograph of the aculeate-serrate, keratinized epithelium.

Conical papillae

The conical papillae were distributed on the dorsal surface of the lingual prominence (Figs. 1A and 1C: 3), the mean total number was 160±10, base diameter was 1.6±0.7 mm, and height was 3.2±0.3 mm. Conical papillae showed a broad base and either a tapering apex (Fig. 3C′), or a blunt apex (Fig. 3C), at the prominence. The postmedian surface of the papillae showed a few mucus-secreting pores, the remainder of the surface showed scales of cornified, epithelial cells (Figs. 3D and D′: Arrows); however, the taste pore was not found.

In light microscopy observations, keratinized epithelium covered the top of the conical papillae, and the thickness of the epithelium was 260±13 μm. No taste buds were found in the epithelium of the conical papillae (Fig. 3B). There were some lymph nodules and lingual gland ducts in the lamina propria (Figs. 3A: LN and GD, respectively, and 3B: LN).

Lenticular papillae

The lenticular papillae were round or oval in shape, distributed on the dorsal surface of the lingual prominence, and the centrally situated papillae were larger in size compared with those situated on the periphery (Figs. 1A and 1C: 2). The total number was 200±15, average base diameter was 2.0±0.4 mm, and height was 3.0±0.4 mm. The papillae were slightly convex and had an obvious encircling groove, separated by the conical papillae (Fig. 4B). Many small mucus-secreting pores (Fig. 4C: Arrow) were detected on each papilla, but the taste pore was not found (Figs. 4B, 4C, and 4D).

Thin keratinized epithelium covered the top of the lenticular papillae (Fig. 4A) and the thickness of the epithelium was 220±16 μm. In the lamina propria, some lingual gland ducts were present; however, serous-rich mixed lingual glands and taste buds were not observed. (Fig. 4A: GD).

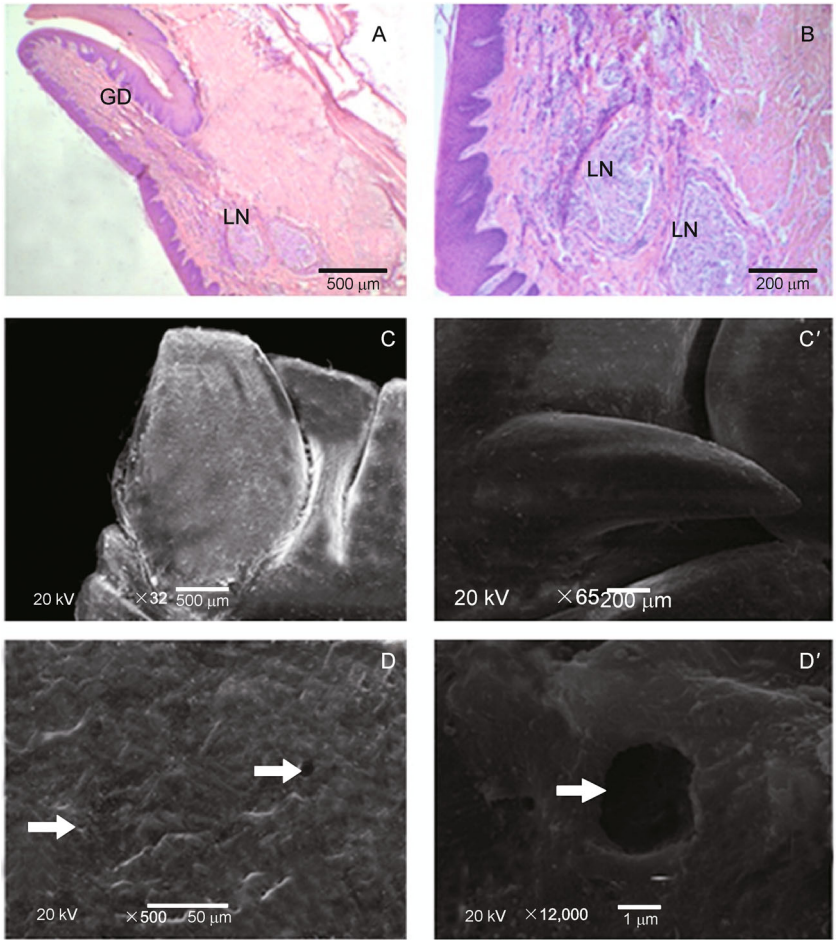

Figure 3 The conical papillae of the cattle-yak: (A) and (B) light micrographs of a sagittal section of the conical papillae. There were some lymph nodules (LN) and lingual gland ducts (GD); (C) SEM micrograph of the external surface of a conical papilla distributed on the dorsal surface of the lingual prominence. The conical papilla was blunted and conical-like in shape; (C′) SEM micrograph of the external surface of a conical papilla distributed on the dorsal surface of the lingual prominence. The conical papilla was tapering and conical-like in shape; (D) SEM micrograph of the external surface of the conical papilla (Arrows: mucus-secreting pores); (D′) SEM micrograph of the external surface of the tapering, conical-shaped apex papillae (Arrow: mucus-secreting pore).

