Variation of Germination Response to Temperature in Formosan Lily (Lilium formosanum Wall.) Collected from Different Latitudes and Elevations in Taiwan

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Abstract: Germination characteristics at different temperatures were examined in Formosan lily (Lilium formosanum Wall.) seeds collected at different latitudes (22° 46'–24° 47' N) and elevations (50-3000 m) in Taiwan. Germination was sensitive to temperature and varied among the populations, especially at 5°C and 25°C. All tested populations germinated fastest at 18°C. At this temperature, it took 8-14 days for initiation of germination (Gin) and 10-19 days to reach 50% of final germination percentage (G50). Days to Gin and G50, were 10-21 and 14-41, respectively, at 10°C, 42-82 and 51-136, respectively, at 5°C and 10-39 and 15-100, respectively, at 25°C. In the low elevation (50-880 m) populations, seeds from higher latitude populations germinated more rapidly at 5°C but more slowly at 25°C than those from a lower latitude. Furthermore, seeds from the lower latitude populations had significantly higher final germination percentages than those from the higher latitude populations at 25°C. Some germination characteristics of seeds from higher elevation habitats at the middle latitude were very similar to those from lower elevation habitats at the lower latitude despite of the difference in air temperature between the habitats. The eco-physiological germination characteristics of Formosan lily in response to temperatures were discussed in relation to the climatic conditions of each habitat.

Key words: Habitat, Lilium formosanum, Lily, Precipitation, Seed germination, Temperature.

Formosan lily (Lilium formosanum Wall.) plants propagated from seeds generally develop flowers in the first year, while the other Lilium species generally take 2-3 years to do so. The rapid growth of plants can reduce the probability of virus infection via seed propagation in commercial production. In addition, since Formosan lily has a high degree of self fertility, it can form a homogeneous population. Thus, it is a good gene source for breeding (Shii, 1977) and is useful as a greenhouse plant for cut flowers and occasionally as potted plants (Post, 1949).

In Taiwan (21°54’–25°18’ N), Formosan lily is commonly distributed from north to south and from a low to high (3300 m) elevation (Li et al., 1978). The geographic distribution of individual plant species primarily is limited by temperature and precipitation (Goldstein et al., 1985; Leishman et al., 1992). The habitats of Formosan lily in Taiwan include a wide range of geo-climatic environment; annual precipitation ranges 1700 mm - 4000 mm and the temperature range is about 2.5°C–18.6°C in January and 11°C–28.5°C in July (Fig.1). The wide distribution of Formosan lily might have resulted from the differentiation of diverse ecotypes adapting to different environments.

Thompson (1970) reported that the germination response to temperature of Caryophyllaceae varied in a way that could be broadly related to the over-all geographical distribution of different species. It was also pointed out that the difference in germination response to temperature among ecotypes and cultivars of orchardgrass (Dactylis glomerata) might be related to precipitation and temperature in their habitats (Pannangpetch and Bean, 1984).

The optimum temperature for germination of Formosan lily seeds in darkness collected from low elevation (200 m) were 12–18°C (Shii, 1977), and that from medium elevation (2000 m) was 9–20°C (Shii, 1977), or 15–20°C (Lee and Yang, 1999). The optimum temperature was a constant temperature of 15°C for Formosan lily seeds propagated in Florida (USA) and 10–15°C, 15–20°C and 15–25°C, at 12-h alternating temperatures (Carpenter and Ostmark, 1990). However, little information is available about the germination response to temperature of Formosan lily from various habitats.

In order to study the basic information on the eco-physiology and on the utilization of gene source of Formosan lily, we collected 10 populations of Formosan lily from sites at various latitudes and elevations from low to high (3000 m) in Taiwan, and examined the effects of temperature on seed germination.
Materials and Methods

Five populations of Formosan lily collected at different latitudes (22°46’–24°47’ N) at low elevations (50-880 m) in western Taiwan and five populations collected at the elevations between 1400 and 3000 m above sea level in central Taiwan (23°29’–24°09’ N) were used in this study.

Five to ten bulbs of each population were collected from the field and planted in a greenhouse in 1997 and cross-pollinated within the same population in 1998. The mature seeds were harvested and used for germination tests. Seeds were germinated on the moist filter paper in Petri dishes of 9 cm diameter. Fifty seeds were distributed fairly evenly on filter paper with 3 replications per treatment and incubated at 5, 10, 18 and 25°C in darkness. Germinated seeds were counted and removed from Petri dishes until the seeds no longer germinated. The germination count was ended at 160-180 days after the start of incubation.

