Maintenance of dominant populations in heavily grazed grassland: Inference from a *Stipa breviflora* seed germination experiment

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An understanding of population adaptation and maintenance mechanisms under interference from large herbivores is lacking and is a major focus of ecological research. In the Eurasian steppe, which has been subjected to continuous interference from domesticated ungulates throughout history and shows increased grazing, it is particularly urgent to analyse the ecological adaptation strategies of widely distributed *Stipa* plants. In this study, *Stipa breviflora* in a group of desert steppes in the Mongolian Plateau was selected to study the potential mechanism underlying the maintenance of dominant populations under the continuous interference of heavy grazing from the new perspective of seed germination rate. Laboratory experimental results showed that the values of the phenotypic traits of *S. breviflora* seeds were lower under a heavy grazing treatment than under a non-grazing treatment, but the seed germination rate did not decrease. The awns of non-grazed seeds significantly affected the seed germination rate, while those of heavily grazed seeds did not. Field observations showed that grazing does not significantly affect the population density of *S. breviflora* at different growth stages except in extremely wet and dry years. Our study suggests that under heavy grazing, *S. breviflora* uses an "opportunistic" ecological strategy to ensure population maintenance by increasing the seed germination rate and reducing dispersal via changes in associated seed phenotypic traits.

1   **Maintenance of Dominant Populations in Heavily Grazed Grassland: Inference from a *Stipa breviflora***

2   **Seed Germination Experiment**

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14   **Abstract:** An understanding of population adaptation and maintenance mechanisms under interference from

15   large herbivores is lacking and is a major focus of ecological research. In the Eurasian steppe, which has been

16   subjected to continuous interference from domesticated ungulates throughout history and shows increased

17   grazing, it is particularly urgent to analyse the ecological adaptation strategies of widely distributed *Stipa* plants.

18   In this study, *Stipa breviflora* in a group of desert steppes in the Mongolian Plateau was selected to study the

19   potential mechanism underlying the maintenance of dominant populations under the continuous interference of

20   heavy grazing from the new perspective of seed germination rate. Laboratory experimental results showed that

21   the values of the phenotypic traits of *S. breviflora* seeds were lower under a heavy grazing treatment than under

22   a non-grazing treatment, but the seed germination rate did not decrease. The awns of non-grazed seeds

23   significantly affected the seed germination rate, while those of heavily grazed seeds did not. Field observations

24   showed that grazing does not significantly affect the population density of *S. breviflora* at different growth stages

25   except in extremely wet and dry years. Our study suggests that under heavy grazing, *S. breviflora* uses an

26   "opportunistic" ecological strategy to ensure population maintenance by increasing the seed germination rate

27   and reducing dispersal via changes in associated seed phenotypic traits.

28   **Introduction**

29   The Eurasian steppe, which includes a wide distribution of *Stipa* plants (Gonzalo et al., 2013; Ghiloufi et al.,

30   2016; Nobis et al., 2016; Wieczorek et al., 2017), stretches across Northeast China, Mongolia, Russia, Ukraine

31   and Hungary. Historically, this region has been subjected to continuous interference from domesticated

32   ungulates, and grazing has been increasing, leading to widespread declines in species diversity and above-ground

33   productivity (Bai et al. 2007). However, even in desert steppes with average annual precipitation of less than

34   200 mm and long-term overgrazing, it is still possible to find *Stipa* plants living stably and with relatively high

35   biomass (Wang et al., 2014). Therefore, explaining the ecological strategies adopted by the *Stipa* genus is

36   essential for the conservation management of plant species and our understanding of species dynamics and

37   maintenance mechanisms.

38   The selective feeding theory for livestock is obviously unable to explain the survival strategies of plants under

39   severe interference from herbivores. The passive, indiscriminate and repeated feeding of herbivores destroys the

40   vegetative and reproductive organs of plants and causes negative effects such as leaf shortening and narrowing

41 and cluster shrinking (Díaz et al., 2007). Life history theory posits that plants have substantial flexibility in

42 resource allocation between vegetative and reproductive growth (Miller et al., 2006). To ensure the survival of

43 the plant, the vegetative organs are often favoured at the expense of sexual propagation. Assuming that this

44 compensation continues, the survival of plant species will be difficult. Therefore, we expect that the species that

45 can survive stably will have a set of effective ecological strategies allowing them to overcome this dilemma, and

46 sexual propagation is the key link.

47 Louault et al. (2005) compared traits in long-term grazed grassland with those in non-grazed grassland and found

48 that grazing caused a series of effects, such as a reduction in seed size and a decrease in seed weight. The size

49 of the seed directly affects its scattering, spread and survival (Chambers, 1995). Compared with large-sized

50 seeds, small-sized seeds are able to disperse farther, thereby improving their fitness (Coomes & Grubb, 2003).

