

Grasshopper Mandibles Functional Morphology Adaptation to Food Plants (Orthoptera: Caelifera) from the Subtropical Forest Ecosystem, Central Taiwan

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Abstract

This article examined 20 species of grasshoppers, belonging to six families, in Guadaushi forest ecosystem by studying the food plants and the morphology of their mandible, among which, three species are still under further identification. Based on SEM observations, the mandibles of them could be grouped into three types corresponding to their food plant: type 1 forb-feeding, the mandible with incisor surface consists of sharp dents, and the molar area is a deep, central concavity surrounded by short ridges; type 2 grass-feeding, the incisor surface is somewhat smooth without dents, and the molar surface has long parallel grinding ridges without central concavity; type 3 obligate-feeding, the incisor is blunt, and the molar consists of ridges with a central concavity shorter than type 1. Among the 20 species of grasshoppers in Guadaushi forest ecosystem, the ones belonging to type 1 are *Traulia ornata ornata* Shiraki, 1910, *Xenocatantops humilis* (Seville, 1839) and *Coptacra* sp. 3 of Catantopidae; *Atractomorpha sinensis* I. Bolivar, 1905 of Pygomorphidae and *Erianthella formosana* (Shiraki, 1910) of Eumastacidae. The species belonging to type 2 are *Oxya podisma* Karny, 1915, *Oxyrrhepes obtuse* (De Haan, 1842) of Catantopidae; *Phlaeoba albonema* Zheng, 1981, *Phlaeoba formosana* Shiraki, 1910, and *Phlaeoba sinensis* I. Bol., 1914 of Acridae; *Formosacris koshunensis* (Shiraki, 1910) and *Dnopherula svenhedini* (Sjöstedt, 1933) of Arcypteridae and *Pternoscirta sauteri* (Karny, 1915), *Heteropternis respondens* (Walker, 1859) and *Trilophidia annulata* (Thunberg, 1815) of Oeipodidae. Type 3 grasshoppers are *Stenocatantops splendens* (Thunb., 1815), *Parapodisma* sp. 1, *Parapodisma* sp. 2, *Sinopodisma kodamae* (Shiraki, 1910), and *Sinopodisma formosana* (Shiraki, 1910) of Catantopidae.

Keywords

Grasshopper, Functional Morphology, Feeding Adaptation, Mandible Types

1. Introduction

In general, grasshoppers are phytophagous and are particular in host plant specific selection. The range of host plants specificity depends on the species [1] and variously on higher categories like as generic level limited. For the specific host plant range of grasshoppers, Chapman [2] classified three categories based on the plant categories. According to Chapman [2], the polyphagous have the host plant range covering with certain preferences species, or several plant families. On the other hand, oligophagous grasshopper has the host plant range only within one single plant family. In the third category is the monophagous, which only feed on the same plant genus as their host plants. Gangwere [3] provided another classification for grasshoppers according to the systematic account of the host plants. The first one is for bivory group that feeds on broad leaves herbs; the second one is graminivory group which feed on Gramineacea grasses; and the last one is mixed herbivory group feeding on both forbs and herbs. It was also identified by Gangwere [4] that the mandibles of grasshoppers vary in different groups. This various morphology is therefore believed to be meeting the different feeding habits of different groups of grasshoppers. Three patterns of mandibles were conducted in correspondence to the feeding groups.

Mandible of the forbivory group possesses protruding teeth in the incisor area and longitudinal grooves in the molar area. It is suitable for feeding on broad leafplants. As to the graminivory group, their mandibles consist of smoothly incisor area and many longitudinal ridges in molar area. It is fitting for the long fibers in herbs. Accordingly, the herbivory group with herbivorous mandibles serves to feed on both forbs and graminis. However, these characters could only be applied to a limited level, and are not clear cut enough, for example, in the median pattern of herbivorous mandibles of grasshoppers. That is the reason why authors study for and in much detail of the functional morphology. The materials collected from the forest ecosystem in central Taiwan are therefore attempts to apply this categorization and further clarify the distinguished characters among different types of mandibles. Bernays [5] reported that the herbivory grasshoppers have the head weight-body weight ratio higher than the forbivory ones, because larger heads possessing larger mandibles and therefore larger musculatures.

While Gangwere *et al.* [6] used the grasshoppers collected from a Spanish island to analyze the feeding habits of grasshoppers, Kang *et al.* [7] also published a case from Inner Mongolia.

This study used the grasshoppers collected from one of the LTER sites in Taiwan. It was the investigation for the long term ecological monitoring for the forest ecosystem. Meanwhile, the food plant of grasshoppers is also studied. The food preference and host plant or food plant must be made sure in some ways and will be publish in the other article in near future.

Isely [8] studied 89 species of grasshopper from Texas, America, among which, 34 species are herbivory, 37 species are forbivory and 18 species mixed type. Gangwere [4] agreed with Isely [8] and pointed out that although both maxillae and labrum are also modified in accordance to feeding habits of grasshoppers, the mandible is no doubt the most significant character.

2. Materials and Methods

The grasshopper community in the Heisun forest experimental station of National Chung Hsing University, Taiwan. The subtropical rain forest was one of the 5 Long Term Ecological Research (LTER) sites in Taiwan. After earthquake 921 in 1999 the research almost stops in this site. This survey finished at that time and not able to do it much more. However, the morphological adaptation of the grasshopper mandibles is worth to publish for further study interesting. the grasshopper collected by insect swept net (40 cm diameter and 60 cm depth) directly from the upper layer of the vegetation. Some insect collected directly by hands off.

The collected grasshoppers are preserved in 70% ethanol for application. The mandible detached from the mouth part cleaned by using ultrasonic shaker because the mandibles of grasshoppers are hard and sclerotized. Specimens were dehydrated in 80%, 90%, 95% ethanol. The mandible is attached on the stub staged by double sticky adhesive right after the material is dried up after 95% ethanol evaporation. The entire specimen was observed using the SEM. Details regarding the SEM method can be found in Yang *et al.* [9] with slight modifications.

3. Results

Morphology of mandibles photographed by SEM and described as followed. The following describes the feeding types of grasshoppers collected from an experimental forest in central Taiwan.

Erianthella formosana (Shiraki, 1910)

Lateral mandible (Figure 1-1) with 4 distinct incisory teeth; incisory teeth with intercalary ridge strongly prominent; intercalary teeth acute at apex obliquely; molar area typically irregularly.

