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Vine length determines the propagation strategy of Japanese yam (*Dioscorea japonica*) in tea gardens

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ABSTRACT

Dioscorea japonica (Japanese yam) is among the most serious weeds in tea gardens in Japan. Currently, tea farmers control Japanese yam vines by pulling them out from the canopy of tea plants or harvesting them above the canopy of tea trees. Japanese yam propagates through seeds and vegetative propagules. This study revealed that a single vine of Japanese yam does not produce both propagules and seeds and that whether propagules or flowers are produced is determined by the length of the vine. Specifically, shorter vines produce propagules, whereas longer vines produce flowers. Furthermore, we also observed no relationship between vine length and the number of propagules. Therefore, shortening the vine does not suppress propagule production, and a certain number of propagules may be produced even when the vine is short. Thus, careless cutting of vines risks increasing the number of propagules that will be the source of the subsequent year's outbreak.

Key words: Japanese Yam (*Dioscorea Japonica*), Vine Weed, Tea Garden, Propagule

INTRODUCTION

Dioscorea japonica (Japanese yam) is a perennial plant widely found in forest margins and woodlands in Japan (Hori, 1984). Traditionally, Japanese yam was collected from its natural habitats and used as food, and recently it has become a locally cultivated crop (Iida, 2001). However, Japanese yam is among the most serious weeds in Japanese tea gardens (Seo, 2012; Ichihara et al., 2020). Japanese yam is a vine weed that thrives on the canopy of the tea tree and gets mixed in during the tea harvest, reducing the quality of the tea. Although weed control in tea gardens is generally done by spraying herbicides between the rows, it is difficult to control Japanese yam with herbicides because it grows from within the tea plant, where herbicides cannot reach. Currently, there are no effective control measures against Japanese yam, and farmers have to hand-pull each vine of Japanese yam that grows over the canopy of tea trees (Seo, 2016; Japan Soil Association, 2012). The farmers have to reach over and into the canopy of the tea tree to pull out the vines of Japanese yam. However, pulling out the Japanese yam vines from the land base is difficult, and the vines often break off in the middle. Therefore, completely removing the vine from its base is difficult, especially if the vine is entangled with the tea plant or with other vines of Japanese yam. If the vine is cut in the middle, the severed vine remains under the canopy of the tea plant and gives rise to side branches; therefore, the vines are only temporarily removed from the picking surface of the tea canopy.

In recent years, weeding machines have been developed to remove Japanese yam vines (Ichihara et al., 2022). These machines function by harvesting vines at the surface of the canopy of tea trees and removing them by winding vines at the surface of the canopy. However, it is difficult to pull out these vines from the base using these machines, and although the upper part of the vines on the picking surface is removed, there is concern that short vines may remain and give rise to side branches.

This study reports the risk of inadvertently cutting vines, which increases the production of propagules the following year as the source of the outbreak.

MATERIALS AND METHODS

Study area

This study was conducted in a tea garden at the Center for Education and Research in Field Sciences, Shizuoka University (Kariyado, Fujieda city, Shizuoka Prefecture, Japan; 34°54'18.8" N, 138°16'19.7" E). Tea trees have been cultivated in this garden using conventional farming methods since 1974.

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Relationship between vine length and production of propagules and flowers of Japanese yam growing naturally in the tea garden

The study site consisted of three 6 m rows in a '*Yabukita*' tea garden that was harvested for the second time on June 25, 2020. Vine length and the number of propagules and flowers of Japanese yam were measured on a total of 22 main stems and all side branches that had attached propagules or flowers growing over the canopy of tea trees in the study area on August 11 and August 17, 2020.

Relationship between vine length and production of propagules and flowers of Japanese yam experimentally planted in the tea garden

Five Japanese yam tubers (approximately 50 g weight, 20 cm long) obtained from propagules cultivated for one year were planted at 30 cm intervals in the '*Yabukita*' tea garden on April 6, 2020. Vine length and the number of propagules and flowers of Japanese yam were measured on all main stems and side branches on September 15, 2020.

RESULTS

Relationship between vine length and production of propagules and flowers of Japanese yam growing naturally in the tea garden

Japanese yam propagates through seeds and vegetative propagules. Our observation confirmed that the length of the vine determined whether a vine would produce propagules or a flower, and there were no vines that produced both propagules and flowers. Fig.1 shows the relationship between the vine length of both the main stems and side branches and the production of propagules and flowers of naturally grown Japanese yams in the tea garden. Longer main stems tended to produce flowers, whereas shorter main stems produced propagules (Fig.1 a). The vines longer than approximately 200 cm tended to produce flowers, whereas the vines shorter than approximately 100 cm tended to produce propagules.

The side branches showed results similar to those of the main stems, and longer vines produced flowers, whereas the shorter vines produced propagules (Fig.1 b). Side branch vines longer than approximately 200 cm tended to produce flowers, whereas the vines shorter than approximately 200 cm tended to produce propagules, with one exception.