51 Studies have found that the awn of *Stipa* seeds can help them spread more efficiently. For example, the

52 pubescence on the awns erects when the air is dry to increase the aerostatic buoyancy (Peart, 1981), which

53 reduces the speed at which the seed falls (Greene & Johnson, 1993); in addition, the pubescence on the awns can

54 attach to the fur of animals to spread the seed. When the propagule falls to the ground, the moisture absorption

55 by the awn allows the seed to move a short distance on the soil surface and complete the self-burial process,

56 allowing the propagule to enter the soil (Elbaum et al., 2007; Jung et al., 2014; Liu et al., 2018a). All of the

57 abovementioned studies suggest the importance of awns for the spread of seeds. There are two interesting

58 conjectures. (Conjecture 1) Awns can inhibit the germination of seeds. Assume that the dispersal process of

59 seeds has not been completed, and seed germination occurs because of favourable temperature, humidity, etc.

60 This seed germination strategy is obviously not ideal. (Conjecture 2) Under heavy grazing, awns cannot

61 effectively inhibit seed germination to prevent unfavourable seed germination and increase the chance of

62 population regeneration.

63 Desert grassland, accounting for 39% of the total grassland area in northern China, is the most arid grassland

64 ecosystem on the Eurasian steppe (Li et al., 2000). This grassland is an important part of the semi-arid grassland

65 area of northern China and has a long history of animal husbandry (Wang et al., 2017a). Compared with other

66 grassland types, desert grassland has a low plant species richness and primary productivity due to drought caused

67 by limited rainfall (Li et al., 2008). Therefore, it is valuable to analyse the survival strategies of the dominant

68   species of the desert steppe that have been overgrazed. Therefore, this study aims to examine the following by

69   focusing on *Stipa breviflora* in the desert grassland in northern China: 1) the effect of grazing on the

70   morphological characteristics of seeds; 2) the effect of awns on seed germination under grazing and non-grazing

71   conditions; and 3) the interannual variability in plant population density in grazing and non-grazing treatments.

72   **Materials and Methods**

73   **Study Area**

74   The experimental area is located in the Inner Mongolia Plateau *S. breviflora* positioning station of Inner

75   Mongolia Agricultural University, Zhurihe Town (E112°47′16.9″, N42°16′26.2″), Xilin (Fig. 1), with an

76   elevation of 1100-1150 m. Here, rain and hot temperatures occur in the same period, with average annual

77   precipitation of 183.0 mm, annual average temperature of 5.8°C, average annual sunshine hours of 3137.3 h,

78   average annual evaporation of 2793.4 mm, and average annual frost-free period of 177 days. The area is

79   characterized by a medium-temperate climate. The average wind speed is 5.1 m/s, and the wind is mostly

80   concentrated in winter and spring and dominated by wind from the northwest. The average number of windy

81   days is 67, and dust storms frequently occur. The soil is light chestnut soil with a deserted surface, and the humus

82   layer is 20-30 cm thick. The grass layer is low, generally 10-25 cm in height, and has a low coverage of 15-25%.

83   The vegetation is composed of *S. breviflora* (cluster of a perennial grass); *Cleistogenes songorica* and *Allium*

84   *polyrhizum* are the dominant plants.

85   **Experimental Design**

86   The grazing trial began in 2010, starting in May and ending in late October each year. During the experimental

87   period, continuous grazing was adopted. In the evening, the flock was allowed in the plot, with no supplementary

88   feeding. The test plots selected in this study are located in the same continuous section with flat terrain and a

89   relatively uniform environment, effectively controlling for differences in background, terrain and spatial

90   heterogeneity. There were two treatments in this study, namely, the heavy grazing and non-grazing treatments,

91   each with three replicates, and each test plot had an area of 2.60 ha. The heavy grazing treatment had a stocking

92   capacity of 3.08 sheep·ha^{-1}·a^{-1}, and the non-grazing treatment excluded interference from humans, livestock and

93   large wild animals (Liu et al., 2018b). The herbivores in the grazing area were Sunite sheep that had generally

94   the same health status, individual size, weight and sex.

Seed Germination Experiment

Since the seeds of *Stipa* undergo a period of dormancy after maturation (Zhang et al., 2017), this study attempts to explore the ecological strategies of *S. breviflora* populations under grazing from the perspective of seed germination. To minimize the effect of seed dormancy, we chose the period when the germination rate of *S. breviflora* seeds was the highest. Then, on June 3, 2015, in each experimental plot, mature reproductive shoots of strong *S. breviflora* plants with a high seed-setting rate were selected. After being air dried, the seeds were manually threshed and stored in a bag for winter use. On June 15, 2016, the seeds were brought back to the laboratory, and the seeds from the same treatment were uniformly mixed. Fifty seeds were randomly selected for each grazing treatment, and the seed width, seed length, seed weight, and awn weight were measured with Vernier callipers.