Right mandible (Figure 1-2) molar area with deeply longitudinal groove, almost cross over molar area about 91%; molar area with 5 short transverse ridges, 1st ridge 0.78 as long as width of molar area, 5th ridge 0.87 long as width of molar area; molar 1.28 times longer than wide, about 1.35 times longer than length of incisory area.

Phlaeoba formosana (Shiraki, 1910)

Left mandible (Figure 2-1) with 4 indistinct incisory teeth; mosaic surface smooth,

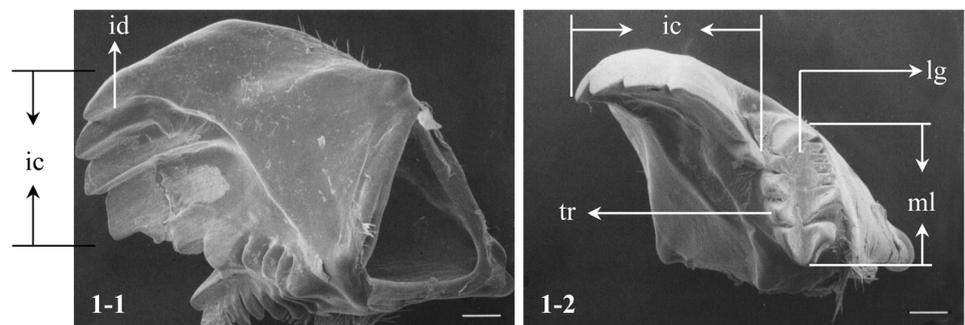


Figure 1. *Erianthella formosana* (Shiraki, 1910), adult mandible (type I), 1-1: left mandible posterior view; 1-2: right mandible lateral view (scale bar = 250 μ m). a: articulation; am: abductor muscle; tr: transverse ridge; lg: longitudinal groove; ic: incisor area; ict: incisor teeth; id: intercalary edge; it: intercalary teeth; ml: molar area.

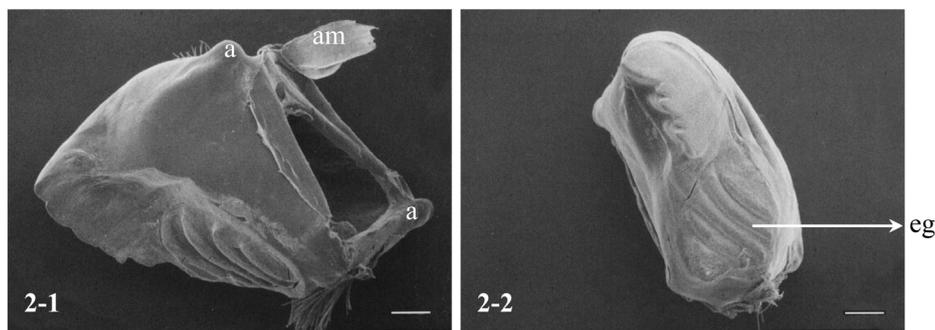


Figure 2. *Phlaeoba formosana* (Shiraki, 1910), adult mandible (type II), 2-1: left mandible posterior view; 2-2: right mandible lateral view (scale bar = 250 μm). a: articulation; am: abductor muscle; tr: transverse ridge; lg: longitudinal groove; ic: incisor area; ict: incisor teeth; id: intercalary edge; it: intercalary teeth; ml: molar area.

incisory teeth without intercalary ridge strongly prominent; intercalary teeth roundly arched at apex; molar area smooth.

Right mandible (**Figure 2-2**) molar area without longitudinal groove; molar area with 5 long ridges, not interrupted by longitudinal groove, 1st ridge 0.61 times as long as width of molar area, 5th ridge 0.56 times as long as width of molar area; molar 1.06 times longer than wide, about 1.23 times longer than length of incisory area.

***Sinopodisma formosana* (Shiraki, 1910)**

Left mandible (**Figure 3-1**) with 4 distinct incisory teeth, digital like, round at apex; mosaic surface with intercalary ridge complete, strongly prominent; intercalary teeth truncate at apex; molar area irregular typically.

Right mandible (**Figure 3-2**) molar area with longitudinal groove, short about 0.45 times of length of molar area, groove not cross over molar area, shallow in depth; molar area with 5 long ridges, only 4th and 5th ones interrupted by longitudinal groove, 1st ridge 0.65 times as long as width of molar area, 5th ridge 0.65 times as long as width of molar area; molar 1.43 times longer than wide, about 1.23 times longer than length of incisory area.

***Xenocatantops humilis* (Seville, 1839)**

Left mandible (**Figure 4-1**) with 4 indistinct incisory teeth, long plate like, truncate at apex; mosaic surface with intercalary ridge complete, strongly prominent; intercalary teeth truncate at apex; molar area irregular typically.

Right mandible (**Figure 4-2**) molar area with longitudinal groove deeply, short about 0.84 times of length of molar area; molar area with 5 short ridges, longitudinal groove formed shallow concaved area, 1st ridge 0.84 times as long as width of molar area, 5th ridge 0.63 times as long as width of molar area; molar 0.51 times longer than wide, about 0.93 times longer than length of incisory area.

***Atractomorpha sinensis* (I. Bolivar, 1905)**

Left mandible (**Figure 5-1**) with 4 distinct incisory teeth, digital like; mosaic surface with intercalary ridge complete, strongly prominent; intercalary teeth truncate at apex; molar area irregular typically.

Right mandible (**Figure 5-2**) molar area with longitudinal groove deeply, almost cross over molar area, about 0.89 times of length of molar area; molar area with 5 short

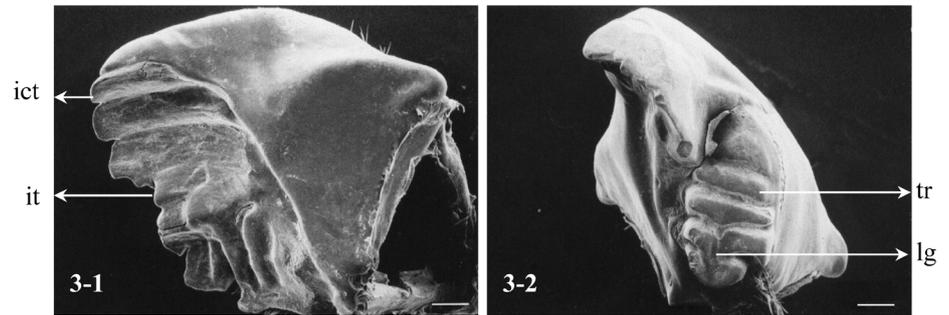


Figure 3. *Sinopodisma formosana* (Shiraki, 1910) adult mandible (type III), 3-1: left mandible posterior view; 3 - 2: right mandible lateral view (scale bar = 250 μ m). a: articulation; am: abductor muscle; tr: transverse ridge; lg: longitudinal groove; ic: incisor area; ict: incisor teeth; id: intercalary edge; it: intercalary teeth; ml: molar area.