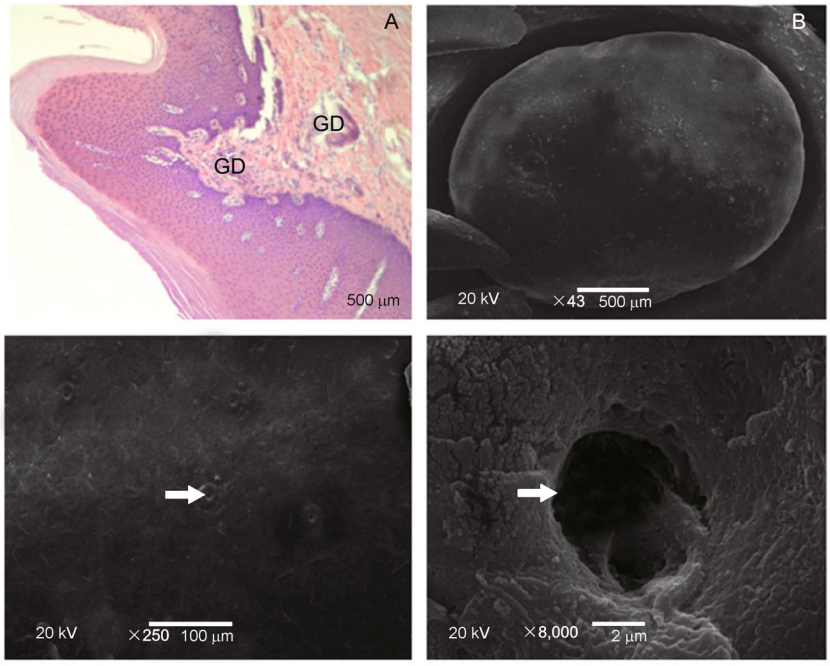

Figure 4 The lenticular papillae of the cattle-yak: (A) light micrograph of a section of the lenticular papilla. The top of the papilla was covered by thin, keratinized epithelium, and the lingual gland ducts (GD) were located on the lamina propria; (B) SEM micrograph of the external surface of the lenticular papilla; (C) and (D) SEM magnified micrographs of the external surfaces of the lenticular papillae (Arrows: mucus-secreting pores).

Fungiform papillae

The fungiform papillae (Figs. 1A and 1D: 4) were embedded among the filiform papillae. The number of papillae gradually decreased from the lingual body to the apex, and each fungiform was surrounded by a deep and evident groove (Fig. 5D). In addition, only dome-shaped fungiform papillae were found in the cattle-yak (Figs. 1 and 5). The mean number (per cm^2) of fungiform papillae on the dorsal surface of the anterior tongue was 1.8±0.5. The taste pore opening lay at the bottom of a crater-like area (Figs. 5A, 5B, and 5C), surrounded by squamous epithelial cells. There were approximately 13 mucus-secreting pores (Figs. 5D: Arrows and 5E: Arrows) on the surface of each papilla (Table 1).

Thin keratinized epithelium covered the fungiform papillae, and some taste buds were distributed in the epithelium (Figs. 5A: TB, 5B: TB, and 5C: TB). The epithelium was 110 ±12 μm (Table 1). There were some lingual gland ducts in the lamina propria (Figs. 5A: GD and 5B: GD).

Vallate papillae

The total SD value of vallate papillae was 28. The vallate papillae were distributed on the posterolateral surface of the lingual prominence in a "V" pattern. Vallate papillae were round or oval in shape, and were surrounded by a prominent groove and a circular, raised area of tough, epithelial tissue (Figs. 6A and 6C). The papillae had a greater mean base diameter of 2.5±0.4 mm than the other 4 papillae, and the mean height was 1.5±0.5 mm (Table 1). The papillae appeared either alone or in pairs with smaller papillae (Fig. 1B), and some mucus-secreting and taste pores were observed on the surface of each papilla (Figs. 6D: Arrows, 6E: Arrow, and 6F: Star).

