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Effects of light and temperature conditions on flowering in Mat Rush*

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Abstract: The effects of photoperiod and light intensity on flowering in Mat Rush cv. Gangshan 3 were studied. The results showed that treatments with longer day length stimulated flowering significantly and increased stem flowering percentage (SFP). Plants treated with low light intensity at early stage had substantially reduced florets per cyme, SFP, tillers per plant and stem length. At middle and late stage, low light intensity significantly reduced SFP. The principal climatic factors affecting SFP were as follows: mean temperatures (MT) of the third ten-day period (TDP) in December and of the second TDP in February, actual sunlight hours (SH) of the third TDP in February and precipitation of the third TDP in March. A nonlinear simulation model for SFP was established with experimental results and corresponding climatic data (see Eq.(2)).

Simulation by the above equation yielded values the same as those observed from 1992 to 2000, indicating its accuracy in describing the relationship between flowering and light and temperature conditions. The interaction between vernalization and SH is also discussed in this paper.

Key words: Mat Rush (*Juncus effuses* L. Var. Decipiens Bchen), Light, Temperature, Stem flowering rate, Simulation model

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INTRODUCTION

Mat Rush (*Juncus effusus* L. Var. Decipiens Bchen) is a perennial herbaceous root plant, whose stem is used as raw material for woven straw mats, seats and hats. In Zhejiang and Jiangsu Provinces, China, it is transplanted in the middle of November and harvested in early June next year. Among many factors determining the quality of the rush stem, the stem length and flowering are the most important (Yu, 1982). The length of the stems initiating lateral cyme would be reduced because of excessive consumption of nutrients by buds and flowers, resulting in easy flecking of the straw mats made of the flowered stems. It is known that flowering transition at the shoot apical meristem is controlled by environmental and endogenous signals (McDaniel et al., 1992; Levy et al., 1998; Lin, 2000). In some species, the timing of flowering is primarily influenced by environmental factors including photoperiod (day length), light quality (spectral composition), light quantity (photo flux density), vernalization and nutrient and water availability; while other species are less sensitive to environmental variables and appear to flower in response to internal cues such as plant size (Levy et al., 1998; Wang et al., 1987; Kinet, 1977; Tooke et al., 2000). Flowering can also be induced by stresses such as nutrient deficiency, drought and overcrowding. Reversion of flowering could occur when environmental conditions are not favorable for maintaining reproductive development; and vegetative structuring is resumed in a meristem after floral development has been initiated (Battey et al., 1990; Lyndon, 1998). So far there are no re-

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ports about the effects of photoperiod and light intensity on flowering of Mat rush. The aim of our experiment was to investigate the influences of photoperiod, light intensity and temperature on flowering of Mat Rush. By systematic analysis and simulation, we will try to determine the relationship between SFP and main agro-climatic factors recorded by local meteorological observatory while setting up a simulation model for predicting the flowering percentage of stems. The data obtained may be widely used in rush planting.

MATERIALS AND METHODS

1. Long-term field trials

To find out the relationship between SFP and main agro-climatic factors, long-term field trials were carried out in the Yinxian Mat Rush Research Center, Zhejiang, P. R. China, from 1992 to 2000. The local commonly used cultivar named Gangshan 3, introduced from Japan in 1978, was planted in paddy soil with moderate fertility. Agronomic management measures followed those used in local production. At harvest stage each year, 12 hills of Mat Rush were randomly collected. Stems longer than one meter and stems with cymes among them were counted. Stem flowering percentages (SFP) were calculated.

2. The effect of photoperiod on flowering

Day-extension treatments with artificial illumination were done from 1998 to 1999 with the aim of studying the effects of different photoperiods on floral differentiation, while a study was also done to identify the main effect of light intensity on floral development. A newly released cultivar, Yinlin 1 (C1) and a Japanese cultivar named Taicao (C2) with easy flowering initiation, was treated by five different photoperiods (P_0, P_1, P_2, P_3 and P_4 as control, control plus 2, 4, 6 h artificial illumination and continuous artificial illumination). Every day, different treatments were illuminated by 150W bulb, which was low light intensity only affecting photoperiod, from 17:30 to 19:30 (P_1), 21:30 (P_2), 23:30 (P_3) and 8:00 next day (P_4) respectively. During dark time, plants were covered by double-layered black cloth to prevent exposure to light. The treatment lasted 62 days from 25 December, 1998 to 25 February, 1999. During that period, natural photoperiod without any artificial illumination was used as the control (P_0), with day length gradually increasing from 7.2 h to 11.7 h. Every treatment had 72 hills of Mat Rush, 18 of which were selected to observe their flowering. With three hills as an observing unit, there were six replicates. In addition, the effect of light intensity on initiation of flowering was investigated in P_4 treatment by covering with shading net, which cut off about 85% of natural light.

