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# Light Enrichment, Flowering Asynchrony and Reproduction Success in Two Field-Grown Soybeans in Northern China

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## ABSTRACT

The flowering process at single plant level in soybean is a continuous dynamic system. Whether a flower can survive to mature depends on where it is located and when it is initiated. A field experiment was conducted to analyse the effect of flowering asynchrony on single flower survival and response of flowers or pods distribution to light enrichment. Our data suggest that early flowers (number 1-5) definitely survive and develop into mature pod because they don't encounter fierce assimilates competition from other flowers or pods. Later flowers are usually prone to abortion, especially when five or more flowers at the same node in two soybean cultivars (*Glycine max* L. Merr. namely, Heinong35 and Kennong18). The flowers on sub-raceme frequently fail to develop into pods. Compared with the flowers on main-raceme, that on sub-raceme maybe have weak competitive ability to assimilation. Most flowers on bottom branches successfully develop into pods due to the strong supply of assimilation from the leaves of branches. Light enrichment significantly increase the number of flowers or pods across the main axis. However, the rate of flower abortion is still relatively high by observing the distribution curves of flowers or pods under light enrichment. Soybean plant has the characteristic of excessive flower production and flower abscission is more likely to be expression of biological adaptability.

**Key words:** Light enrichment, Pod number, Flower abscission, Yield component.

**Abbreviations:** Soybean cultivar Heinong 35: HN35, Soybean cultivar Kennong18: KN18, Light enrichment: LE, Natural light: CK.

## INTRODUCTION

Solar radiation intercepted by the canopy affects the rate of flower survival and then influences soybean yield (Umezaki and Yoshida, 1992; Board and Harvill, 1996; Onat *et al*., 2017; Li *et al*., 2013). Liu *et al*. (2015a) indicated that soybean yield components in lower, middle and upper mainstem parts have different sensitivity to light enrichment and shading. Wiebold *et al*. (1981) found that about 32 to 81% soybean flowers per plant can't develop into mature pods. The flowering process is a continuous dynamic system, in which a flower surviving to mature is decided by its location and initial time. The temporal distribution of soybean flower and dynamic of pod production have important roles in deciding pod and seed number at physiological maturity (Egli and Bruening, 2006a).

At the individual node, both of flowering and pod-production periods are the almost same long periods, namely 30 days or more (Huff and Dybing, 1980). Because of the intense competition for assimilation from large rapidly pods and seeds, the late developing flowers have a high abortion rate (Egli and Bruening, 2006b; Constable and Ross, 1988). Kuroda *et al*. (1998) reported that a majority of flowers are produced in a relatively short time, although the soybean reproductive period is very long. At soybean plant level, the opening of the last flower may be 15-50 days later than that of the first flower and the flowering order also varies between inter- and intra-nodes (Dybing, 1994; Zheng *et al*., 2002). The key reason in determining a flower survival or abscission is its location in main axis, closely related to the time of flowering. Heitholt *et al*. (1986) indicated that the abortion of early developing flowers always had lower than those developing later flowers. This happens frequently in soybean plants, when the uppermost nodes are still in the process of producing flowers and while the lowermost nodes just start filling seeds. Woodworth (1932) first defined that indeterminate and determinate growth habits according to the stem termination and floral initiation in soybean. Soybean plants, whether it's an indeterminate or determinate growth habit, all show highly asynchronous flowering or pod filling. Asynchrony exists not only in inter-node but also intra-node, which leads to more complex situation (Saitoh *et al*., 1998). It is inevitable that flowers are still blooming and while some pods are filling in the same node. At single node, the flowering first starts at the base of the primary raceme and continues upward and there is an interval of 1-2 days between adjacent flowers (Huff and Dybing, 1980). Liu *et al*. (2015a) stated that abscission is unavoidable for late developing pod, when a large assimilate absorptive sink exists, namely, there is a large number of young pod.

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Although several studies have included the information about light enrichment and flowering or pod-filling asynchrony (Mathew *et al*., 2000; Nakamoto *et al*., 2001; Zheng *et al*., 2002, Liu *et al*., 2010), little information is available for detailed analysis the effect of flowering asynchrony on a flower survival. More detailed research is also needed to analyze effect of light treatment on the survival of soybean flowers across main axis. The purpose of our research is to explicate relationships between flowering asynchrony and reproduction success under light enrichment.