For both main stems and side branches, longer vines tended to produce more flowers, and a significant positive correlation $r = 0.93$ ($p = 0.007$) was observed in the combined analysis of main stems and side branches. However, there was no clear correlation between vine length and the number of propagules ($r = 0.24$).

Relationship between vine length and production of propagules and flowers of Japanese yam experimentally planted in the tea garden

Similar to the results of naturally growing Japanese yam, the length of the vines determined whether a vine would produce propagules or a flower, and there were no vines that produced both propagules and flowers. Fig.2 shows the relationship between the vine length of both the main stems and side branches and the production of propagules and flowers of Japanese yams experimentally planted in the tea garden.

Of the five main stems, three vines produced flowers and two vines produced neither flowers nor propagules. Of the 49 side branches, three produced flowers (6.1%) and five produced propagules (10.2%). Forty-one vines produced neither flowers nor propagules (83.7 %). Similar to the results of naturally growing Japanese yam, the longer main stems tended to produce flowers, whereas the shorter main stems produced propagules (Fig. 2). The vines longer than approximately 150 cm tended to produce flowers, while the vines shorter than approximately 150 cm tended to produce propagules, with one exception. The combined analysis of main stems and side branches indicated a significant positive correlation $r = 0.72$ ($p = 0.044$). However, there was no clear correlation between vine length and the number of propagules ($r = 0.03$).

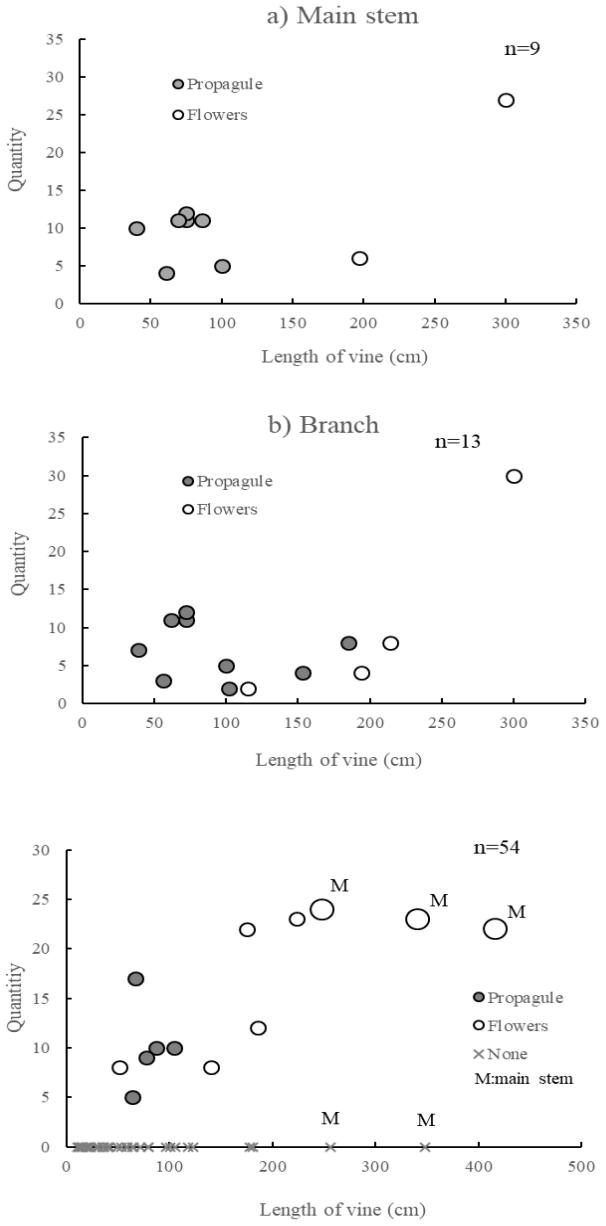

Fig 1: The relationship between the vine length of main stems (a) and side branches (b) and the production of propagules and flowers of naturally grown Japanese yam in the tea garden.

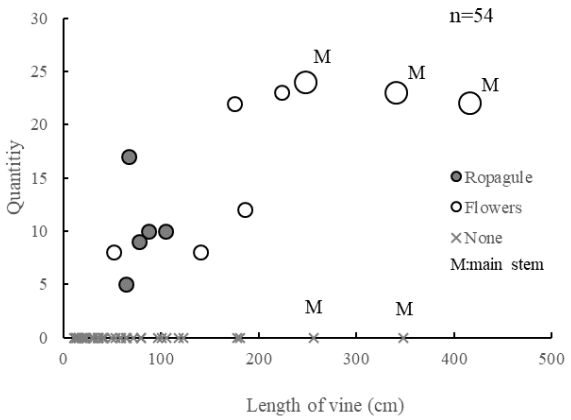

Fig. 2: The relationship between the vine length of main stems and side branches and the production of propagules and flowers of Japanese yam experimentally planted in the tea garden.