3. The effect of light intensity on flowering

The effect of light intensity on SFP was studied by using different shading nets, cutting off 20 − 30% (I_1), 45 − 50% (I_2) and 60 − 70% (I_3) of natural light intensity respectively. Natural light intensity without any shading treatment was used as the control (I_0). Each light intensity treatment lasted 30 days (T_1), 60 days (T_2) and 90 days (T_3), starting on 13 March, 2001. The trial was laid out as a completely random block design with three replicates. From each plot, six hills of Mat Rush were randomly selected and monitored for changes of SFP.

RESULTS

1. Effects of photoperiod and light intensity at early stage on SFP in Mat Rush

Day-extension treatments significantly affected SFP (Table 1). Under longer day length, both cultivars not only blossomed earlier, but their SFP was also almost doubled, which indicated that Mat Rush has the characteristics of a long-day plant. There was obvious difference in SFP between the two cultivars. Taicao had stem flowering rate of 73.4% at harvest stage in natural photoperiod and no difference among five photoperiods existed, while Yinlin 1 had stem flowering rate of only 0.71% in natural photoperiod and the differences among changing photoperiods were significant. It suggested that there was difference in response to photoperiod in terms of flower initiation among genotypes.

Table 1 Effect of different photoperiods (P_0, the control, natural day-length; P_1, P_2, P_3, the control plus 2, 4, 6 hours artificial illumination; P_4, continuous illumination) on stem flowering percentage (SFP%) in Mat Rush (*Juncus effusus* L. Var Decipiens Bchen) cv. Yinlin 1 (C1) and Taicao (C2)

Observing date		P_0	P_1	P_2	P_3	P_4
Apr. 10	C1	0±0 a*	0±0 a	0±0 a	0±0 a	0±0 a
	C2	0±0 a	2.7 ±0.4b	5.7±0.5c	7.5±0.5d	17.7±3.3e
Apr. 30	C1	0±0 a	0±0 a	1.2±0 b	2.5±0.4c	7.5±2.0d
	C2	55.3±6.0a	65.5±6.5b	68.5±7.3b	68.6±7.8b	72.6±8.8b
July. 6	C1	0.71±0.1a	0.9±0.1a	3.1±0.4b	4.7±0.7b	21.8±4.6c
	C2	73.4±6.3a	74.3±4.9a	74.8±7.6a	76.6±6.4a	76.4±5.8a

* Data is presented as mean±SEM, with the same letter within a row indicates no significant difference at 5% possibility

Mat Rush grew very slowly over winter because of the low temperature. Light-shading treatments significantly inhabited growth and floral development (Table 2). In comparison with the control, stem number per hill, stem length, SFP and florets per cyme were apparently reduced.

Table 2 Effect of light intensity on stem growth, stem flowering percentage (SFP %) and florets per cyme in Mat Ruch (*Juncus effusus* L. Var Decipiens Bchen) cv. Gangshan 3

Treatment	Number of stems per hill	Stem length (cm)	Stem flower-set rate (%)	Number of florets per cyme
Natural sunlight	117.7±14.2b*	93.3±4.5b	17.3 ±3.3b	59.0±8.5b
15% natural sunlight	76.8±10.8a	84.5±4.2a	10.9±3.1a	22.6±5.6a

* Data is presented as mean±SEM. The same letter within a column indicates no significant difference at 5% possibility

2. Effect of light intensity on SFP in the middle and late growing stage

Table 3 shows that that decreased light intensity at middle and late stages significantly decreased SFP, stem length, number of stems per hill, and dry matter accumulation in Mat Rush (Shen et al., 2002). With the reduction of light intensity, SFP decreased to zero under 30% - 40% of natural light intensity (I_3). The longer the shading treatment lasted, the lower the SFP was.

Table 3 Effects of light intensity (I_0 the control, natural light intensity; I_1, I_2, I_3 20% - 30%, 45% - 50% and 60% - 70% natural one respectively) and treatment duration (T_1, 30 days; T_2, 60 days and T_3, 90 days) on stem flowering percentage (SFP%) in Mat Rush (*Juncus effusus* L. Var Decipiens Bchen) cv. Gangshan 3

Treatment	T_1	T_2	T_3
I_0	14.5±3.6d*	14.5±3.6c	14.5±3.6c
I_1	7.8±2.8c	7.6±2.9b	4.9±2.5b
I_2	2.0±0.4b	0.9±0.2a	0±0 a
I_3	0±0 a	0±0 a	0±0 a

* Data is presented as mean±SEM. The same letter within a column indicates no significant difference at 5% possibility