The taste buds were arranged in the epithelium of the vallate papillae as a monolayer (Figs. 6A: TB and 6B: TB) and serous-rich mixed lingual glands (Fig. 6A: S) and their ducts (Fig. 6A: GD) were observed in the lamina propria. The mean number of taste buds in each vallate papilla was 32±8, and the thickness of epithelium of the vallate papillae was of 440±40 μm (Table 1).

Discussion

In this study, we investigated the general anatomy and morphological structures of the cattle-yak tongue. The results show that there were five types of papillae identifiable on the tongue surface: filiform, conical, lenticular, vallate, and fungiform. In domestic animals, morphological studies on the tongue papillae have been reported for the dog (Ojima, 2001), pig (Kumar and Bate, 2004), goat (Kumar et al., 1998), sheep (Emura et al., 2000a), cow (Steflik et al., 1983), buffalo (Emura and El Bakary, 2014), horse (Pfeiffer et al., 2000), camel (Qayyum et al., 1988; Eerdunchaolu et al., 2001), yak and cattle (Shao et al., 2010). The present study showed that

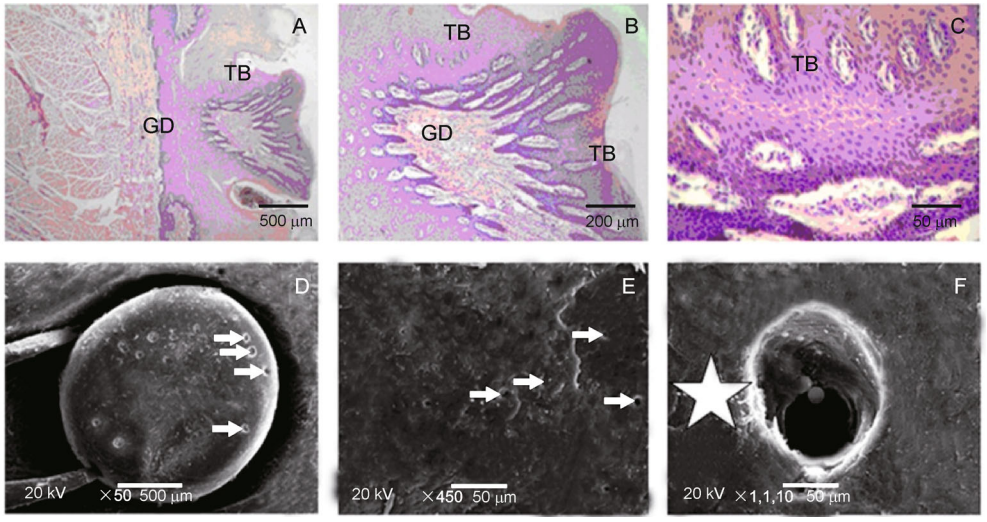

Figure 5 The fungiform papilla of the cattle-yak: (A), (B), and (C) light micrographs of a sagittal section of the base of the filiform papillae occurring on the anterior part of the tongue. The taste buds were observed on the dorsal surface of the epithelium (TB), and the lingual gland ducts (GD) were observed on the lamina propria; (D) SEM of the surface view of the round, fungiform papilla showing several mucus-secreting pores (Arrows), note the few, sharp filiform papillae at its periphery; (E) and (F) SEM micrographs of the external surfaces of the fungiform papillae, the flat scale-like peeling of the epithelium is a characteristic feature of the taste pore (star) and mucus-secreting pores (Arrows).

in the cattle-yak hybrid, the morphology of papillae was similar to that of the yak and cattle; however, the lingual prominence was higher and more developed than that in the yak (Shao et al., 2010). Within each mammalian clade, the morphology of lingual papillae has unique characteristics, reflecting the evolutionary taxonomic position and dietary niche of the animal (Yoshimura et al., 2008). Adaptation to environmental pressure and available diet may also affect the morphology of the lingual mucosa (Yoshimura et al., 2008).