## MATERIALS AND METHODS

In this study, two soybean (Glycine max L. Merr. namely, Heinong35 and Kennong18) were sub-indeterminate cultivars, grown in the northeastern China. Research of flowering asynchrony was conducted in Agricultural experiment station of Jilin Normal University and experiment of light enrichment was carried out in Hailun Agroecological Experimental Station. Soybean cultivars (Heinong35 and Kennong18) was grown in field and the density is 27 plants $m^{-2}$. Each soybean was treated by light enrichment with three replications and soybeans in natural light as control. The technique of light enrichment used in this experiment is first introduced by Mathew *et al*. (2000) and has non-disruptive and duplicative properties. Solar radiation intensity is promoted 25% under light enrichment in middle row per plot by arranging wire mesh with 90cm height and 45° slope to fence two adjacent rows.

In the flowering stage, flowering dynamics on the sub-/main raceme and sub-/main branches in every day were marked on diagrammatic sketch, which includes the information of flower reproductive abortion or success and node positions. Pods at mature period represent successful flowers and the failure of young pods means the abortion of flowers. At maturity, flower scars across main axis form 15 plants in each plot represent spatial distribution of the flowers. Number of pods across vertical stem and branches is also counted. The fisrt and second nodes are the cotyledon node and unifoliate node, respectively. Data analysis is carried out by SAS software (SAS Institute, Inc. 1996).

## RESULTS AND DISCUSSION

### Effect of flowering asynchrony on reproductive success

As can be seen from Fig 1 and 2, the branches of two soybean cultivars usually are located at the bottom of the main axis. These flowers at the bottom branches (from third and fourth nodes) can always survive and develop successfully into pods. It may be due to the strong supply of

