Phytolith Production and Morphotypes in Modern Plants on the Tibetan Plateau

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The Tibetan Plateau is the “third pole” of Earth and significantly influences the world’s ecosystems. However, limited work on phytolith analysis has been done due to its harsh environment, and no study on phytolith production and morphotypes in modern plants on the Tibetan Plateau has been carried out yet. In this study, we investigated 73 modern plant samples collected on the Tibetan Plateau to study phytolith production and morphology. The results showed that the major phytolith producers are Poaceae and Cyperaceae plants, the production of phytolith is higher than 0.4 million grains/g in most samples. We found one new morphotype, BILOBATE SADDLE, which could be the diagnostic type for Tribe Stipeae and phytoliths morphotypes might indicate different hydrological conditions on the Tibetan Plateau. Our findings add new information about phytoliths on the Tibetan Plateau and will aid the future phytolith analysis in this region.

Keywords: phytolith production, phytolith morphology, Poaceae, Cyperaceae, Tibetan Plateau

INTRODUCTION

The Tibet Plateau (TP) is well known as the “Earth’s Third Pole,” with an average altitude of 4,000 m (Zheng and Yao, 2004). The TP has a unique but vulnerable ecosystem due to the anoxic and strong ultraviolet radiation environment, which is highly sensitive to climate change and human activities (Yao and Zhu, 2015). Therefore, it is crucial to understand the past environmental changes for policy-making and address future climate changes (Chen D.L. et al., 2015). The TP also played an important role in understanding the dispersal of modern humans in Asia (Bae et al., 2017). Meanwhile, the time humans appeared on the TP (Zhang et al., 2018; Chen et al., 2019) and their permanent occupation of the TP (Chen F.H. et al., 2015) are fascinating topics in archeology. However, much more details of how and when humans conquered the TP remain to be studied.

In TP, fossil pollen assemblages and charred seeds are most used as indicators for the past environment (Tang et al., 2021) and agricultural activities (Gao et al., 2020; Ren et al., 2020; Wang et al., 2020), respectively. However, less attention has been paid to phytolith analysis (Chen et al., 2008). Phytoliths are micro silica bodies originating from plant cells (Piperno, 1988), which are of high taxonomical value and have been applied in reconstructing the paleoenvironment...
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Barboni et al., 2010; Gu et al., 2012; Stromberg et al., 2013; Zhang et al., 2020; Li et al., 2021) and prehistory agricultural activities (Piperno et al., 2009; Deng et al., 2017; Wang et al., 2017; Zhang et al., 2017; Dunseth et al., 2019; Huan et al., 2022) in many regions. In contrast with pollen and charred seeds, the in situ deposition of phytoliths could provide more local information (Rovner, 1971) and phytoliths are more durable in fire pits or environments where organic matter is hard to preserve (Piperno, 2006). Previous studies implied that regional modern phytoliths references are crucial for the better interpretation of sedimental phytoliths assemblages (Fredlund and Tieszen, 1997; Prebble et al., 2002; Lu and Liu, 2005; Lu et al., 2006; Liu et al., 2018). Thus, phytolith analysis could be a promising tool for reconstructing TP’s paleoenvironment and past agricultural activities.

The primary vegetation type on the TP is alpine grassland and alpine meadow, and the dominant species are mainly from Poaceae and Fabaceae (Tsering et al., 2021), which are typical phytoliths producers and non-producers. The most cultivated crops on the TP are naked barley (Hordeum vulgare var. nudum), which is also a phytolith producer. However, no study on modern plant phytoliths has been published yet, which resulted in a lack of knowledge on diagnostic phytolith types and the relationship between phytoliths and environmental factors on the TP. Thus, the study on modern plants could provide insight into the phytolith assemblages and further aid the studies on reconstructing the regional paleoenvironment and past agricultural activities on the TP.