1) Seeds with superior morphological characteristics were selected, rinsed with tap water, sterilized with 75% ethanol, rinsed with deionized water, and treated with awning and non-awning treatments. The seeds were then placed in twenty 9-cm-diameter Petri dishes, with 50 seeds per dish. Each treatment was repeated 5 times. The light and dark periods were each 12 h, and the dishes were kept at 25°C in a constant temperature incubator. The germination status of the *S. breviflora* seeds in each dish was recorded every 24 h. An appropriate amount of water was added after recording the germination status to ensure consistent processing conditions. The assay was terminated after 14 days (Liu et al., 2018a) (Fig. 1A).

2) To assess whether the seeds of *S. breviflora* were dormant, a low-temperature treatment method was used in this study as well as in preliminary and related studies (Wang et al., 2017b). The seeds from the heavy grazing treatment and non-grazing treatment were placed in a refrigerator at 4°C for the low-temperature treatment. After 4 weeks of the low-temperature treatment, all seeds were removed, rinsed with distilled water and then germinated. Step 1 was repeated for the germination test (Fig. 1B).

3) To analyse the potential factors affecting the germination rate (germination percentage) of *S. breviflora* seeds, we added the awns, seeds, and seeds + awns, which were heavily grazed, to the culture medium for the germination test of non-grazed seeds, whose awns, seeds, and seeds + awns were separately added to the culture medium for the germination test of heavily grazed seeds. Specifically, 50 heavily grazed *S. breviflora* seeds (HGSs) were selected and pulverized with a ball mill, and the powder was then placed in culture medium and

122   covered with damp blotting paper. The production of heavily grazed awn (HGA), heavily grazed seed + awn

123   (HGT), non-grazed seed (NGS), non-grazed awn (NGA), and non-grazed seed + awn (NGT) additives was

124   completed as described above. The seed germination test without additives was set as a control treatment (CK),

125   and each treatment was repeated 5 times. Fifty heavily grazed seeds were placed in the medium where NGS

126   additives had been added, and 50 NGSs were added to the medium where heavily grazed seed additives had been

127   added; an appropriate amount of distilled water was then supplied. Step 1 was repeated for the germination test

128   (Fig. 1C).

129   4) To further verify the factors affecting the germination rate of *S. breviflora* seeds, this study selected cabbage

130   seeds as the test object and used the six types of additives described above to perform germination tests (Bao et

131   al., 2015). Germination experiments without any additives were set as controls, and each treatment was repeated

132   5 times. Fifty grazed cabbage seeds were placed in each medium, and the seed germination process was carried

133   out with the abovementioned germination test procedure (Step 1) (Fig. 1D).

134   **Survey of the *S. breviflora* Population**

135   During the period of peak plant growth from 2010 to August 2017, five sample plots, each with an area of 1×1

136   m^2, were randomly selected in each test plot to determine the number of *S. breviflora* individuals. According to

137   the measured basal diameter (Bd) of *S. breviflora* and a previous study (Liu et al., 2017), *S. breviflora* was

138   divided into five stages based on age: seedling stage (Bd $\leq$ 4 mm), juvenile stage (4 mm < Bd $\leq$ 20 mm), adult

139   stage (20 mm < Bd $\leq$ 40 mm), pre-ageing stage (40 mm < Bd $\leq$ 70 mm), and ageing stage (Bd > 70 mm). From

140   2015 to the first ten-day period of August 2017, five sample plots, each with an area of 1×1 m^2, were randomly

141   selected in each test plot to investigate the number of *S. breviflora* individuals at each growth stage.

142   **Meteorological Data**

143   Meteorological data were obtained from a micro weather station (GroWeather® software version 1.2, Davis

144   Instruments Corporation, USA) located at the experimental site (Wang et al., 2014).

145   **Statistical Analysis**

146   An independent t-test was conducted to study the seed width, length and weight; awn weight; germination rate

147   of seeds with awns and those without awns as well as the germination rate of seeds with awns and those without

148   awns after the non-grazing treatment under the heavy grazing and non-grazing treatments. One-way analysis of

149 variance was performed to compare the NGSs, NGAs, NGTs and germination rates of heavily grazed *S.*

150 *breviflora* seeds with the CK, and Duncan's test was used for multiple comparisons. Furthermore, one-way

151 analysis of variance was performed to compare the HGSs, HGAs, HGTs and germination rates of non-grazed *S.*

152 *breviflora* seeds with the CK, and Duncan's test was used for multiple comparisons. Additionally, the NGSs,

153 NGAs, NGTs, HGSs, HGAs, HGTs and seed germination rates of Chinese cabbage (CK) were analysed, and

154 Duncan's test was used for multiple comparisons. An independent t-test was adopted to compare the density

155 ratio of *S. breviflora* and the density of *S. breviflora* between the heavy grazing treatment and non-grazing