In the cattle-yak, most of the filiform papillae were distributed on the dorsal surface of the anterior tongue, and filiform papillae gradually increased in size from the lingual body to the apex. Filiform papillae consist of a larger main papilla with smaller secondary papillae. The filiform papillae in some domestic and wild ruminants are similar in shape and structure to that of the cattle-yak (Kobayashi, 1990; Emura et al., 2004; Shao et al., 2010; Kocak et al., 2011), except for variations in size and number per unit area of both the main and secondary papillae. In the cattle-yak, there were 5–10 secondary papillae that originated from the basal portion of the main filiform papilla, compared with 5–8 in the yak (Shao et al., 2010), 2 in the goitered gazelle (Kocak et al., 2011), 6–8 in the goat (Kumar et al., 1998), 2–4 in the Bactrian camel (Eerdunchaolu et al., 2001) and 1 in the one-humped camel (Qayyum et al., 1988). In the present study, on the basis of the shape and structure, we conclude that the filiform papillae exhibited purely mechanical functions of grasping food and grooming in the cattle-yak. Furthermore, on the basis of their distribution, we conclude that the filiform papillae may also protect the fungiform papillae, and perform mechanical cleaning of the inter-dental spaces of the lower jaw in the cattle-yak, similar to cattle and the yak (Shao et al., 2010).

In the cattle-yak, the conical papillae are distributed on the dorsal surface of the lingual prominence, and they are longer, flattened, and directed posteriorly, whereas in some species of carnivores, the conical papillae have a smooth surface and are not very prominent (Iwasaki et al., 1987a). The morphology and position of conical papillae in the cattle-yak are similar to those described for various other herbivores (Steflik et al., 1983; Qayyum et al., 1988; Kumar et al., 1998; Emura et al., 2000b; Pfeiffer et al., 2000; Eerdunchaolu et al., 2001; Kumar and Bate, 2004; Kobayashi et al., 2005; Shao et al., 2010). In the cattle-yak, the conical papillae possess mucus-secreting pores and lingual gland ducts, the upper part of the papillae are covered with keratinized epithelium, and the mucus-secreting pores and microfolds distributed on the papillary surfaces resemble those of some carnivores (Iwasaki et al., 1987b; Emura et al., 2000c), as well as cattle and the yak (Shao et al., 2010). However, the keratinized epithelium of the conical papillae of the cattle-yak was thicker than that of the yak, and the papillae were larger, indicating an enhanced mechanical function for the cattle-yak conical papillae compared with those in the yak (Shao et al., 2010). In the cattle-yak, the conical papillae possessed some lymph nodules, indicating that the conical papillae may have immune functions, and resemble the conical papillae of the pig (Kumar and Bate, 2004). To date, the lymph nodule characteristics have not been studied in other herbivores, which may be one of the most important features contributing to the vigor of the hybrid cattle-yak.

In the cattle-yak, the lenticular papillae were distributed on the dorsal surface of the lingual prominence. The papillae were slightly convex and had an obvious encircling groove separated by the conical papillae. Many small mucus-