MATERIALS AND METHODS

The samples for this study mainly were collected on the northern high plateau of Tibet (above 4,000 m) in July and August 2018, where the vegetation type is the alpine meadow (Tsering et al., 2021). The growing season is from June to August in the northern high plateau of Tibet, when the monthly temperature and precipitation could be above 10°C and 20 mm, respectively, (Hu et al., 2022); the sampling sites in this region (Figure 1) shared the same climate. Plant samples collected in this study were fully ripened and could be found with seeds (if not eaten by animals). However, most plant samples were no higher than 20 cm due to the grazing in these regions, and inflorescences were mostly eaten by animals. Thus, the identification of plant samples was limited to genera level and sometimes to species level (if applicable). A total of 73 plant specimens were involved in this study and ultrasonically cleaned with distilled water to clean the surface of collected aerial parts; all samples were dried in a drier and then weighted before phytolith extraction.

Phytolith extraction followed the previously published wet oxidation method (Ge et al., 2020b). Additional polypodium tablet (ca. 27560 grains per tablet) is added to estimate the phytolith yield in each specimen (one tablet for one specimen). Phytolith count in each sample was above 300 grains, except for Salix bangongensis, in which we observed only one phytolith in two slides. As we knew that some taxa might not produce phytoliths, 21 plant specimens from Fabaceae, Asteraceae, Polygonaceae, and Primulaceae were identified at the family level.
level, and after phytolith extraction, they were examined to be non-phytolith producers. Thus, only 52 samples (Table 1) were applied for further analysis. The identification and imaging of phytoliths were under 400× with a Leica DM750 microscope. Phytolith nomenclature follows the ICPN 2.0 rules (Neumann et al., 2019) and a previous study (Ge et al., 2020a).