156 treatment in the same year. The statistical analyses described above were completed in SAS 9.0 (SAS Institute

157 Inc., Cary NC, USA).

158 **Results**

159 **Seed Phenotypic Traits and Germination Rate**

160 The results of the independent t-test (Fig. 2) showed that the values of the phenotypic traits of non-grazed *S.*

161 *breviflora* seeds were significantly higher than those of heavily grazed *S. breviflora* seeds ($P < 0.001$);

162 specifically, the seed length, width, and weight and awn weight were 10.47%, 13.60%, 36.02%, and 41.85%

163 higher, respectively. The germination rate of non-grazed *S. breviflora* seeds with no awns was 386.96% higher

164 than that of such seeds with awns ($P < 0.001$), while there was no significant difference in the germination rate

165 between the two types of seeds under the heavy grazing treatment ($P > 0.05$) (Fig. 3A). The germination rate of

166 heavily grazed seeds with awns was significantly higher than that of NGSs with awns. However, there was no

167 significant difference in the germination rate of seeds with no awns between the heavy grazing treatment and the

168 non-grazing treatment.

169 **Impact of Awns on Seed Germination Rate**

170 Regarding whether the germination rate of *S. breviflora* seeds is affected by seed dormancy, this study found

171 that the germination rate was the same before and after dormancy release by physically breaking dormancy.

172 Specifically, under the non-grazing treatment, seeds with awns had a significantly lower germination rate than

173 those without awns, and the germination rate of seeds without awns was not obviously different between the

174 heavy grazing treatment and the non-grazing treatment (Fig. 3B).

175 The results of the tests with additives showed (Fig. 4) that *S. breviflora* seeds under the heavy grazing treatment

176 in the culture medium with the NGA and NGT additives had a significantly lower germination rate than seeds

177 with no additive (CK) (P < 0.05), while the germination rate of those with NGS additives did not significantly

178 differ from that of seeds with no additive (CK) (P < 0.05) (Fig. 4A). In the culture medium of non-grazed *S.*

179 *breviflora* seeds, the germination rate with the NGS additive was significantly higher (P < 0.05) than that with

180 the NGA additive under heavy grazing, but there was no significant difference in the germination rate between

181 those with the NGT additive and those without any additive (Fig. 4B).

182 To avoid the regulation of *S. breviflora* seed germination by their own substances and further verify that awns

183 affect the germination of *S. breviflora* seeds, this study used cabbage seeds as a test object. The germination rate

184 of Chinese cabbage seeds with the awn additive was significantly lower than that of the CK, and that of cabbage

185 seeds with the NGA additive was 49.10% lower than that under the heavy grazing treatment (P < 0.05) (Fig. 5).

186 **Dynamics of *S. breviflora* Populations**

187 The 2010-2017 field survey results (Fig. 6) showed that in all years except 2014 and 2016, there was no

188 significant difference in the ratio of the density of heavily grazed *S. breviflora* plants to the number of plants in

189 the community and that of non-grazed *S. breviflora* plants to the number of plants in the community (P > 0.05).

190 Further analysis revealed that there was also no significant difference in the density and density ratios of *S.*

191 *breviflora* at different growth stages between the heavy grazing and non-grazing treatments in 2015 and 2017,

192 and in 2016, the *S. breviflora* seedlings and juveniles in the non-grazing treatment showed a significantly higher

193 density than those in the heavy grazing treatment, with no difference displayed at any of the other growth stages

194 (Fig. 7).

195 **Discussion**

196 Chen et al. (2017) found that heavy grazing affects the morphological characteristics of grassland plant seeds,

197 and this finding is consistent with the findings of this study. Specifically, compared with the non-grazing

198 treatment, heavy grazing significantly reduced the seed length, seed width, seed weight, and awn weight of *S.*

199 *breviflora* on the desert steppe. This finding may be because grazing reduced the number of reproductive

200 individuals in the *S. breviflora* population (Liu et al., 2018a). Moreover, although the plants have substantial

201 flexibility in resource allocation between growth and reproduction (Miller et al., 2006), their vegetative and

202 reproductive organs are destroyed when they suffer from severe interference from herbivores and repeated

203   feeding by livestock. When plants have a constant total amount of resources and a limited ability to assimilate

204   resources, they have to invest more resources to produce vegetative organs, compensating for the grazing-

205   induced damage at the expense of sacrificing sexual reproduction (Fornara & Du Toit, 2007) and causing a series

206   of reactions such as the seed shortening, narrowing, and weight reduction observed in *S. breviflora*. A study in

207   the Mediterranean steppe further validated our conjecture. When the stocking capacity is greater than 3 sheep·ha-

208   ^{1}, the native plant species show a significant increase in vegetative growth and a reduction in reproductive growth

209   (De Miguel et al., 2010). This pattern indicates that to some extent, phenotypic trait changes are a comprehensive

210   manifestation of plant populations adapting to changes in the external environment (Louault et al., 2005).