3. The relationship between some climatic factors and SFP

Plant blossoming is a process involved in qualitative transition of growing pattern. The transition is controlled by genetic traits, and also affected by environmental factors, such as photoperiod, temperature, water and nutrition (Fu and Meng, 1997; Levy and Dean, 1998; Araki, 2001). Flowering reversion, could occur when external conditions are not suitable for further development of initiated flowers (Battey and Lyndon, 1990). Thus, whether the rush blossoms or not (or SFP is high or low) is related to at least two processes, floral differentiation induction and full development of floral organs. SFPs were observed successively from 1992 to 2000 where the plants grew in the same cultural conditions. Climatic data were gathered from the local meteorological observatory. Four factors (Table 4) and a linear regression Eq. (1) were obtained by correlation analysis between SFP and corresponding TDP mean temperature (MT), precipitation (P), rainy days (RD) and actual sunlight hours (SH) using SPSS software yielding the relationship:

$$SFP = 37.881 + 7.173 \times (\text{the third TDP MT in Dec.}) - 2.799 \times (\text{the second TDP MT in Feb.}) - 1.871 \times (\text{the third TDP SH in Feb.}) - 0.130 \times (\text{the third TDP P in Mar.}) \quad (1)$$

It can be seen from Eq. (1): that SFP is positively correlated with the third TDP MT in Dec. ; and its standardized contribution value was the highest. SFP was negatively correlated with the second TDP MT in Feb, which implied that flowering in Mat Rush might be promoted by vernalization. Similar results was obtained in a low temperature treatment experiment that Mat Rush was a typical plant requiring vernalization. Commonly, Mat Rush is transplanted in mid-November, thus bio-mass and tillers will increase if the temperature in the third TDP of December is still high, and more buds will be vernalized, particularly when the temperature in the second TDP of Feb. is still low. In addition, the third TDP SH in Feb. and the third TDP P in March also affected SFP, although the contribution of P was very small.

Table 4 Effects of some climatic factors on stem flowering percentage(SFP %) in Mat Rush(*Juncus effusus* L、Var Decipiens Bchen)cv. Gangshan 3

Climatic factor	Standardized contribution	Coefficients
3rd TDP MT in Dec.	0.565	7.173
2nd TDP MT in Feb	0.267	−2.7999
3rd TDP SH in Feb.	0.086	−1.871
3rd TDP P in Mar.	0.021	−0.130

4. SFP stimulation model

Although Eq. (1) explanatorily describes the relationship between SFP and some climatic factors, it does not function effectively for forecasting SFP as it need climatic data on the third TDP P in March. The physiological mechanism of vernalization should be considered in order to make the equation functional. Vernalization is a slow and quantitative process. The effect of low temperature is accumulated, and could be compensated by longer duration. Besides low temperature, other factors and their interaction with temperature are involved in vernalization (Lang, 1965; Vince-Prue, 1975). In light of the vernalization mechanism, Eq. (1), and practical prediction requirment, we adopted following SFP stimulation model obtained by referring to the model given by Yin et al. (1994) and McMaster et al. (1992).

$$SFR = A + B\{\sum_i [X_i(\sum_{j<i} X_j) F(SHi)]\} \quad (2)$$

$$F(SHi) = \exp[(SHi - SH) \times k] \quad (3)$$

Where $\sum_{j<i} X_j$ is vernalization accumulation for the i-th TDP; the sum of the preceding TDP vernalization contribution X_j is defined by

$$X_j = \begin{cases} 1, & t_1 \leqslant AT \leqslant t_2, \\ 0, & \text{otherwise.} \end{cases}$$

t_1 and t_2 are temperature bounds which depended on variety of genetic character; j valued 1 to 9 from December to February(total 9 TDPs); exp $(x) = e^x$ the exponent function for e = 2.71828 ……; SHi is actual sunlight hours of the i-th TDP; SH was taken to be 45, the mean value of 50 years in the locality (Ningbo, China); A, B and k are parameters which could be obtained from trials.

By using SFP and climatic data from 1992 to 2000, we obtained all optimum parameters of the nonlinear Eq. (2) for Mat Rush Gangshan 3 after running the data on a computer with FORTRAN language. A, B and k were 1.023, 0.258 and −0.0686, respectively, and t_1 and t_2 were 3.3 and 6.4 ℃. Putting the above parameters into Eqs. (2) and (3), yielded the following Eq. (4).

$$SFP = 1.023 + 0.258\{\sum_i [X_i(\sum_{j<i} X_j) e^{-0.0686(SHi-45)}]\} \quad (4)$$

Eq. (4) was applied for simulation of SPP by using FORTRAN Powerstation program. The difference between simulated and observed SFP was less than 1.5% for all tested years, except 1992/1993 (Table 5). With the same climatic data in the past 50 years, SFP was nearly zero if calculated by Eq.(1), but it was 7.19% if calculated by Eq.(4). On an actual average of 8 years from 1992 to 2000, observed SFP was about 10.0%, indicating that Eq.(4) was a more accurate forecast of SFP.