Days to initiation of germination (G_0) was estimated from the linear extrapolation of the germination
percentage at two count days just after initiation of germination; and days to reach 50% of final germination after incubation ($G_{50}$) was estimated from the linear interpolation of the germination percentages at two count days, nearest to 50% and just over 50% of final germination (Steinmaus et al., 2000). The relative final germination percentage (RFGP) and germination rate index (GRI) in each treatment were calculated as follows:

$$RFGP = \frac{FGP}{HFGP} \times 100\%$$

$$GRI = \sum_{i=1}^{n} \left( \frac{GP_i}{i} \right)$$

where, $FGP$ is the final germination percentage and $HFGP$ is the highest final germination percentage among four incubated temperatures in the same population. RFGP was used to evaluate germination ability of each population. GRI (Hsu et al., 1985) was calculated as the summation of germination percentage at each day ($GP_i$) divided by the total days ($i$) of incubation. The value of GRI was higher when seeds germinated earlier.

**Results**

The patterns of seed germination of Formosan lily was considerably affected by incubation temperature in all the populations tested (Figs. 2-3). Seeds of all the populations germinated and reached HFGP most
rapidly at 18°C or 10°C. The $G_{in}$ ranged 8-14 and 10-21 days and $G_{50}$ ranged 10-19 and 14-41 days at 18 and 10°C, respectively (Figs. 2-3 and Fig. 4A-B). Based on the single regression analysis, both $G_{in}$ and $G_{50}$ in all the tested populations exhibited a significant negative correlation with latitude of collection site when seeds were incubated at 10°C; and $G_{50}$ of those populations exhibited significant negative correlation with latitude at 18°C (Table 1).

Marked geographic variation in seed germination response among populations was observed when seeds were incubated at 5 and 25°C (Figs. 2-4). The $G_{in}$ in the population from the low elevation in northern Taiwan ($24°30'\text{N-}24°47'\text{N, 50-100 m}$) was 44-55 days at 5°C, while that in the populations from low elevation in southern Taiwan ($22°46'\text{N-}23°36'\text{N, 700-800 m}$) and from all of the elevations in central Taiwan ($23°29'\text{N-}24°09'\text{N, 800-3000 m}$) was 70-82 days. $G_{50}$ at 5°C was 51-67 days in the northern Taiwan populations and 90-136 days for the low elevation of central and southern Taiwan populations; and that for the populations of central Taiwan increased from 82 to 125 days with the increase of elevation from 1500 to 3000 m (Figs. 3 and 4B). Both $G_{in}$ and $G_{50}$ showed a significant positive correlation with elevation at 5°C (Table 1). $G_{in}$ in the northern Taiwan populations was 30-39 days at 25°C, while that in the southern and central Taiwan populations was 10-19 days (Figs. 2-3).
The highest (ca 100%) RFGP at 18°C or 10 ºC, while and Fig. 4C-D their RFGP. Most populations had of the populations incubated at different temperaturesǽ correlated with elevation at 5 and 10ºC (Table 1).

The difference in seed germination among populations might be related to the precipitation and temperature of the habitat (Thompson, 1970; Pannangpetch and Bean, 1984). Fig. 1 shows the monthly mean air temperature and precipitation from meteorological stations at different latitudes and elevations in Taiwan. Mean air temperatures in the lowland of both northern (Hsinchu station, 24º48' N) and southern (Kaohsiung station, 22 º38' N) Taiwan are between 15 ºC and 18.6 ºC in January, and between 28.1ºC and 28.5 ºC in July,. In central Taiwan, monthly mean air temperatures from the lowland up to 3910 m range from 16 to 1.6 ºC in January, and from 28.4 to 7.6°C in July. The rate of temperature decrease with increasing elevation is about 0.5°C per 100 m. Monthly precipitation varies with the season and location. More than 130 mm month⁻¹ is recorded in the wet season

Discussion

There is no dormancy in Formosan lily seeds, but that their germination is sensitive to temperature (Shii, 1977). Formosan lily seeds germinated earliest at 18 °C (Shii, 1977) or at 15°C (Carpenter and Ostmark, 1990) in darkness; and took 10-15 days (Shii, 1977; Carpenter and Ostmark, 1990) to reach 50% of a final germination percentage at these temperatures. Our results were concordant with the previous data in spite of use of diverse seed sources with different geographic origins. However, we also found that Formosan lily seeds showed a wide range of germination characteristics among populations in the response to the lower (5ºC) and higher (25 ºC) temperature (Figs. 2 and 4).

The seeds of the higher latitude populations germinated rapidly at 5°C but more slowly at 25ºC compared to those of the lower latitude populations (Fig. 4A and E, Table 1). At 25ºC, furthermore, RFGP of the lower latitude population was higher than that of the higher latitude populations (Figs. 2 and 4C). Thus, seed of the higher latitude populations adapted to germinate at to lower temperatures than the lower latitude populations, and the lower latitude populations adapted to germinate at higher temperatures than the higher latitude populations. However, the results obtained in this study also indicated that despite the great difference in temperatures between the habitats, germination characteristics of some seed from medium to high elevation populations of central Taiwan were very similar to those from the lower elevation population of southern Taiwan (Fig. 4). Thus, it can be deduced that the variation in seed germination characteristics among different geographic populations was related to the environmental conditions of their habitats.