DISCUSSION

Several plants propagate using both seeds and vegetative propagules. Vegetative propagation has the advantage of large initial population size and strong competitiveness, whereas seed propagation has the advantage of high proliferation rates and large migration distances (Harada et al.,1997; Winkler & Fischer, 1999). There are two types of vegetative propagation organs: "non-dispersed," such as rhizome and stolon, and "dispersed," which can be mobile and dispersed, such as the turion, propagule, and gemmae (Inoue, 2007). Non-dispersed vegetative propagation organs are used to analyze the adaptive significance of clonal plants because of their distinct differences from seeds that can move (Winkler & Fischer, 2001; Magori et al., 2003). In contrast, mobile, dispersed vegetative propagation organs, which can move like seeds, are not clearly differentiated from seeds. In addition, resource partitioning between non-dispersed and dispersed vegetative propagation is extremely complex. Therefore, there are few studies on dispersed vegetative propagation (Tomimastu et al., 2007). Non-dispersed vegetative propagation has advantages in undisturbed conditions, whereas seed reproduction develops in highly disturbed conditions. Therefore, dispersed vegetative propagation organs are considered to be an adaptation to an environment with small-scale disturbances (Tomimastu et al., 2007). There are three methods of reproduction in Japanese yam: 1) tubers, which are non-dispersed vegetative propagation organs, 2) propagules, which are dispersed vegetative propagation organs, and 3) seeds. Our previous study (Inagaki & Ishiwata, 2022) reported that the reproduction of Japanese yam in tea gardens, where there are small-scale disturbances, is predominantly by propagules rather than by seeds.

This study demonstrated that a single vine of Japanese yam does not produce both propagules and seeds and that the length of each vine determines whether propagules or flowers are produced on it. This suggests that the vines of Japanese yam can choose to reproduce by either producing propagules or seeds. Vegetative propagation has several advantages compared with seed propagation (Tomimatsu et al., 2007). For example, vegetative propagation organs have an advantage in competition and are more likely to become established in a population because they are much larger than seeds and have more resources than seeds. Moreover, using vegetative propagation, populations can be maintained even if they cannot produce seeds. Furthermore, they achieve physiological integration, which is the exchange of resources such as assimilated products and nitrogen among ramets in the case of connected ramets (Tomimatsu et al., 2007). Despite the many advantages of vegetative propagation, most clonal plants also produce seeds (Fukui & Araki, 2017). Although the reasons for this are not clear, it is considered that seed propagation has merit in the point of maintaining genetic diversity (Maynard & Smith, 1980; Eriksson, 1997) and avoiding risks from environmental changes due to long-distance dispersal (Jansen & Yoshimura, 1998). In fact, it has been reported that clonal plants often exhibit a high genetic diversity despite forming populations asexually through vegetative reproduction (Andrew et al., 1997). Our results indicate that shorter vines produce propagules, whereas longer vines produce flowers. Although the significance of this is not clear, several hypotheses can be considered. First, seed production is less certain and carries a higher risk of reproduction failure than propagule production. Therefore, long vines with available capacity may be responsible for the risky and challenging seed production, while short vines produce propagules. Second, since Japanese yam originally grows naturally in forests, its long vines can reach the forest canopy. Because Japanese yam has a wind-dispersed seed (Hori, 1984; Tateno, 1995; Minami & Azuma, 2003), long vines may be an essential factor for seed dispersal.

The Japanese yam vines that grow above the canopy of tea trees are cut by harvesting machinery during tea harvest. In addition, although the weeding of Japanese yam in tea gardens is done by hand-pulling each vine from the canopy of the tea tree (Seo, 2016; Soil Association of Japan, 2012), the vines often break off in the process. This is problematic because our results indicate that shorter vines produce propagules—the source of proliferation in tea gardens. Although there is no relationship between vine length and the number of vines produced, shortening the vines promotes the production of propagules (rather than flowers), which promote proliferation of Japanese yam in tea gardens. Therefore, we conclude that careless cutting of vines risks encouraging the formation of side branches, increasing the number of vines, and increasing the number of propagules that will be the source of the following year's outbreak.

Conclusion

This study indicates that the decision of whether vines of Japanese yam produce seeds or propagules is related to the length of the vine; longer vines produce seeds, whereas shorter vines produce propagules. Weed control in tea gardens is done by mowing or pulling weeds on the canopy of tea trees, which is the harvest position of tea leaves. In recent years, weeding machinery has also been developed to control Japanese yam. However, there is a risk of cutting the vines in the process, shortening them. Our study indicates that the shortening of vines by these methods may

enhance the problem by producing propagules, which are proliferative in nature and increase weed infestation in the subsequent year. Therefore, we conclude that for effectively controlling Japanese yams in tea gardens, either the vines should be pulled out completely, or a novel method should be developed to control them at the ground level.

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