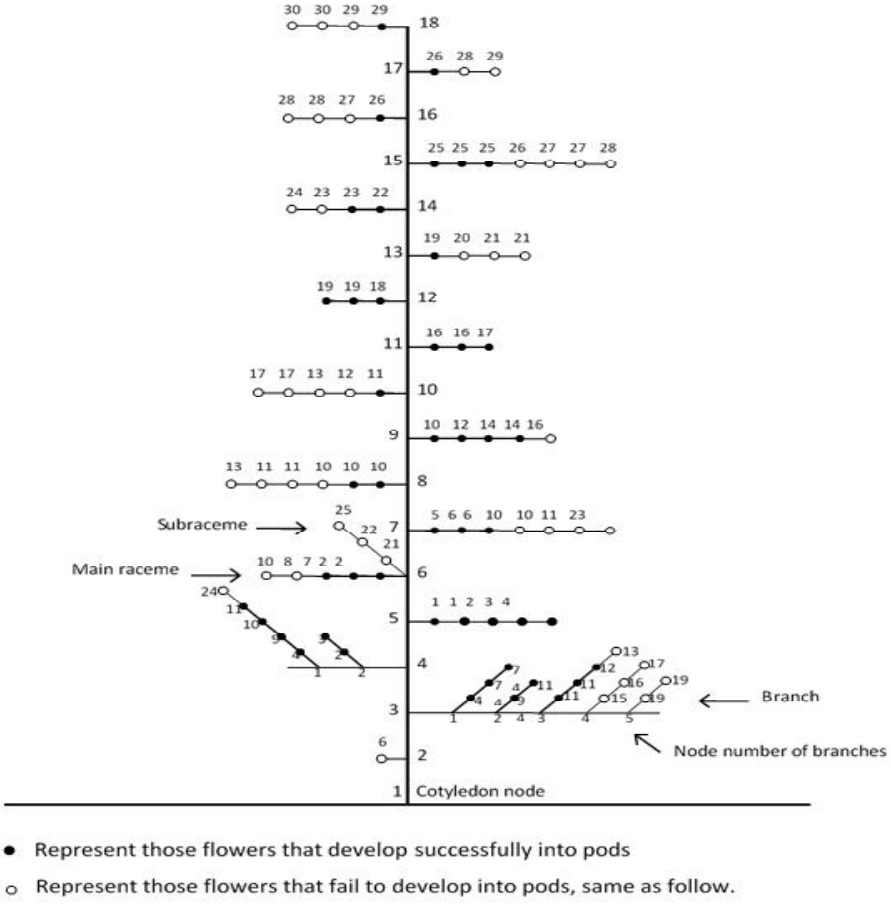



**Fig 1**: Blooming chart showing flower position on different subdivisions in HN35 soybean cultivar.

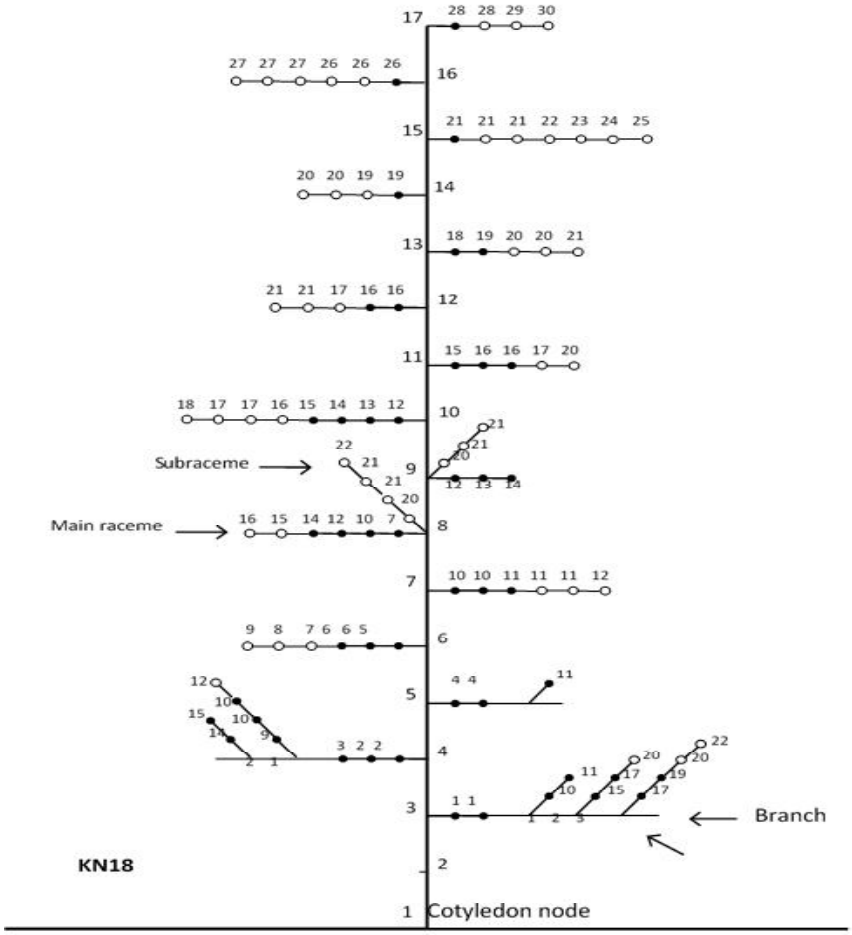



**Fig 2:** Blooming chart showing flower position on different subdivisions in KN18 soybean cultivar.

assimilation from the leaves of branches. The first flower starts at the third node on the main axis in two soybean. Early flowers (number 1-5) definitely survive and develop into mature pods (Fig 1), which indicates that the early flowers encounter little assimilates competition from other flowers or pods. Flowers at the 7-10th nodes of HN35 are at high risk of abortion (Fig 2). Later flowers are usually prone to abortion, especially when five or more flowers at the same node. Same matter was also found on KN18.

The node location of a flower in soybean main axis determines, in part, when it starts. Appearance of flowers at the apical nodes is usually the latest. At last three nodes on the top of the main axis, only one flower can successfully develop into pod (Fig 2). This indicates that many rapidly growing pods and seeds consume a large amount of assimilates. The abortion of the late flowers at several apical nodes is inevitable. The flowers on sub-raceme frequently fail to develop into pod. As shown in the diagram, the flowers (20-22) at eighth node for KN18 abort undoubtedl and so is the flowers (11, 22, 25) at sixth node for HN35. Compared with the main-raceme, the sub-racemes have weak competitive ability to assimilation (Egli and Bruening, 2006; Zhao *et al*., 2013).