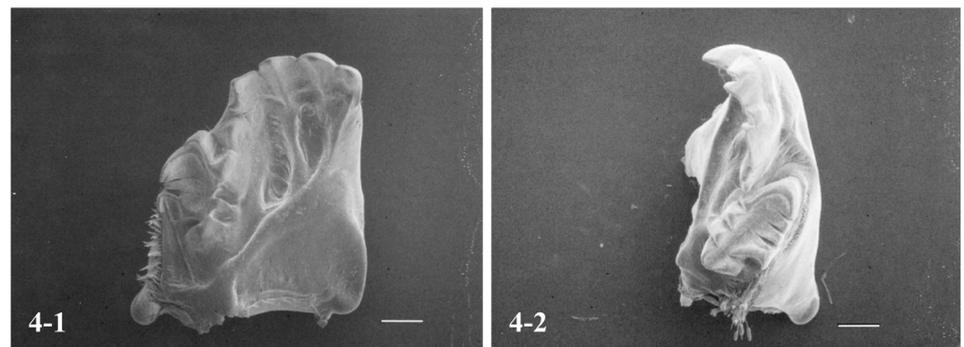


Figure 4. *Xenocatantops humilis* (Seville, 1839) adult mandible, 4-1: left mandible posterior view; 4-2: right mandible lateral view (scale bar = 333 μ m).

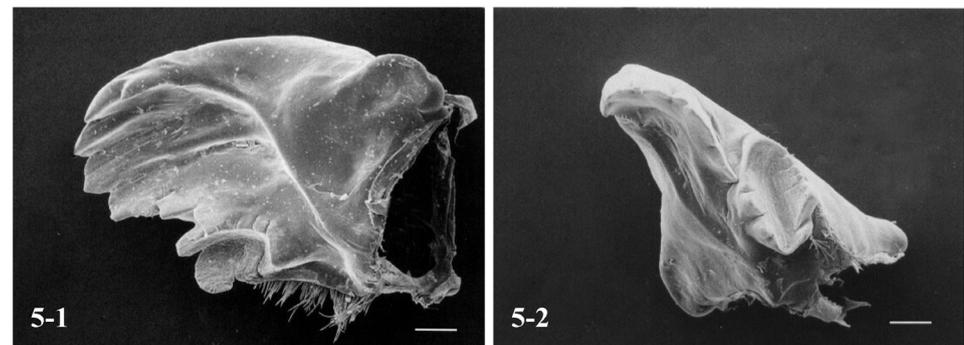


Figure 5. *Atractomorpha sinensis* I. Bolivar, 1905 adult mandible, 5-1: left mandible posterior view, 5-2: right mandible lateral view (scale bar = 200 μ m).

ridges, longitudinal groove formed shallow concaved area, 1st ridge 0.67 times as long as width of molar area, 5th ridge 0.57 times as long as width of molar area; molar 1.96 times longer than wide, about 1.08 times longer than length of incisory area.

***Coptacra* sp. 3**

Left mandible (**Figure 6-1**) similar to *Atractomorpha sinensis* with 4 distinct incisory teeth, digital like; mosaic surface with intercalary ridge complete, strongly prominent; intercalary teeth truncate at apex; molar area with cone like processes irregular typically.

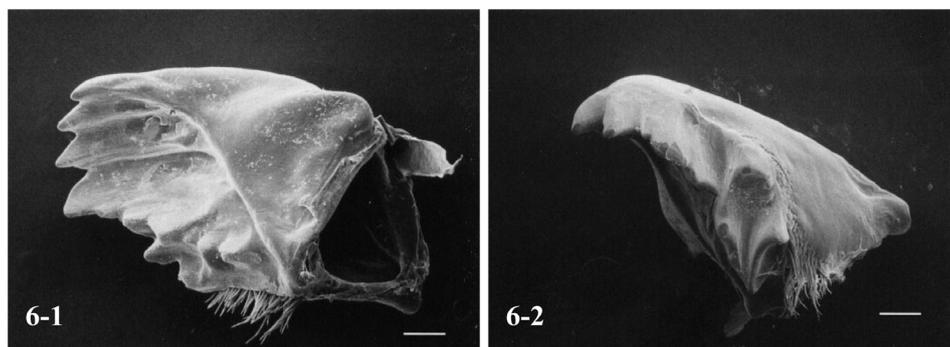


Figure 6. *Coptacra* sp. 3 adult mandible, 6-1: left mandible posterior view; 6-2: right mandible lateral view (scale bar = 200 μ m).

Right mandible (**Figure 6-2**) molar area with longitudinal groove deeply, formed shallow concaved area about 0.80 times of length of molar area; molar area without recognizable ridge; molar 2 times longer than wide, about 1.05 times longer than length of incisory area.

***Traulia ornata ornata* (Shiraki, 1910)**

Lateral mandible (**Figure 7-1**) is similar to *Erianthella formosanas* incisory area with 4 distinct incisory teeth; incisory teeth with intercalary ridge strongly prominent; intercalary teeth acute at apex midly; molar area typically irregular.

Right mandible (**Figure 7-2**) similar to *Sinopodisma formosana* molar area with longitudinal groove deeply, short about 0.68 times of length of molar area, groove not cross over molar area; molar area with 5 long ridges, 3rd, 4th and 5th ones interrupted by longitudinal groove, 1st ridge 0.80 times as long as width of molar area, 5th ridge 0.60 times as long as width of molar area; molar 1.85 times longer than wide, about 1.10 times longer than length of incisory area.

***Stenocatantops splendens* (Thunb., 1815)**

Left mandible (**Figure 8-1**) similar to *Atractomorpha sinensis* with 4 distinct incisory teeth, digital like, roundly acute at apex; mosaic surface with intercalary ridge complete, strongly prominent; intercalary teeth acute at apex; molar area with one cone like and two plate like processes arranged in line.