211   Although heavy grazing alters the morphological characteristics of seeds, it is interesting to note that heavily

212   grazed *S. breviflora* seeds (without an awn) generally exhibit the same germination rate as NGSs (without an

213   awn); that is, the germination rate of large seeds does not differ from that of small seeds, which is contrary to

214   the results of Zimmerman and Weis (1983), Hendrix and Trapp (1992), and Greipsson and Davy (1995). We

215   assume that in response to heavy grazing, *S. breviflora* has formed its own unique survival strategy over its long-

216   term interaction with livestock: *S. breviflora* can carry out both sexual reproduction and asexual reproduction.

217   However, it is obviously not favourable to increase the number of asexually reproducing individuals under severe

218   interference from livestock because individuals who vegetatively propagate seedlings usually form small-scale

219   aggregations with the mother plant, which will undoubtedly reduce the feeding cost of livestock and is not

220   conducive to the survival of the population. Compared to large seeds (no grazing), at the same wind speed, awns

221   can help smaller seeds (heavy grazing) disperse farther (Matlack, 1987), and this increase in dispersal is more

222   propitious for the spread and colonization of the population. However, there is an obvious problem. If the seed

223   can spread farther but has a lower germination rate, then further dispersal obviously has no biological

224   significance. This condition means that the seeds of heavily grazed plants need a higher germination rate. Our

225   previous findings provide the basis for this hypothesis. Grazing can disrupt the threshold for germination of *S.*

226   *breviflora* seeds; that is, the weights of germinable seeds under a heavy grazing treatment were 25% lower than

227   those under a non-grazing treatment (Liu et al., 2018a). The results of this study also showed that grazing does

228   not affect the germination rate of *S. breviflora* seeds (Fig. 3), suggesting that the high germination rate of heavily

229   grazed seeds may be an important mechanism for population maintenance.

230   Additionally, the germination rate of heavily grazed *S. breviflora* seeds (with awns) was significantly higher

231   than that of NGSs (with awns), and the germination rate of awn-free seeds was significantly higher than that of

232   seeds with awns. This result indicates that awns can dramatically affect the germination rate of *S. breviflora*

233   seeds. Numerous studies have suggested that rapid seed germination is a common survival mechanism for plants

234   in arid regions (Wallace et al., 1968), but our results do not fully support this view. This discrepancy probably

235   occurs because the desert grassland is dry and rainless, and effective rainfall can promote not only large-scale

236   seed germination but also the growth and development of individual plants. In the non-grazing treatment, with

237   relatively good plant growth, this increase in performance due to rainfall will undoubtedly increase the

238   competitiveness within and among plant species and cause the death of *S. breviflora* seedlings that are poor

239   competitors, which is not conducive to the regeneration and survival of the population. Furthermore, awns can

240   help seeds disperse over long distances. If seeds germinate before they are dispersed, then this trait is obviously

241   not propitious for the colonization and reproduction of the population. Garnier and Dajoz (2001) also confirm

242   our view, as the germination of *Hyparrhenia diplandra* seeds was not observed during the dispersal process in

243   savannas. All of the abovementioned findings indicate that awns can reduce the germination rate of *S. breviflora*

244   seeds, especially those not subjected to grazing (Fig. 5). Therefore, we believe that the awn of the propagule

245   may play an extremely important role in the reproduction of plants. Once the seeds are mature, the propagule is

246   detached from the spikelets by the twisting of the awns (Raju & Ramaswamy, 1983), and the population is able

247   to spread with the help of wind or animals. In this process, the presence of the awn columns inhibits the

248   germination of the seeds and prevents germination from occurring under unfavourable conditions.

249   However, in the heavy grazing treatment, although the germination rate of seeds without awns was 22.90%

250   higher than that of seeds with awns, the awns did not significantly affect the germination rate of *S. breviflora*

251   seeds (Fig. 3). This result seems to contradict the aforementioned result, but we believe that this pattern reflects

252   a series of behavioural mechanisms for plants to adapt to herbivores. The change in awns is highly heritable

253   (Garnier and Dajoz, 2001). In the case of heavy grazing, due to long-term, intense feeding of livestock, individual

254   plants become sparse, the competition within and among species is weakened, the exposed land area is increased,

255   and the water holding capacity is reduced. Assuming awns effectively inhibited seed germination at this time,

256   this would undoubtedly exacerbate the decline in the population. Therefore, under heavy grazing conditions, the

257   presence of awns not only provides more favourable sites for the survival of new individuals but also does not

258   force the seeds to germinate after awning, which greatly reduces the time required for seed germination and

259   creates greater odds for the survival of the *S. breviflora* population.