**Effect of light enrichment on spatial distribution of flower or pod across the main axis**

Compared with natural light, light enrichment significantly increased the number of flowers or pods across the main axis (Fig 3). Most flowers or pods were produced at the middle nodes across main axis, however there was some differences of the flowers or pods increments between HN35 and KN18. For HN35, the flowers or pods number in middle nodes across the axis was greatly increased by light enrichment, while for KN18, light enrichment significantly increased flowers or pods number in lower nodes.

The curve of flower distribution is more flexible than that of pod distribution in our experiment. It is obvious that the alteration of flowers was greater than that of pods under light enrichment. A possible reason is that production of a flower needs less assimilates than pod growth (include seed filling). Differences in flower and pod distribution curves between two cultivars were observed. The space between flower distribution curves in HN35 was wider than that in KN18. This indicated that light enrichment had much stronger effect on flower number per node in HN35 than that in KN18. The space between the distribution curves of flower and pod represents the flower abortion status across

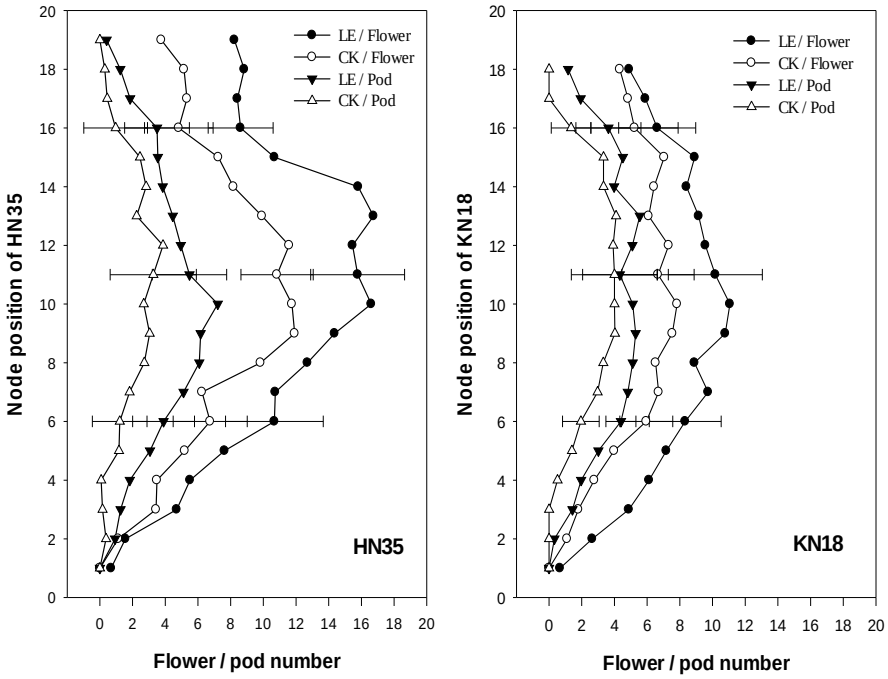



**Fig 3:** Distribution of flower/pod number in the main stem of two soybean cultivars under natural light and light enrichment treatment. HN 35 and KN18 are Heinong 35 and Kennong 18, respectively. CK and LE are natural light and light enrichment treatment. Bar indicates standard error of the mean.

main axis under same light condition. The larger space means the much higher abortion rate.

Light enrichment greatly increased the number of flowers per node, however relative abortion rate is still high by observing the space between both distribution curves. Flower abscission in middle nodes of main stem accounts for 50% of total abscission (Zhao *et al*., 2013). Sharma *et al*. (1996) indicated that there was a genotypic variation in flowers per node. Heindl and Brun (1984) also reported that only a slight variation in flower number at each node. Liu and Qu (2015a) indicated that soybean plant had characteristic of excessive flower production and excessive flower produced per plant only was precondition as reproductive prosperity.