Right mandible (**Figure 8-2**) similar to *Traulia ornata ornata* molar area with longitudinal groove moderately deep, short about 0.43 times of length of molar area, groove not cross over molar area; molar area with 5 long ridges, 4th and 5th ones interrupted by longitudinal groove, 1st ridge 0.56 times as long as width of molar area, 5th ridge 0.60 times as long as width of molar area; molar 1.67 times longer than wide, about 1.12 times longer than length of incisory area.

***Sinopodisma kodamae* (Shiraki, 1910)**

Lateral mandible (**Figure 9-1**) similar to *Erianthella formosanas* incisory area with 4 distinct incisory teeth, acute at apex, medially; incisory teeth with intercalary ridge strongly prominent; intercalary teeth acute round at apex; molar area with 3 broad-plate like processes.

Right mandible (**Figure 9-2**) similar to *Stenocatantops splendens* and *Traulia ornata ornata* molar area with longitudinal groove, broad, moderately deep, short about 0.59

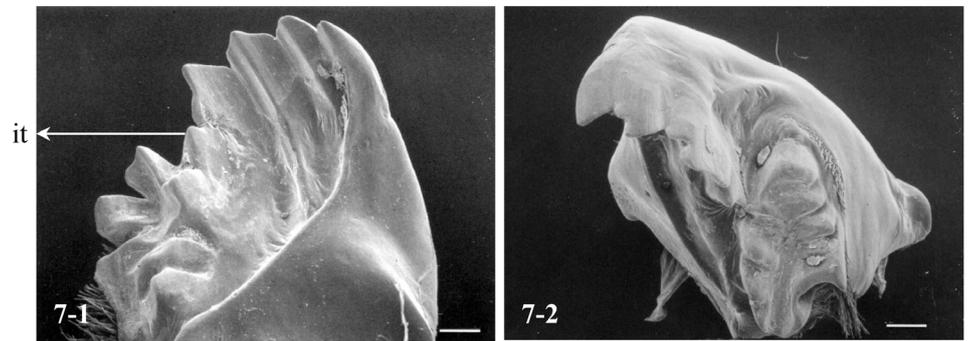


Figure 7. *Traulia ornata ornate* Shiraki, 1910 adult mandible, 7-1: left mandible, posterior view; 7-2: right mandible lateral view (scale bar = 250 μ m). it: intercalary teeth.

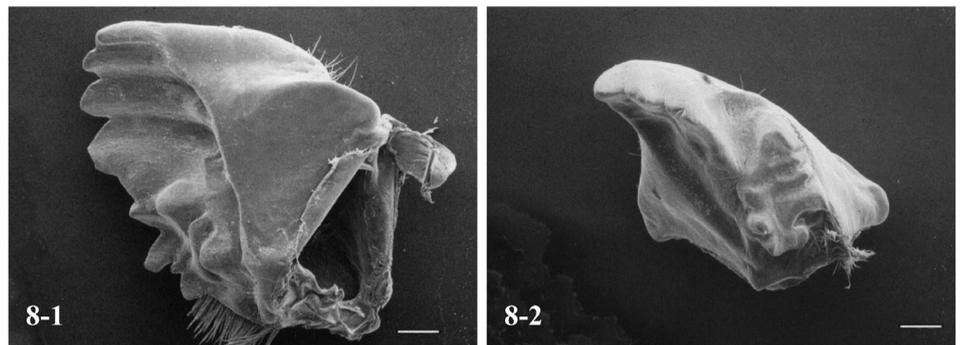


Figure 8. *Stenocatantops splendens* (Thunb., 1815) adult mandible, 8-1: left mandible posterior view; 8-2: right mandible lateral view (scale bar= 250 μ m).

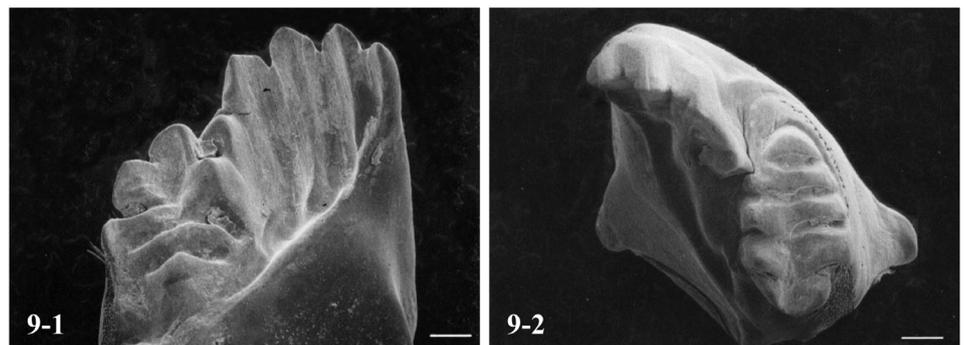


Figure 9. *Sinopodisma kodamae* (Shiraki, 1910) adult mandible, 9-1: left mandible posterior view; 9-2: right mandible lateral view (scale bar = 250 μ m).

times of length of molar area, groove not cross over molar area; molar area with 5 long ridges, 4th and 5th ones interrupted by longitudinal groove, 1st ridge 0.64 times as long as width of molar area, 5th ridge 0.64 times as long as width of molar area; molar 1.82 times longer than wide, about 1.02 times longer than length of incisory area.

***Parapodisma* sp. 1**

Lateral mandible (**Figure 10-1**) similar to *Erianthella formosanas* and *Sinopodisma kodamae* incisory area with 4 distinct incisory teeth, truncate at apex; incisory teeth with intercalary ridge strongly prominent; intercalary teeth obtusely acute at apex; molar area with 3 indistinct processes.