### Table 1 | Sampling information and phytolith production of studied specimens.

| Sample number | Original code | Specimen (Latin name) | Phytolith yield (grains/g) | N | E | Elevation (m) | Description | Date |
|---------------|--------------|-----------------------|---------------------------|---|---|---------------|-------------|-------|
| Plant 44      | ZW-ALGJ-2    | Elymus sp.            | 895952                    | 32°22' | 80°37' | 4770          | Open area near the main road | 2018/7/23 |
| Plant 45      | ZW-ALGJ-2    | Stipa sp.             | 5306509                   | 32°22' | 80°37' | 4770          | Open area near the main road | 2018/7/23 |
| Plant 25      | ZW-DZH-1     | Poa sp.               | 7695325                   | 32°26' | 80°2'  | 4264          | The dry lake basin of the Dingzhong Lake | 2018/7/16 |
| Plant 26      | ZW-DZH-2     | Elymus atratus        | 12371378                  | 32°26' | 80°2'  | 4264          | The dry lake basin of the Dingzhong Lake | 2018/7/16 |
| Plant 27      | ZW-DZH-4     | Elymus dahuricus      | 6021261                   | 32°26' | 80°2'  | 4296          | The dry lake basin of the Dingzhong Lake | 2018/7/16 |
| Plant 28      | ZW-DZH-6     | Elymus nutans         | 3819272                   | 32°26' | 80°2'  | 4264          | Mountain slope near the Dingzhong Lake | 2018/7/16 |
| Plant 47      | ZW-GJ-1      | Hordeum vulgaris var. nudum_straw | 1091662       | 32°23' | 81°1'  | 4509          | In the garden of the hotel, the straw | 2018/8/1 |
| Plant 48      | ZW-GJ-2      | Hordeum vulgaris var. nudum_leaf | 3924019        | 32°23' | 81°1'  | 4509          | In the garden of the hotel, the leave | 2018/8/1 |
| Plant 49      | ZW-GJ-3      | Hordeum vulgaris var. nudum _inflorescence | 1576348      | 32°23' | 81°1'  | 4509          | In the garden of the hotel, the inflorescence | 2018/8/1 |
| Plant 18      | ZW-GZ-1      | Kobresia robusta      | 1806164                   | 31°52' | 85°58' | 4851          | Near a small lake next to the main road | 2018/7/14 |
| Plant 19      | ZW-GZ-2      | Pennisetum alopecuroides | 2435948          | 31°52' | 85°58' | 4851          | Near a small lake next to the main road | 2018/7/14 |
| Plant 20      | ZW-GZ-3      | Stipa sp.             | 3837600                   | 31°52' | 85°58' | 4851          | Near a small lake next to the main road | 2018/7/14 |
| Plant 21      | ZW-GZ-4      | Elymus atratus        | 8029147                   | 31°52' | 85°58' | 4851          | Near a small lake next to the main road | 2018/7/14 |
| Plant 7       | ZW-LJHB-2    | Stipa sp.             | 2985667                   | 31°31' | 89°6'  | 4733          | Next to the southern lakeside of the Siling Co | 2018/7/10 |
| Plant 8       | ZW-LJHB-2    | Stipa sp.             | 8316351                   | 31°31' | 89°6'  | 4733          | Next to the southern lakeside of the Siling Co | 2018/7/10 |
| Plant 9       | ZW-LJHB-3    | Scirpus pumilus       | 2581179                   | 31°31' | 89°6'  | 4733          | Next to the southern lakeside of the Siling Co | 2018/7/10 |
| Plant 10      | ZW-LJHB-5    | Carex moorcroftii     | 1487365                   | 31°31' | 89°6'  | 4733          | Next to the southern lakeside of the Siling Co | 2018/7/10 |
| Plant 11      | ZW-LJHB-6    | Carex setosa          | 1862162                   | 31°31' | 89°6'  | 4733          | Next to the southern lakeside of the Siling Co | 2018/7/10 |
| Plant 1       | ZW-LJSP-1    | Carex moorcroftii     | 2203286                   | 31°30' | 89°12' | 4800          | On a terrace to the south of the Siling Co, with a brook nearby, far from the lakeside | 2018/7/9 |
| Plant 2       | ZW-LJSP-2    | Stipa sp.             | 5477550                   | 31°30' | 89°12' | 4800          | On a terrace to the south of the Siling Co, with a brook nearby, far from the lakeside | 2018/7/9 |
| Plant 3       | ZW-LJSP-3    | Stipa sp.             | 3014375                   | 31°30' | 89°12' | 4800          | On a terrace to the south of the Siling Co, with a brook nearby, far from the lakeside | 2018/7/9 |
| Plant 4       | ZW-LJTO1-1   | Kobresia littledalei | 6568467                   | 31°30' | 89°12' | 4796          | On a terrace to the south of the Siling Co, with a brook nearby, far from the lakeside | 2018/7/9 |
| Plant 5       | ZW-LJTO1-2   | Stipa sp.             | 22542667                  | 31°30' | 89°12' | 4796          | On a terrace to the south of the Siling Co, with a brook nearby, far from the lakeside | 2018/7/9 |