Our data suggested that light enrichment markedly increased pod number per plant by improving photosynthetic efficiency of leave and assimilate availability. High abortion rate of flowers looks like soybean plant own characteristic and even light enrichment can't alter it. Egli and Bruening (2006b) indicated that young pod abortion was one of the important reasons affecting soybean yield. In my experiment, young pod abortion was also classified as flower abortion. Intense competition of assimilates between late pods and early pods was maybe a primary reason of pod abortion. Pod number per plant as the yield component was most influenced by cultural and environmental conditions (Herbert and Litchfield., 1982; Board *et al*., 1992). Our study indicated that light enrichment significantly alleviated the heavy competition of assimilates between late pods and early pods and therefore those late pod can survive more than before.

**Effect of light enrichment on flower, pod number and yield in two soybean**

Light enrichment significantly increased flower number per plant compared with that of the ambient light (Table 1). Light enrichment increased flower number per plant by 42.4% for HN35 and by 43.3% for KN18, respectively (Table 1). Egli and Bruening (2002) indicated that flower number and temporal distribution played an important role in determining pod or seed number at maturity. In our experiment, the flowers number on main raceme, sub-raceme and branch greatly increased by 42.4%, 57.1% and 34.7% for HN35 under light enrichment, respectively and by 43.4%, 42.2% and 43.7% for KN18 under light enrichment, respectively.

The variation in flowers number directly resulted in fluctuation of pods number per plant. Pod number per plant as the yield component was the most influenced by environmental condition (Board an Tan, 1995; Egli, 2005). Mathew *et al*. (2000) showed that light enrichment initiated at early flowering stages increased seed yield by 144-252%, mainly by increasing pod number. Our data suggested that light enrichment only increased pod number per plant by 51.6% for HN35 and by 55.6% for KN18, respectively. The following possible reason may result in the difference. Soybean cultivars in previous experiment were more profusely branching ones, while cultivars used in our studies only have one or several branches.

Although light enrichment significantly increased the number of flowers and pods in two cultivars, the increases between flowers and pods were proportional, which leads to no significant decrease in the abortion rate of flowers

**Table 1:** Effect of light enrichment on flower, pod number and yield in two soybeans.

| Cultivar | Light treatment | Number of flowers | | | Pods number | Success (%) | Yield (g.Plant$^{-1}$) |
|---|---|---|---|---|---|---|---|
| | | Main-raceme | Sub-raceme | Branch | | | |
| HN35 | LE | 81.6a | 13.2a | 22.5a | 48.8a | 41.6% a | 19.5a |
| | CK | 57.3b | 8.4b | 16.7b | 32.2b | 39.1% a | 12.9b |
| KN18 | LE | 98.2a | 16.5a | 20.4a | 66.3a | 49.1% a | 20.2a |
| | CK | 68.5b | 11.6b | 14.2b | 42.6b | 45.2% a | 14.8b |

HN35 and KN18 are soybean cultivars Heinong 35 and Kennong 18, respectively. LE and CK are light enrichment and natural light. Different letters within the row represent significantly different from light enrichment and natural light under same cultivar (P<0.05).

under light enrichment. Another potential reason for this phenomenon is that soybean plant has the characteristic of excessive flower production. Liu and Qu (2015a) stated that excessive flower produced per plant is a precondition as reproductive prosperity. Other cultural conditions, such as fertilizer (Zahoor *et al*., 2013) and planting patterns (Gulluoglu *et al*., 2016; Swapan *et al*., 2019 and Baghdadi *et al*., 2016) may have greater impacts on yield and flower abortion rate. In fact, it is impossible that flower abscission is completely avoided. Flower abscission is more likely to be expression of biological adaptability of soybean.

## CONCLUSION

The dynamics of flowering were highly asynchronous and early flowers always had a high survival rate. Most flowers produced on lower branches could survive due to the strong assimilate supply capacity from branches system. This branches system is relatively independent from main axis system in the whole plant. Light enrichment proportionally increased between the numbers of flowers and pods and so there was no significant change in rate of flower abortion. Over-flowering and high-abortion of flowers may be strategies for soybean reproduction.

Flowering asynchrony and reproduction success under light environment had very complex correlations. If we want to fully explain the formation process of soybean yield, more studies will be conducted to further understand the reproductive complexity.

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