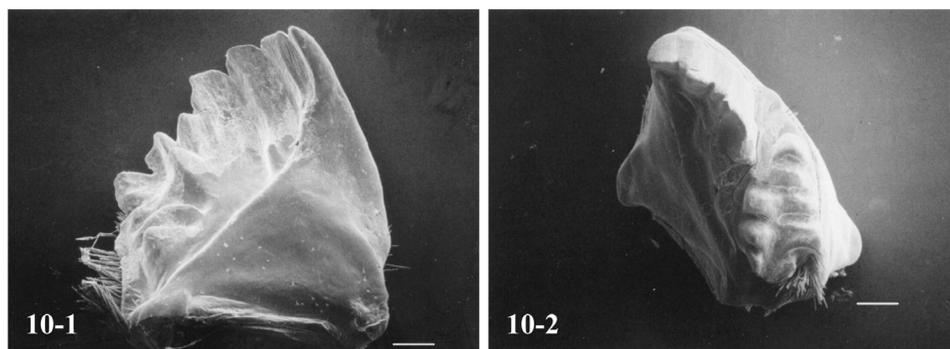


Figure 10. *Parapodisma* sp. 1adult mandible, 10-1: left mandible posterior view; 10-2: right mandible lateral view (scale bar = 250 μ m).

Right mandible (**Figure 10-2**) similar to *Stenocatantops splendens* and *Sinopodisma kodamae* molar area with longitudinal broad groove moderately deep, short about 0.57 times of length of molar area, groove not cross over molar area; molar area with 5 long ridges, 3rd, 4th and 5th ones interrupted by longitudinal groove, 1st ridge 0.63 times as long as width of molar area, 5th ridge 0.66 times as long as width of molar area; molar 2 times longer than wide, about 1.05 times longer than length of incisory area.

***Parapodisma* sp. 2**

Lateral mandible (**Figure 11-1**) similar to *Erianthella formosanas* and *Sinopodisma kodamae* incisory area with 4 distinct incisory teeth, round acute at apex; incisory teeth with intercalary ridge strongly prominent; intercalary teeth truncate at apex; molar area moderate long stripe like processes.

Right mandible (**Figure 11-2**) similar to *Stenocatantops splendens* and *Sinopodisma kodamae* molar area with longitudinal broad groove moderately deep, short about 0.57 times of length of molar area, groove not cross over molar area; molar area with 5 long ridges, 3rd, 4th and 5th ones interrupted by longitudinal groove, 1st ridge 0.59 times as long as width of molar area, 5th ridge 0.59 times as long as width of molar area; molar 1.92 times longer than wide, about long as length of incisory area.

***Oxya podisma* (Karny, 1915)**

Left mandible (**Figure 12-1**) with 4 indistinct incisory teeth, round at apex; mosaic surface smooth, incisory teeth with intercalary ridge strongly prominent; intercalary teeth almost as long as incisory teeth, truncate at apex; molar area with 4 long stripe processes.

Right mandible (**Figure 12-2**) molar area without longitudinal groove; molar area with 6 long ridges, not interrupted by longitudinal groove, 1st ridge 0.62 times as long as width of molar area, 6th ridge 0.56 times as long as width of molar area; molar 1.05 times longer than wide, about 1.35 times longer than length of incisory area.

***Oxyrrhepes obtuse* (De Haan, 1842)**

Left mandible (**Figure 13-1**) with 4 - 5 not recognizable incisory teeth, almost formed plate like; mosaic surface smooth, incisory teeth without intercalary ridge strongly prominent; intercalary teeth indistinct, as long as incisory teeth, truncate at apex; molar area with 5 long stripe like processes.

Right mandible (**Figure 13-2**) molar area sub-elliptical, without longitudinal groove; molar area with 5 long ridges, not interrupted by longitudinal groove, 1st ridge 0.48

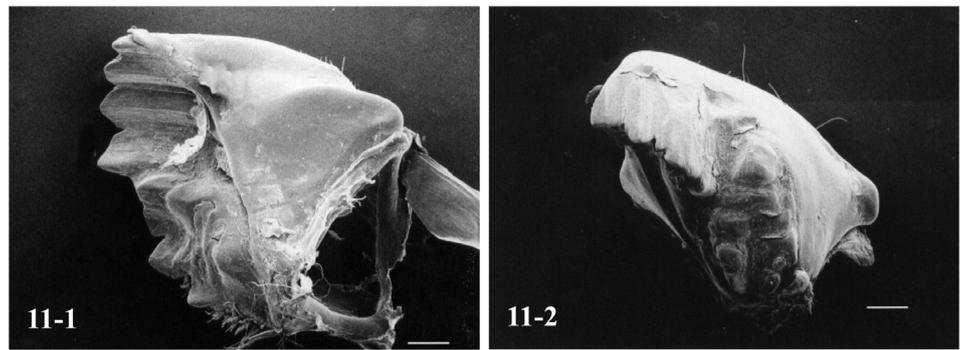


Figure 11. *Parapodisma* sp. 2 adult mandible, 11-1: left mandible posterior view; 11-2: right mandible lateral view (scale bar = 333 μ m).

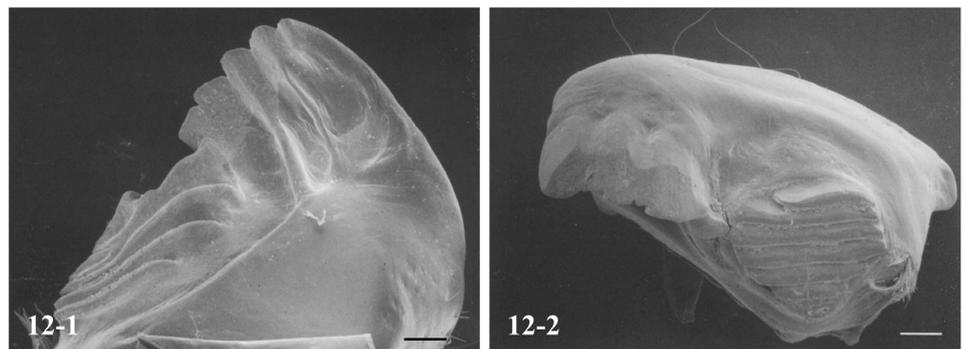


Figure 12. *Oxya podisma* (Karny, 1915) adult mandible, 12-1: left mandible posterior view; 12-2: right mandible lateral view (scale bar = 286 μ m).