Table 5 Comparison of simulated SFP and observed SFP (%) in Mat Rush(*Juncus effusus* L.Var Decipiens Bchen)cv. Gangshan 3

Year	92－93	93－94	94－95	95－96	96－97	98－99	98－99	99－00
Simulated value	1.02	33.01	2.25	22.08	13.09	1.15	1.88	5.73
Observed value	4.21	32.9	0.94	23.20	11.60	0.11	1.53	5.60
Difference	3.19	0.11	1.31	1.12	1.49	1.04	0.35	0.13

DISCUSSION

1. Effect of light on flowering in Mat Rush

The effects of light on plant include direct photo-morphogenesis and indirect photosynthesis. The effect of photoperiod on SFP in Mat Rush is direct. As an environmental signal, light affects activities of many enzymes or interacts with signal-conducting proteins by photoreceptor, being related to seed germination, leaf movement, stem elongation and floral differentiation (Ahmad et. al., 1998; Frankhauser et al., 1999; Battey, 2000). Day-extension treatment in this study promoted flowering and increased SFP in Mat Rush. Although the photoperiod was basically the same during each growing season for two experimental years, there was a large difference in SFP between them, being 0.71% in 1998/1999 and 14.5% in 1999/2000. This result was much larger than the treatment making day length 6 hours longer in 1998/1999. It indicated that besides photoperiod, other factors or their interactions with photoperiods also affect SFP.

Light intensity plays an important role in flower initiation, mainly through its effect on photosynthesis and accumulated assimilation (Ruo et al., 1991). Comparison of the effects of light intensity on floral development and SFP at early stage with those at middle and late stage showed that shading (cutting off 85% natural light intensity) for 60 days at early stage reduced florets per cyme and SFP by 38.3% and 63% respectively even under continuous lighting condition, but at middle and late stage, slight shading (cutting off 20%－30% natural light intensity) caused great reduction in SFP but little change in florets per cyme. SFP reduced to almost zero in the shading treatment by cutting off 60%－70% of natural light intensity. The results implied that low light intensity at the flowering-inducing stage (or at early stage) mainly affected floral development, while at floral development stage (or at middle and late stage) it might result in flowering reversion, the response of plants to external conditions (Battey et al., 1990). It may be deduced that zero SFP in the low light intensity treatment at middle and late stage was the result of stopped floral development or flowering reversion. Similar results were observed in violet orychophragmus (Chen and Li, 1993). Thus, it can be assumed that yearly difference in SFP is related to the difference in the external conditions including light intensity at the floral development stage.

2. The temperature and duration for vernalization in Mat Rush

In general, －4℃ to 12℃ is the temperature for plants vernalization, the most effective being 1℃－2℃ (Lang, 1965). The nonlinear model in this study showed that the effective TDP temperature for vernalization was 3.3℃≤MT≤6.4℃. Mat Rush cv. Gangshan 3 would enter the vernalizing phrase when TDP temperature is in this range. It was found from the climatic data of the past 8 years that Gangshan 3 was undergoing vernalization from the first or second TDP in January to the third TDP in February. It may be seen from Eq. (1) that more tiller buds might be in vernalization if the temperature in the third TDP of December still remains high, leading to increase in SFP. From the biological point of view, it might be too simple to define that the contribution value of TDP to vernalization is one when TDP temperature is in the effective range for Eq.(4), otherwise it is zero. Therefore, TDP was adopted as a step in our simulation model rather than one day as a step in the general models (Bouman and Vankeulen, 1996; Yin, Qi and Xie, 1989), probably avoiding errors in the process of mathematical calculation and finally reaching reasonable results in simulation. It should be pointed out that the effective TDP temperature is different from general requirements for vernalizing temperature and we cannot state that vernalization will not occur if the temperature in a given day is lower than t_1 or higher than t_2.

3. The effect of interaction between vernalization and sunlight on flowering in Mat Rush

SH (actual sunlight hours) mainly depends on weather and climatic conditions. Eq. (1) shows that SH in the third TDP of February was one factor affecting SFP and that less SH would result in larger SFP. Similarly, the negative k value in Eq.(4) means that when SHi is smaller than SH, SH will exponentially enhance the effect of vernalization contribution to accumulation of SFP values. Alternately, when SHi is larger than SH, SH will weaken the effect of vernalization contribution to accumulation of SFP values. The effect of SH on SFP becomes stronger gradually with the growth and development of Mat rush from December to February. The effect of interaction between SH and vernalization on floral differentiation and development is different from that of either photoperiod or light intensity. The physiological mechanisms of the interaction remain to be studied further.

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