260   Based on the population density of *S. breviflora* expressed as a proportion of the number of plants in the

261   community in 2010-2017, our research verifies the abovementioned theory to a certain extent; that is, there was

262   no significant difference between the heavy grazing treatment and non-grazing treatment (except in 2014 and

263   2016). Oesterheld & Sala (1990) also found that grazing increases the number of individuals of dominant species.

264   This result occurs because, in addition to the seeds themselves, livestock have a high ability to spread seeds

265   (Rosenthal et al. 2012), create more favourable habitat opportunities for seed germination, and reduce individual

266   damage caused by competition within or between species. This phenomenon suggests that compared to the *S.*

267   *breviflora* population under the non-grazing treatment, the heavy grazing treatment adopts a mechanism of

268   accelerating the population renewal rate to maintain the relative stability of the population size. Further analysis

269   found that in 2015 and 2017, there was no significant difference in the number and proportion of *S. breviflora*

270   individuals between the heavily grazed and non-grazed treatments. In arid and rainless desert steppes, extreme

271   precipitation events during the growing season may be triggers that impact the number of dominant populations.

272   Consistent with this pattern, in 2014 (precipitation in May-July = 51.7 mm) and 2016 (precipitation in May-July

273   = 122 mm), the population of heavily grazed *S. breviflora* represented a smaller proportion of the plant

274   community than that of non-grazed *S. breviflora*, and in 2016, the density of non-grazed *S. breviflora* seedlings

275   and juveniles was significantly higher than that of heavily grazed *S. breviflora* seedlings and juveniles.

276   This study explored the potential maintenance mechanism of dominant populations from a new perspective of

277   seed germination rate. However, unfortunately, the chemical composition changes of awns under different

278   treatments were not analysed, which means that the biochemical perspective was not included. Additionally, the

279   density of *S. breviflora* individuals at different growth stages was not investigated from the beginning of this

280   study, but from 2015; thus, the typical drought year of 2014 was missed.

281   **Conclusion**

282   The results suggested that heavy grazing reduced the phenotypic characteristics of *S. breviflora* seeds but did

283   not significantly reduce the seed germination rate, and the awns did not inhibit seed germination. Compared with

284   the no grazing and heavy grazing treatments, *S. breviflora* seeds made full use of the spreading functions of awns

285   and adopted the ecological strategies of maintaining the seed germination percentage and "opportunism" to

286   ensure population maintenance.

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Figure 1

Seed germination test process. NAT denotes normal atmospheric temperature
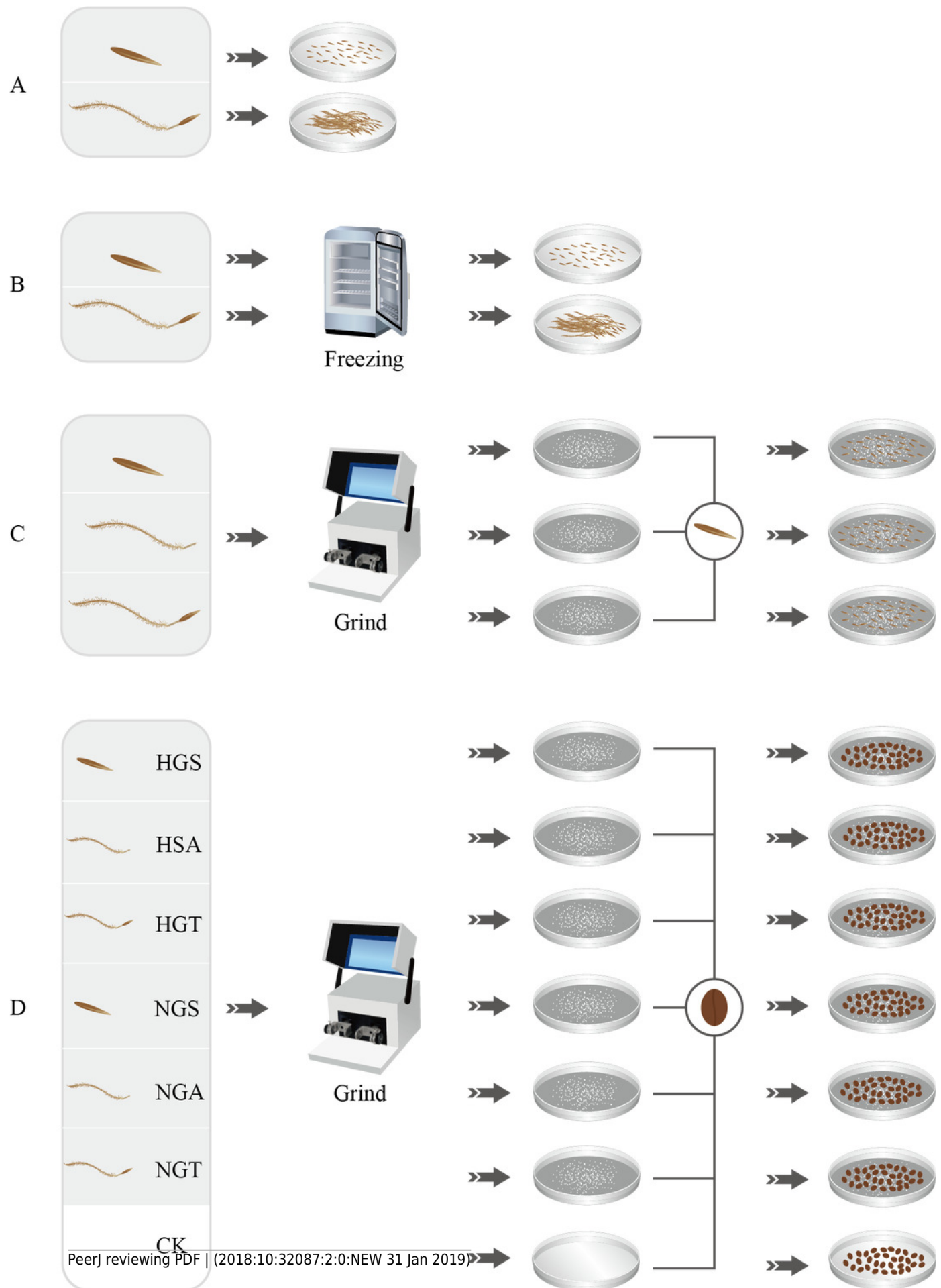
Figure 2