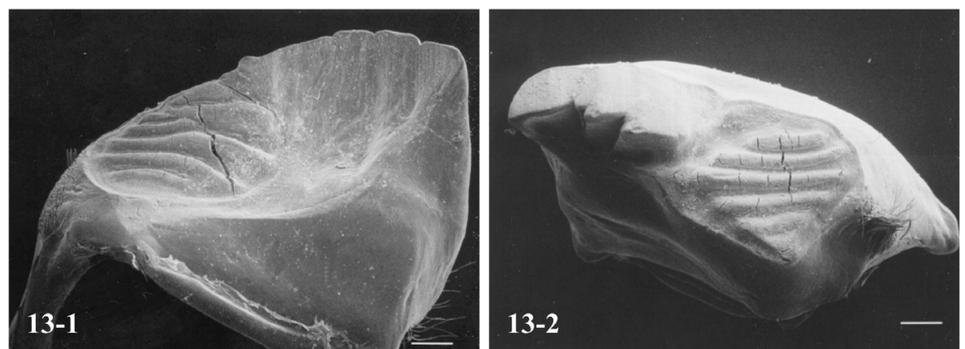


Figure 13. *Oxyrhopes obtuse* (De Haan, 1842) adult mandible, 13-1: left mandible posterior view; 13-2: right mandible lateral view (scale bar = 250 μ m).

times as long as width of molar area, 5th ridge 0.40 times as long as width of molar area; molar 1.06 times longer than wide, about 1.32 times longer than length of incisory area.

***Phlaeoba sinensis* (I. Bol., 1914)**

Left mandible (**Figure 14-1**) with 4 incisory teeth not recognizable, almost formed plate like; mosaic surface smooth, incisory teeth without intercalary ridge; intercalary teeth indistinct, slightly shorter than incisory teeth, truncate at apex; molar area with 4 long stripe like processes.

Right mandible (**Figure 14-2**) molar area subquadrate, without longitudinal groove; molar area with 5 long ridges, not interrupted by longitudinal groove, 1st ridge 0.66

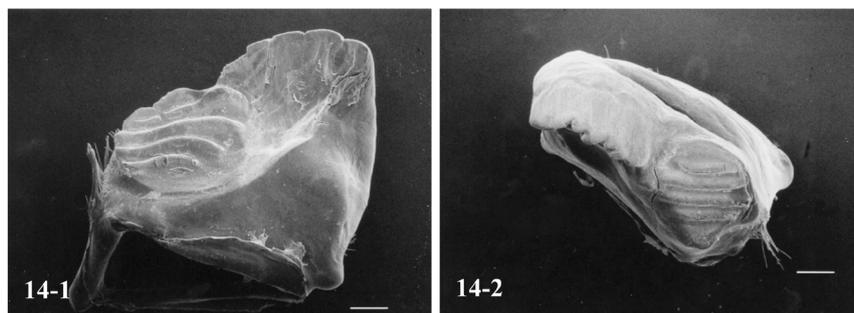


Figure 14. *Phlaeoba sinensis* (I. Bol., 1914) adult mandible, 14-1: left mandible posterior view; 14-2: right mandible lateral view (scale bar = 250 μ m).

times as long as width of molar area, 5th ridge 0.41 times as long as width of molar area; molar 1.10 times longer than wide, about 1.37 times longer than length of incisory area.

***Phlaeoba albonema* (Zheng, 1981)**

Left mandible (**Figure 15-1**) with 4 incisory teeth not recognizable, almost formed plate like; mosaic surface smooth, incisory teeth truncate at apex, without intercalary ridge; intercalary teeth indistinct, slightly shorter than incisory teeth, truncate at apex; molar area with 5 long stripe like processes.

Right mandible (**Figure 15-2**) molar area subquadrate, without longitudinal groove; molar area with 5 long ridges, not interrupted by longitudinal groove, 1st ridge 0.77 times as long as width of molar area, 5th ridge 0.52 times as long as width of molar area; molar 1.10 times longer than wide, about 1.45 times longer than length of incisory area.

***Heteropternis respondens* (Walker, 1859)**

Left mandible (**Figure 16-1**) with 4 incisory teeth not recognizable, almost fused and formed plate like; mosaic surface smooth, incisory teeth without intercalary ridge; intercalary teeth indistinct, slightly shorter than incisory teeth, truncate at apex; molar area with 3 layers prominent arranged in concentric triangle.

Right mandible (**Figure 16-2**) molar area oblong, without longitudinal groove; molar area with 5 long ridges, not interrupted by longitudinal groove, 1st ridge 0.73 times as long as width of molar area, 5th ridge 0.33 times as long as width of molar area; molar 1.03 times longer than wide, about 1.19 times longer than length of incisory area.

***Pternoscirta sauteri* (Karny, 1915)**

Left mandible (**Figure 17-1**) with 4 incisory teeth not recognizable, almost formed plate like; mosaic surface smooth, incisory teeth truncate at apex, without intercalary ridge; intercalary teeth indistinct, shorter than incisory teeth, round acute at apex; molar area with 4 long stripe like processes, first one incomplete.

Right mandible (**Figure 17-2**) molar area oblong, without longitudinal groove; molar area with 5 long ridges, not interrupted by longitudinal groove, 1st ridge 0.79 times as long as width of molar area, 5th ridge 0.32 times as long as width of molar area; molar 1.16 times longer than wide, about 1.21 times longer than length of incisory area.

***Trilophidia annulata* (Thunberg, 1815)**

Left mandible (**Figure 18-1**) with 4 incisory teeth not recognizable, almost formed plate like; mosaic surface smooth, incisory teeth truncate at apex, without intercalary ridge; intercalary teeth indistinct, shorter than incisory teeth, round at apex; molar area with 3 long stripe like processes.

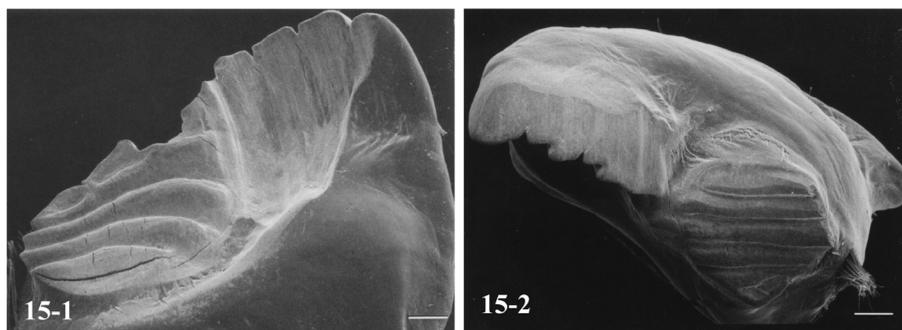


Figure 15. *Phlaeoba albonema* (Zheng, 1981) adult mandible, 15-1: left mandible posterior view; 15-2: right mandible lateral view (scale bar = 250 μ m).