(Continued)
| Sample number | Original code | Specimen (Latin name) | Phytolith yield (grains/g) | N  | E     | Elevation (m) | Description                                                                                       | Date       |
|---------------|---------------|-----------------------|---------------------------|----|-------|-------------|--------------------------------------------------------------------------------------------------|------------|
| Plant 6       | ZW-LJT01-8    | Carex moorcrofti      | 8502553                   | 31°30′ | 89°12′ | 4796        | On a terrace to the south of the Siling Co, with a brook nearby, far from the lakeside          | 2018/7/9   |
| Plant 51      | ZW-LSQ-1      | Pennisetum alopecuroides | 2898245                  | 29°19′ | 90°40′ | 3590        | At the Lhasa river valley, near the main road                                                      | 2018/8/3   |
| Plant 52      | ZW-LSQ-3      | Eragrostis nigra       | 16370640                  | 29°19′ | 90°40′ | 3590        | At the Lhasa river valley, near the main road                                                      | 2018/8/3   |
| Plant 22      | ZW-MLDP-1     | Kobresia dasyi         | 2902596                   | 32°13′ | 81°14′ | 4587        | From the bank of Shiquan River to the nearby mountain slope                                       | 2018/7/15  |
| Plant 23      | ZW-MLDP-4     | Elymus sp.             | 6202223                   | 32°12′ | 81°14′ | 4590        | From the bank of Shiquan River to the nearby mountain slope                                       | 2018/7/15  |
| Plant 46      | ZW-MLDS-1     | Poa crymophila         | 5836235                   | 32°13′ | 81°14′ | 4662        | On a mountain top near the Shiquan River                                                         | 2018/7/24  |
| Plant 24      | ZW-SG-3       | Scirpus and Carex      | 2340833                   | 32°23′ | 80°15′ | 4743        | At a river bank not far from the main road                                                       | 2018/7/15  |
| Plant 32      | ZW-SOHZ-1     | Elymus sibiricus       | 4770000                   | 32°24′ | 80°1′  | 4321        | Open area near the Shiquanhe Town                                                                | 2018/7/18  |
| Plant 33      | ZW-SOHZ-2     | Elymus sp.             | 6112667                   | 32°24′ | 80°1′  | 4321        | Open area near the Shiquanhe Town                                                                | 2018/7/18  |
| Plant 34      | ZW-SOHZ-3     | Poa sp.                | 9304444                   | 32°24′ | 80°1′  | 4321        | Open area near the Shiquanhe Town                                                                | 2018/7/18  |
| Plant 12      | ZW-WL-1       | Stipa sp.              | 37206000                  | 31°47′ | 87°29′ | 4540        | Inside a fence that used to prevent overgrazing, much taller than the outside ones               | 2018/7/12  |
| Plant 13      | ZW-WL-2       | Stipa sp.              | 14139478                  | 31°47′ | 87°29′ | 4540        | Outside the fence, much smaller than the inside ones                                            | 2018/7/12  |
| Plant 50      | ZW-YHX-1      | Pennisetum alopecuroides | 33452138                 | 32°31′ | 82°28′ | 4895        | Open area near the main road                                                                   | 2018/8/2   |
| Plant 14      | ZW-YPS-1      | Stipa purpurea         | 3796168                   | 31°10′ | 86°48′ | 4922        | In the vally next to the Tangra Yumco                                                          | 2018/7/13  |
| Plant 15      | ZW-YPS-2      | Stipa sp.              | 4056210                   | 31°10′ | 86°48′ | 4922        | In the vally next to the Tangra Yumco                                                          | 2018/7/13  |
| Plant 16      | ZW-YPS-3      | Poa sp.                | 3003832                   | 31°10′ | 86°48′ | 4922        | In the vally next to the Tangra Yumco                                                          | 2018/7/13  |
| Plant 17      | ZW-YPS-4      | Salix bangongensis     | 2                        | 31°10′ | 86°48′ | 4922        | In the vally next to the Tangra Yumco                                                          | 2018/7/13  |
| Plant 35      | ZW-ZD-1       | Poa sp.                | 4169333                   | 31°29′ | 79°48′ | 3708        | In Zanda county, near a brook                                                                  | 2018/7/20  |
| Plant 36      | ZW-ZD-10      | Populus alba           | 425211                    | 31°29′ | 79°48′ | 3708        | In Zanda county, roadside                                                                       | 2018/7/20  |
| Plant 37      | ZW-ZD-2       | Carex crebra           | 2907985                   | 31°29′ | 79°48′ | 3708        | In Zanda county, near a brook                                                                  | 2018/7/20  |
| Plant 38      | ZW-ZD-4       | Poa annua              | 776259                    | 31°29′ | 79°48′ | 3708        | In Zanda county, near a brook                                                                  | 2018/7/20  |
| Plant 39      | ZW-ZD-7       | Elymus sp.             | 1076749                   | 31°29′ | 79°48′ | 3708        | In Zanda county, near a brook                                                                  | 2018/7/20  |
| Plant 40      | ZW-ZD-8       | Achnatherum inebrians  | 1844833                   | 31°29′ | 79°48′ | 3708        | In Zanda county, near a brook                                                                  | 2018/7/20  |
| Plant 41      | ZW-ZD-9       | Phragmites australis   | 3376100                   | 31°29′ | 79°48′ | 3708        | In Zanda county, near a brook                                                                  | 2018/7/20  |
| Plant 42      | ZW-ZDH-2      | Pennisetum alopecuroides | 20597410                 | 31°30′ | 80°1′  | 4608        | Open area near the main road                                                                   | 2018/7/20  |
| Plant 43      | ZW-ZDH-3      | Stipa sp.              | 5811101                   | 31°30′ | 80°1′  | 4608        | Open area near the main road                                                                   | 2018/7/20  |
| Plant 29      | ZW-ZDQ-1      | Poa alpina             | 1987320                   | 31°8′  | 80°44′ | 4340        | Open area between the main road and the bank of Xiangquan River                                 | 2018/7/17  |
| Plant 30      | ZW-ZDQ-2      | Pennisetum alopecuroides | 4669889                  | 31°8′  | 80°44′ | 4340        | Open area between the main road and the bank of Xiangquan River                                 | 2018/7/17  |
| Plant 31      | ZW-ZDQ-3      | Poa sp.                | 4724571                   | 31°8′  | 80°44′ | 4340        | Open area between the main road and the bank of Xiangquan River                                 | 2018/7/17  |