Seed characteristics of *Stipa breviflora*.
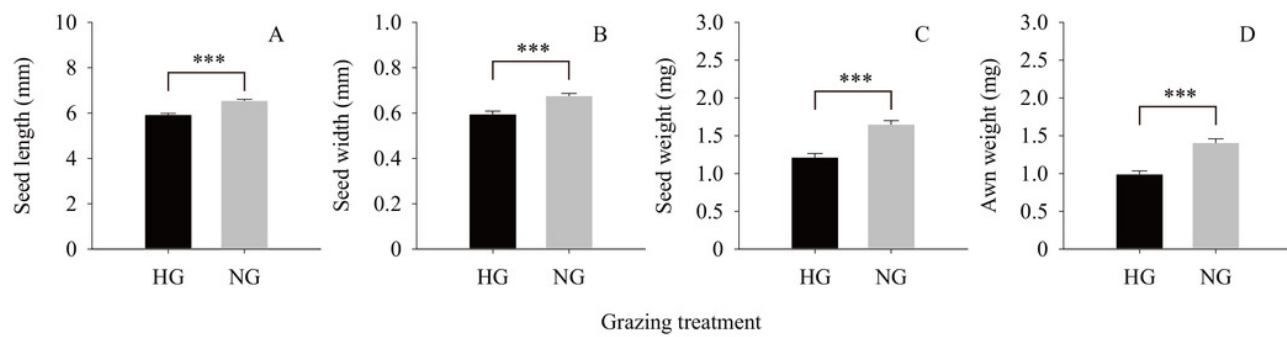
Figure 3

Characteristics of seed germination of *Stipa breviflora*.
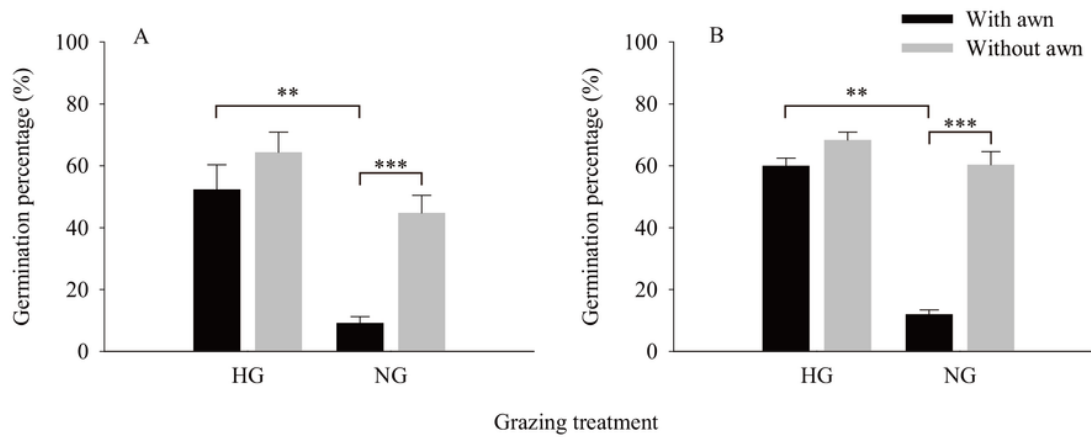
Figure 4

Effect of *Stipa breviflora* additives on the seed germination of *Stipa breviflora*.