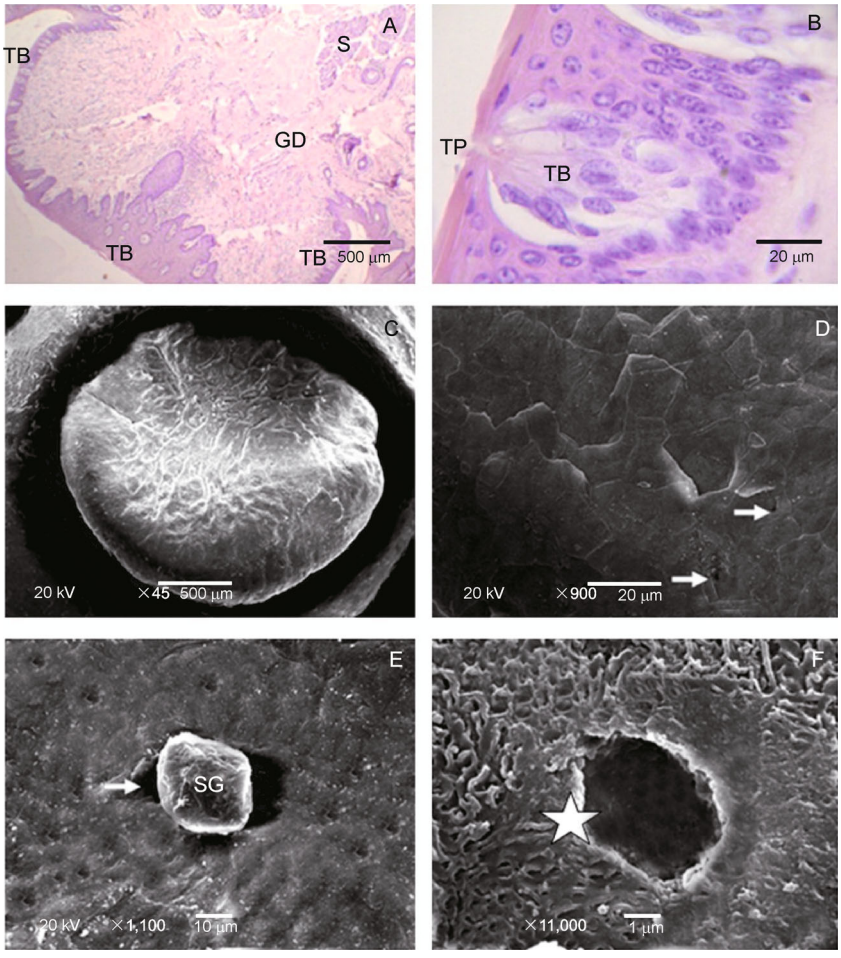

Figure 6 The vallate papilla of the cattle-yak: (A) and (B) light micrographs of a sagittal section of the vallate papillae. The taste buds (TB) were found on the dorsal surface of the epithelium, serous-rich, mixed lingual glands (S) and the lingual gland ducts (GD) were observed on the lamina propria; (C) SEM of the vallate papilla showing vallum, moat on its surface; (D) SEM magnified micrograph of the external surface of the papilla (Arrows: mucus-secreting pores); (E) SEM showing the opening of the secretory duct of the vallate papilla (Arrow: mucus-secreting pore) and secretory granules (SG); (F) SEM showing the honeycomb-like, inner surface and taste pore (star) on the surface of the body of a vallate papilla.

secreting pores (Fig. 4C: Arrow) were detected on each papilla, but the taste pore was not found in the cattle-yak, or the yak. However, in cattle, some taste pores were observed to be multilayered within the lateral epithelium (Shao et al., 2010). The papillary dorsal surface in the cattle-yak and the yak was convex and covered by a thin, keratinized epithelium, but this was not the case for cattle (Shao et al., 2010).

In the cattle-yak, the fungiform papillae were embedded among the filiform papillae, which provide protection to the cattle-yak. In the cattle-yak, these papillae were only dome-shaped, which is similar to cattle, but not to the yak that has two shapes (bud and dome) (Shao et al., 2010). In the fungiform papillae of the cattle-yak, there are many taste buds and taste pores in the epithelium, and the surface of the papillae is covered with keratinized epithelium, indicating that they possess both mechanical and gustatory functions. The cattle-yak has more mucus-secreting pores on the surface of each papilla than the yak ($P < 0.05$) (Shao et al., 2010), which suggests that the cattle-yak tongue may have a more developed sublingual gland than the yak.

In the cattle-yak, there were approximately 28 vallate papillae on the posterolateral surface, which were arranged in a "V" pattern. The number of vallate papillae differed from that in other mammals; 22–28 in the yak (Shao et al., 2010), 22–32 in cattle (Shao et al., 2010), 26 in the goitered gazelle (Kocak et al., 2011), 9–12 in the one-humped camel (Qayyum et al., 1988), 23 in the Formosan serow (Atoji et al., 1998), 11–14 in the chital deer (Serkan and William, 2014), and so on. In addition, the taste buds were arranged in the epithelium as a monolayer in the cattle-yak and the yak, but were multilayered in cattle (Shao et al., 2010), resulting in fewer taste buds in each vallate papilla in the cattle-yak and the yak than in cattle. Compared with cattle, the vallate papillary epithelium of the cattle-yak was thicker and the surface was covered with a thin keratinized epithelium, suggesting that the

vallate papillae of the cattle-yak may function as a grinding organ against the palate.

Summary

In conclusion, the tongue of the cattle-yak showed unique morphological characteristics; the lingual prominence was more developed, the mechanical papillae were more numerous and covered by thicker keratinized epithelium. The conical papillae may have immune functions, the fungiform papillae have more mucus-secreting pores, and the sublingual glands were more developed. The cattle-yak is a hybrid, and exhibits obvious hybrid vigor. They outperform the yak in their capacity to produce milk and meat, and the potential for military service when compared in the same foraging highlands of the Qinghai-Tibetan Plateau environment. This may be due to the morphological adaptations of the cattle-yak tongue to the foraging environment of the Qinghai-Tibetan Plateau. Further investigations regarding this hybrid species are needed.

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Compliance with ethics guidelines

Yanping Ding, Shiyuan Yu and Baoping Shao declare that they have no conflict of interest. All institutional and national guidelines for the care and use of laboratory animals were followed.

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