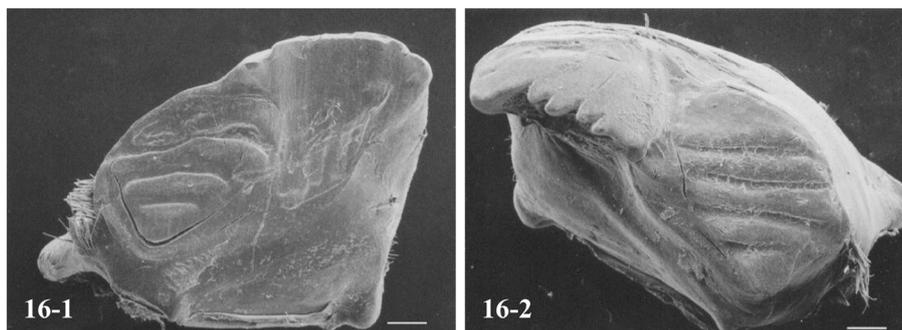


Figure 16. *Heteropternis respondens* (Walker, 1859) adult mandible, 16-1: left mandible posterior view; 16-2: right mandible lateral view (scale bar = 250 μ m).

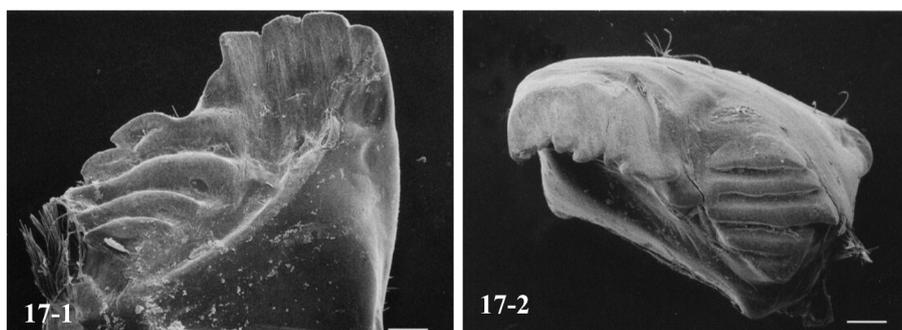


Figure 17. *Pternoscirta sauteri* (Karny, 1915) adult mandible, 17-1: left mandible posterior view; 17-2: right mandible lateral view (scale bar = 200 μ m).

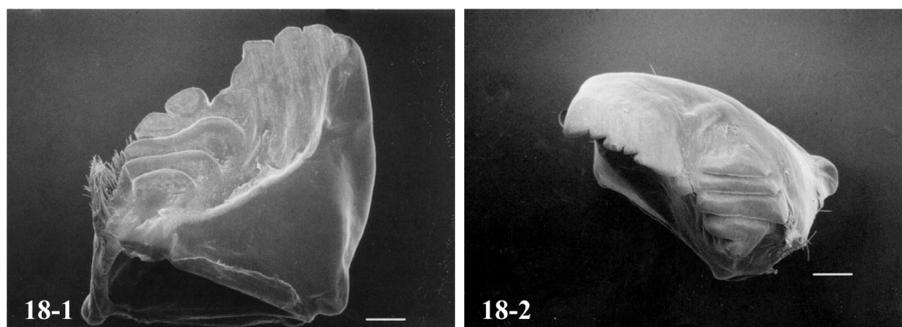


Figure 18. *Trilophidia annulata* (Thunberg, 1815) adult mandible, 18-1: left mandible posterior view; 18-2: right mandible lateral view (scale bar = 250 μ m).

Right mandible (**Figure 18-2**) molar area oblong, without longitudinal groove; molar area with 5 long ridges, not interrupted by longitudinal groove, 1st ridge 0.70 times as long as width of molar area, 5th ridge 0.37 times as long as width of molar area; molar 1.19 times longer than wide, about 1.19 times longer than length of incisory area.

***Dnopherula svenhedini* (Sjöstedt, 1933)**

Left mandible (**Figure 19-1**) with 4 incisory teeth not recognizable, almost fused and formed plate like; mosaic surface smooth, incisory teeth without intercalary ridge; intercalary teeth indistinct; molar area with 2 long stripe like processes.

Right mandible (**Figure 19-2**) molar area transverse long, without longitudinal groove; molar area with 5 long ridges, not interrupted by longitudinal groove, 1st ridge 0.52 times as long as width of molar area, 5th ridge 0.36 times as long as width of molar area; molar 1.24 times longer than wide, about 1.30 times longer than length of incisory area.

***Formosacris koshunensis* (Shiraki, 1910)**

Left mandible (**Figure 20-1**) with incisory teeth not recognizable, almost fused and formed plate like; mosaic surface smooth, incisory teeth truncate at apex, without intercalary ridge; intercalary teeth indistinct; molar area with 4 long stripe like processes.

Right mandible (**Figure 20-2**) with molar area oblong, without longitudinal groove; molar area with 5 long ridges, not interrupted by longitudinal groove, 1st ridge 0.59 times as long as width of molar area, 5th ridge 0.41 times as long as width of molar area; molar 1.05 times longer than wide, about 1.08 times longer than length of incisory area.

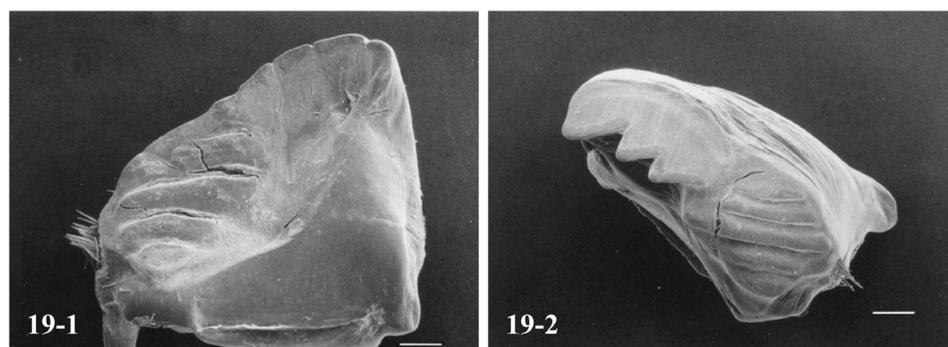


Figure 19. *Dnopherula svenhedini* (Sjöstedt, 1933) adult mandible, 19-1: left mandible posterior view; 19-2: right mandible lateral view (scale bar = 250 μ m).