G₅₀ for low elevation populations was 15-100 days at 25°C; it was longer in northern Taiwan populations and shorter in the southern Taiwan population. G₅₀ in the populations from medium to high elevations (1400-3000 m) of central Taiwan was 30-47 days. Both G₅₀ and G₅₀ at 25°C showed a significant positive correlation with latitude (Table 1).

The values of GRI had almost a negative relationship to those of G₅₀ and G₅₀. Generally, GRI was highest at 18°C, medium at 10°C and the lowest at 5 ºC or 25°C for most of the populations (Fig. 4E-F). GRI of all the populations was positively correlated with latitude at 10 and 18°C, but negatively correlated with latitude at 25°C. GRI of all populations was also negatively correlated with elevation at 5 and 10°C (Table 1).

Figs. 2 and 3 show the final germination percentages of the populations incubated at different temperatures and Fig. 4C-D their RFGP. Most populations had the highest (ca 100%) RFGP at 18°C or 10°C, while the values were 60-100% and 4-99% at 5°C and 25°C, respectively. At 5, 10 and 18°C, no significant correlation was observed between RFGP and latitude or elevation. However, there was a significant negative correlation between RFGP and latitude at 25 °C (Table 1). RFGP at 25°C was only 4-5% in the northern Taiwan populations, but 75% in the southern Taiwan population. In addition, the RFGP was 25-38% in the populations from medium to high elevations (500-3000 m) populations (Fig. 4C-D).

| Temperature (°C) | Gin | G₅₀ | GRI | RFGP |
|------------------|-----|-----|-----|------|
|                  | La  | El  | La  | El   | La  | El   | La  | El   |
| 5                | -0.693* | 0.804** | -0.499NS | 0.651* | 0.510 NS | -0.666* | 0.001 NS | -0.541 NS |
| 10               | -0.733* | 0.613NS | -0.784** | 0.156 NS | 0.644* | -0.646* | -0.040 NS | -0.382 NS |
| 18               | -0.340NS | 0.406NS | -0.792** | 0.313 NS | 0.756* | -0.480 NS | -0.426 NS | 0.319 NS |
| 25               | 0.810** | -0.265NS | 0.830** | -0.284 NS | -0.864** | 0.063 NS | -0.762* | 0.289 NS |

G₅₀: The days to initiation of germination; G₅₀: Number of days to reach 50% of final germination percentage during incubation; GRI: Germination rate index; RFGP: The relative final germination percentage; NS, * and **: Not significant, P < 0.05 and <0.01, respectively (df=8).

Table 1. Coefficients of correlation of four seed germination indices (G₅₀, G₅₀, GRI and RFGP) of Formosan lily populations incubated at different temperature with latitude (La) and elevation (El) at site of collection.
mean temperature is about 15ºC, and precipitation is higher than 130 mm month⁻¹ in the lowland of southern Taiwan from November to May, the precipitation becomes higher than 100 mm month⁻¹ (Fig. 1). Thus, it is considered that Formosan lily seeds from northern Taiwan populations were suitable for germination at low temperatures. In southern Taiwan, however, precipitation is low from autumn to winter in southern Taiwan (Fig. 1). The dry condition is considered to be disadvantageous for seed germination and seedling growth. At the beginning of the wet season, in April to May, the precipitation becomes higher than 100 mm month⁻¹, and the temperature increases above 25ºC (Fig. 1). Thus, it is considered that the higher germination ability at 25ºC of the seeds of southern Formosan lily populations might be advantageous to the higher temperature of the wet season, the conditions specific to the lowland of southern Taiwan.

At 5ºC, the germination speed indicated by G50 and GRI in the higher elevation populations was as low as that in the lowland population of southern Taiwan (Fig. 4). At 25ºC, final germination percentages of the seeds from the medium to higher elevation (1500-2550 m) populations were as high as, or higher than, those from the lowland population in southern Taiwan (Fig. 4C-D). These results indicated that Formosan lily seeds from the higher elevation populations were more likely to germinate at higher temperatures, in spite of the lower temperature conditions at high elevation. Thompson (1970) reported that the species of Caryophyllaceae distributed in southern Europe might germinate in the cold season because it is intensely arid. On the contrary, the species of Caryophyllaceae distributed in northern Europe, might germinate in the warm season to avoid the cold winter. Thus, the species distributed in southern Europe germinates more rapidly at lower temperatures than the species distributed in northern Europe. In Taiwan, the temperature at a high elevation in winter is too low for the survival of lily seedlings. Thus, the germination of the seeds of the higher elevation populations might be delayed until the favorable temperatures arrive in spring or summer.

Seed germination may be influenced by the temperature of the surface soil, which is higher at a high elevation than at a low elevation, because the soil surface at a higher elevation is largely bare and the soil is directly exposed to solar radiation (Cabrera et al., 1998) including infrared radiation (Shibata, 1996). This might be the reason why Formosan lily seeds can favorably germinate at higher temperatures at a higher elevation.

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