Except Hordeum vulgare var. nudum, the aerial parts of other specimens have not been separated for phytolith extraction.
RESULTS

Phytoliths are found in three families: Poaceae, Cyperaceae, and Salicaceae. The highest production is 37 million grains/g in a *Stipa* sp. sample, while the lowest is two grains/g in *S. bangongensis*, and all other samples are higher than 0.4 million grains/g (Table 1). In Poaceae plants, phytolith production range from 0.6 million to 37.2 million grains/g, with an average of 7.2 million grains/g; in Cyperaceae plants, phytolith production range from 1.4 million to 8.5 million grains/g, with an average of 3.3 million grains/g; in Salicaceae plants, *S. bangongensis* barely produces phytoliths while *Populus alba* produces 0.4 million grains/g. Phytolith production is lowest in Salicaceae and highest in Poaceae; the production of Poaceae plants is twice higher than that of Cyperaceae with a larger SD (8258549.7 for Poaceae and 2316185.8 for Cyperaceae).

There are 22 morphotypes of phytoliths observed in the studied species, including diagnostic morphotypes produced in specific subfamilies and common morphotypes found in different families.

In Pooideae plants, *RONDEL CONICAL* (Figure 2-1), *RONDEL CARINATE* (Figure 2-2), *CRENATE SINUATE* (Figure 2-3), *BILOBATE SADDLE* (Figure 2-4), *ELONGATE DENDRITIC* (Figure 2-6,7) and *PAPILLATE CIRCULAR/RADIATE* (Figure 2-9,10) are diagnostic phytolith types; *BLOCKY* (Figure 2-8) and *SILICIFIED EPIDERMIS* (Figure 2-5) are insignificant types. *ELONGATE DENDRITIC* and *PAPILLATE CIRCULAR/RADIATE* originated from the inflorescence, *SILICIFIED EPIDERMIS* originated from the straw, and other types originated from leaves. *BILOBATE SADDLE* (Figure 2-4) from Tribe Stipae has a dumbbell-shaped base with one bracket-shaped ridge on each lobe; the two bracket-shaped ridges on each lobe together form the saddle top. On the other hand, the typical *BILOBATE* (Figure 3-4,5) from Panicoideae has a dumbbell-shaped base with two bracket-shaped ridges on each lobe. The morphological difference: one or two bracket-shaped ridges on top of the dumbbell base could be the discriminate criteria for distinguishing *BILOBATE SADDLE* from Tribe Stipae with *BILOBATE* from Panicoideae.