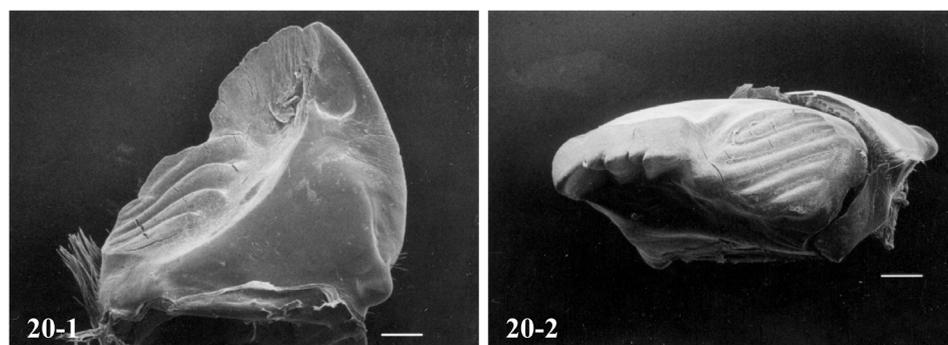


Figure 20. *Formosacris koshunensis* (Shiraki, 1910) adult mandible, 20-1: left mandible posterior view; 20-2: right mandible lateral view (scale bar = 250 μ m).

4. Discussion

Three types of Mandibles of Grasshoppers to Food adaptation: based on the right mandible of totally 20 species of grasshoppers, there are three types of food adaptation that were identified.

Type 1: **Figure 12-1** and **Figure 12-2** incisory teeth digitate, distinct; molar area of right mandible with transverse ridge short and longitudinal groove present; longitudinal groove more than 68% width of molar area, right mandible with molar area longer than wide about 1.3 - 2 times. This type much more matched the description of previous works [4] [8] which they defined as forbivory mandibles. The longitudinal groove is significant for feeding on the leaves, flowers, and buds of broad leaves plant, the forbs accordingly.

Type2: **Figure 13-1** and **Figure 13-2**, incisory teeth indistinct, margin smoothly. Molar area without longitudinal groove, instate, comprise of many long ridges. Right mandible with molar area is broad and flat, wider than long about 0.8 - 1.3 times. This type is close to the definition of [8] and [4] as the graminivorous mandibles, that are good for feeding on herbs.

Type 3: **Figure 14-1** and **Figure 14-2**, incisory area with intercalary teeth distinct; molar area of right mandible with short longitudinal groove, as long as molar area about 0.4 - 0.6 times. Right mandible with molar area is longer than wide about 1.4 - 2 times.

The grasshoppers belong to each of three types are list up in **Table 1**. The grasshop

Table 1. The species numbers and taxa of grasshoppers possessed different mandibular types in Guandaushi forest ecosystem, central Taiwan.

| Mandible type | Grasshopper species | Species No. |
|--|---------------------------------|-------------|
| Type1 Forbivory feeding | Catantopidae | 5 |
| | <i>Traulia ornata ornata</i> | |
| | <i>Xenocatantops humilis</i> | |
| | <i>Coptacra</i> sp. 3 | |
| | Pyrgomorphidae | |
| | <i>Atractomorpha sinensis</i> | |
| Type 2 Graminivory feeding | Eumastacidae | 10 |
| | <i>Erianthella formosana</i> | |
| | Catantopidae | |
| | <i>Oxya podisma</i> | |
| | <i>Oxyrrhepes obtusa</i> | |
| | Acrididae | |
| | <i>Phlaeoba albonema</i> | |
| | <i>Phlaeoba formosana</i> | |
| | <i>Phlaeoba sinensis</i> | |
| | Arcypteridae | |
| <i>Formosacris koshunensis</i> | | |
| <i>Dnopherula svenhedini</i> | | |
| Type 3 Obligate type Herb-forb feeding | Oedipodidae | 5 |
| | <i>Pternoscirta sauteri</i> | |
| | <i>Heteropternis respondens</i> | |
| | <i>Trilophidia annulata</i> | |
| | Catantopidae | |
| | <i>Stenocatantops splendens</i> | |
| <i>Parapodisma</i> sp. 1 | | |
| <i>Parapodisma</i> sp. 2 | | |
| <i>Sinopodisma kodamae</i> | | |
| <i>Sinopodisma formosana</i> | | |

per belonging to type 1 are *Traulia ornata ornate*, *Xenocatantops humilis* and *Coptacra* sp. 3 of Catantopidae; *Atractomorpha sinensis* of Pygomorphidae and *Erianthella formosanas* of Eumastacidae. The species belonging to type 2 are *Oxya podisma*, *Oxyrhepes obtusa* of Catantopidae; *Phlaeoba albonema*, *Phlaeoba formosana* and *Phlaeoba sinensis* of Acridae; *Formosacris koshunensis* and *Dnopherula svenhedini* of Arcypteridae and *Pternoscirta sauteri*, *Heteropternis respondens* and *Trilophidia annulata* of Oeipodidae. The species belonging to type 3 are *Stenocatantops splendens*, *Parapodisma* sp. 1, *Parapodisma* sp. 2, *Sinopodisma kodamae*, and *Sinopodisma formosana* of Catantopidae. In terms of the grasshopper diversity in the forest ecosystem related to the diversity of plant species, the feeding behavior adaptation interact to the food plant types in the subtropical forest based on the morphology of mandible is reasonable and proved.

Based on SEM observations, the mandibles of them could be grouped into three types corresponding to their food plant. The three types were defined according to the morphology of longitudinal groove, the incisory teeth in addition to the central concavity of molar area [7]. Other characters were compared with previous works [4] [8].

The report of Kang *et al.* [7] emphasizes that the central concavity of mandible is the key character of herbivore grasshoppers. We found similar result that the type 1 for b-feeding, central concavity of molar area surrounded by short ridges; type 2 grass-feeding, the molar surface has long parallel grinding ridges without central concavity; type 3 obligate-feeding, the molar consists of ridges with a central concavity shorter than type 1. It is obvious to define the central concavity of molar area as the diagnostic character for the grasshopper mandible type.

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