The seed germination rate of *Stipa breviflora* treated with heavy grazing after adding non-grazing seeds (NGSs), awns (NGAs) and seeds + awns (NGTs) was studied. The germination rate of *Stipa breviflora* seeds (HGSs), awns (HGAs) and seeds + awns (HGTs) without grazing was studied. CK denotes the control. Different lowercase letters indicate significant differences, P<0.05.
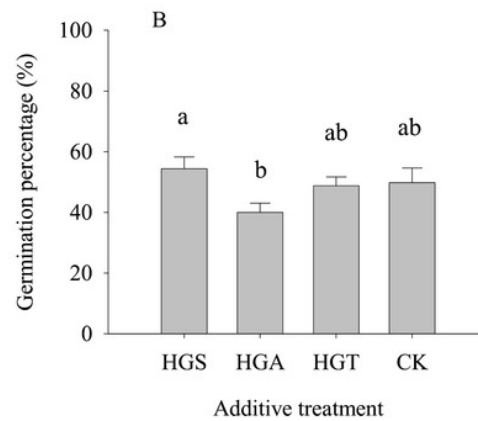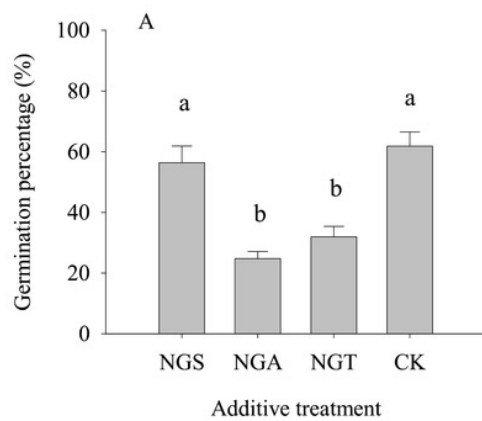
Figure 5

Effect of *Stipa breviflora* additives on the seed germination of Chinese cabbage.

HGS, HGA and HST indicate the seed, awn and seed + awn of *Stipa breviflora* under heavy grazing. NGS, NGA, and NGT indicate the seed, awn and seed + awn of *Stipa breviflora* under no grazing. CK was treated for contrast. Different lowercase letters indicate significant differences, P<0.05.
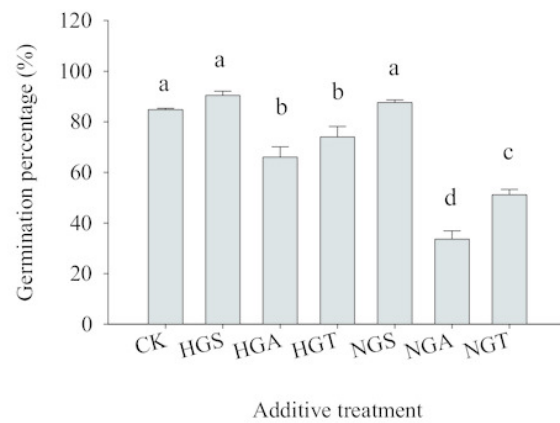
Figure 6

Population dynamics of the *Stipa breviflora* population.

The shadow depicts the standard error. * denotes P<0.05; ** indicates P<0.01. HG and NG represent heavy grazing and no grazing, respectively.
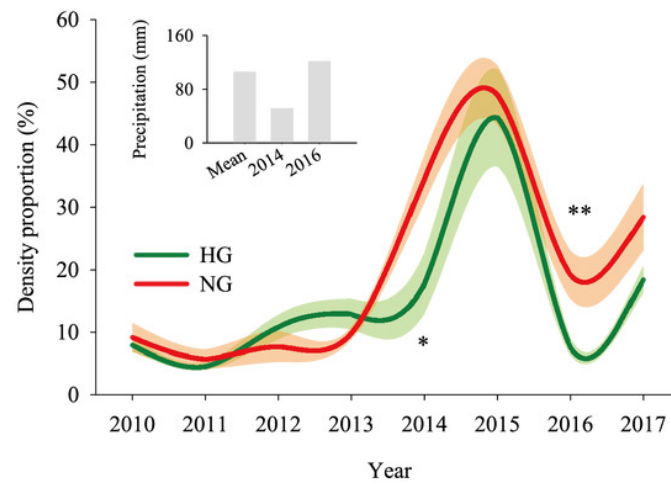
Figure 7

Population density characteristics of *Stipa breviflora* at different growth stages.

A, B and C are 2015, 2016 and 2017, respectively. * * indicates P<0.01. HG and NG represent heavy grazing and no grazing, respectively.