In Panicoideae plants (one species, *Pennisetum alopecuroides*), *BILOBATE* (Figure 3-4,5) and *INTERDIGITATING* (Figure 3-3,7) are diagnostic phytolith types. *BULLIFORM* (Figure 3-1,2), *BLOCKY* (Figure 3-1,2) and *SPHEROIDAL FAVOSE* (Figure 3-8) are insignificant types. *BULLIFORM* was found in three specimens, which originated from leaves. *INTERDIGITATING* was found in two specimens, which originated from the flowerhead.

In Arundinoideae (one species, *Phragmites australis*) and Chloridoideae (one species, *Eragrostis nigra*), *BULLIFORM* flabellate (*Figure 4-6) and *Saddle* (*Figure 4-4,7) are diagnostic types. Although these two specimens were collected at the lower elevation basin area (around 3,700 m), they were not observed in the high elevation area (over 4,000 m).

In Cyperaceae, *PAPILLATE* phytolith is the dominant and diagnostic type. *PAPILLATE* phytoliths have three major morphotypes, *PAPILLATE SINGULAR* (*Figure 5-1,4,6) with one conical papilla, *PAPILLATE Binate* (*Figure 5-7,9) with two conical papillae and *PAPILLATE MULTIPLE* (*Figure 5-2,5,8) with multiple conical papillae. Another potential diagnostic type is *RECTANGULAR DENTATE* (*Figure 5-3) which originated from the inflorescence. It has a rectangular shape with dentate long sides and smooth short sides.
FIGURE 3 | Phytoliths morphotypes in Panicoideae plants. 1 and 2. Bottom and side view of BULLIFORM; 3 and 7. INTERDIGITATING; 4 and 5. BILOBATE; 6. BLOCKY; and 8. SPHEROIDAL FAVOSE.

In Salicaceae, TRACHEARY (Figure 4-1) and BLOCKY (Figure 4-2) were observed in P. alba, and only one SPHEROIDAL FAVOS phytolith was observed in S. bangongensis. However, these types of phytoliths could also be found in other plants.

Some phytolith types could be observed in many species, which are defined as insignificant types, including ACUTE BULBOSUS (Figure 4-3), ELONGATE ECHINATE (Figure 4-5), ELONGATE ENTIRE (Figure 4-8), and TRACHAERY ELONGATE (Figure 4-9). These phytolith types are common in both Poaceae and Cyperaceae plants.

The assemblages of phytoliths types showed significant differences on the family level, tribe level or genus level, as shown in Figure 6. It is possible to distinguish different taxon using phytoliths assemblages on the TP.

DISCUSSION

In Tibetan Plateau, overgrazing is the primary biotic stress during the growing season, and grassland degradation has become a major threat to the sustainable development of livestock raising (Niu et al., 2019; Zhan, 2020). As a result, most samples collected in this study have been eaten by herbivores, the aerial parts are no higher than 20 cm. Only one specimen (Stipa sp.) was collected inside a closed fence, which grew 50 cm higher, and the phytolith production is the highest of all samples (37 million grains per gram of dry weight). While the specimen collected outside the fence grew only no higher than 10 cm, and the phytolith production was much lower (14 million grains per gram of dry weight). It has been known that phytoliths deposit
while plants grow (Ma and Yamaji, 2006) and increase with the evapotranspiration (Madella et al., 2009); inside the closed fence, plants could grow better and have higher evapotranspiration; thus, they accumulate more phytoliths. In recent years, phytoliths have been considered a long term carbon sink (Carter, 2009; Song et al., 2022). However, in Tibet, overgrazing influenced the biomass of plants and decreased the production of phytoliths, which might eventually influence the sustainable development of grassland and carbon sink in these regions.

On the northern Tibetan Plateau, most plants grow during the growing season (Che et al., 2014). Thus, the temperature and precipitation are the same during the phytolith accumulation in the sampling sites (Hu et al., 2022). However, humidity showed to be a more critical factor in the growth of plants (Fu and Shen, 2016). During the exploration and sampling, we found that Cyperaceae plants only grew in or near the open water and formed sedge communities; away from the open water, Poaceae plants became dominant species and formed grass communities. Within the Poaceae plants, *P. australis* and *E. nigra* grew near water, *P. alopecuroides* grew near, or not far from open water, *Stipa* sp. grew better in drier areas than *Poa* sp. Thus, the phytolith producers in this study showed that the hydrological conditions influenced their distribution; in other words, the vegetation changed along the hydrological gradient. In many cases, phytolith types have been considered to represent particular climate and environment types (Fredlund and Tieszen, 1997; Boyd, 2005; Gu et al., 2007; Li et al., 2017; Zuo et al., 2020). In China, RONDEL and CRENATE phytoliths from Pooidae plants indicated a cooler climate, BILOBATE phytoliths from Panicoideae plants indicated a warmer climate and PAPILLATE phytoliths from Cyperaceae plants were found to indicate a wetter environment (Wang and Lu, 1993). In contrast, the phytolith types in Tibet might reflect the hydrological condition: PAPILLATE, BULLIFORM FLABELLATE, and SADDLE might indicate a strong humid environment, BILOBATE might indicate a less strong humid environment, RONDEL and

**FIGURE 4** Phytoliths morphotypes in Arundinoideae, Chloridoideae, and Salicaceae. 1. TRACHEARY, in *Populus alba*; 2. BLOCKY, in *Populus alba*; 3. ACUTE BULBOSUS, in Poaceae and Cyperaceae plants; 4. SADDLE, in *Eragrostis nigra*; 5. ELONGATE ECHINATE, in Poaceae and Cyperaceae plants; 6. BULLIFORM FLABELLATE, in *Phragmites australis*; 7. SADDLE, in *Phragmites australis*; 8. ELONGATE ENTIRE, in Poaceae and Cyperaceae plants; and 9. TRACHEARY ELONGATE, in Poaceae and Cyperaceae plants.
FIGURE 5 | Phytoliths morphotypes in Cyperaceae plants. 1. PAPILLATE SINGULAR; 2, 5, and 8. PAPILLATE MULTIPLE; 3. RECTANGULAR DENTATE; 4 and 6. PAPILLATE SINGULAR; 7 and 9. PAPILLATE BINATE; and 10. BLOCKY.

FIGURE 6 | Phytolith assemblages in studied species.
CRENATE might indicate a medium humid environment, and BILOBATE SADDLE might indicate a relative drier environment. Such differences in the relationship between phytoliths types and environmental factors would lead to the different explanations of phytoliths combination in soil profiles on Tibetan Plateau, which also emphasizes the importance of regional study before the implication of phytolith analysis.

CONCLUSION

This study explored the phytolith production and types in modern plants on the Tibetan Plateau. The results showed that the major phytolith producers are Poaceae and Cyperaceae plants, and we have found that BILOBATE SADDLE might be the new diagnostic type for the discrimination of Tribe Stipeae. Furthermore, phytoliths morphotypes and assemblages on the TP respond to the environmental hydrological gradients rather than temperature compare with other regions in China: PAPILLATE, BULLIFORM LABELETTE, SADDLE, BILOBATE represented a more humid environment, RONDEL, CRENATE, and BILOBATE SADDLE represented a relative dryer environment. These new data on modern phytoliths morphotypes and assemblages, as well as their response to the hydrological conditions could help future studies on the identification of phytoliths origins and the reconstruction of paleohydrological conditions.

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DATA AVAILABILITY STATEMENT

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

YG and XZ designed the research. YG, YJ, and XZ collected the samples. YG performed the experiment, and carried out the image process and data analysis. All authors were involved in the writing and discussion of the manuscript, read and approved the final manuscript.

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