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Effect of flowering slips on the yield of sweet potato (*Ipomoea batata* (L.) Lam.) tubers

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Creating a nursery for sweet potato cultivation in tropical and subtropical areas including Okinawa is not necessary because planting is possible throughout the year. In general, sweet potato blooms under natural conditions in tropical and subtropical areas. Sweet potatoes are grown from non-flowering slips, which farmers generally select from a field of a previous cropping. Although the selection and collection of non-flowering slips are very time-consuming, the effect on yield when flowering slips are used is unknown. This study sought to investigate the effect of flowering on sweet potato yield. The results revealed no significant difference in yield between flowering and non-flowering slips. This can significantly reduce the preparation time of slips, shorten the working time of the farmers and is useful for sweet potato cultivation in tropical and subtropical areas.

Key words: Convolvulaceae, sweet potato cultivation, weevil damage.

INTRODUCTION

Sweet potato (*Ipomoea batata* (L.) Lam) is one of the world's most important crops, and it is extensively cultivated in developing countries. Sweet potatoes are highly nutritious, used for a wide variety of purposes, including as food, in processed products and animal feed, and as a source of alcohol, starch, flour and pigments. Sweet potato is currently ranked as the seventh most important crop in the world with a total production of 103 MT in 2013 (FAOSTAT, 2015). Asia is the world's largest producer of sweet potatoes (accounting for up to 76.1% of world production in 2013), followed by Africa (19.5%) (FAOSTAT, 2015). The top five sweet potato-producing nations in 2014 were China, Nigeria, Uganda, Indonesia, and the United Republic of Tanzania (FAOSTAT, 2015). After potato (*Solanum tuberosum* L.) and cassava (*Manihot esculenta* Crantz), sweet potato is the third most important root crop in the world (FAO, 1998). Total production in Okinawa, a subtropical island in southern Japan, is 4,810 t (Japan Ministry of Agriculture, Forestry and Fisheries, 2016).

Usually, sweet potato cultivation in mainland Japan starts between May and June, harvesting takes place in

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November at the latest to prevent damage to the plants by frost during winter in mainland Japan. Therefore, slips for planting are obtained from the seed tuber every year. In tropical and subtropical areas including Okinawa and Thailand, however, cultivation is usually possible throughout the year. Therefore, unlike the cultivation in mainland Japan, slips for the following year are not obtained from seed tubers, but it is more common to use slips from the field. The planting term for sweet potato in Okinawa is twice a year; a spring term (planting from March to May) and an autumn term (planting from September to October). Sweet potatoes produce flowers in preparation of the slips needed for planting in early spring and early autumn in Okinawa. In general, desirable slips for planting have enough energy for vegetative growth such as rooting and plant extension. Flowering plants appear to be unsuitable for slips compared with non-flowering plants because of the energy needed for generative growth. In crops like sugarcane, flowering was found to reduce the cane yield and quality (Rao 1977). Similarly, tuber quality in yam bean (a leguminous root crop) was also affected by flowering compared to non-flowered plants (Vimala and Nambisan, 2005). Furthermore, it is important to avoid lottery because reproductive growth accompanied by bolting significantly degrades the quality of roots in the cultivation of Japanese radish (Amagasa et al., 1993). Therefore, sweet potato farmers prepare the slips from non-flowering plants. Choosing non-flowering slips from the nursery wastes time and labor, although ease of making flowers differs with cultivar and environment. In addition, by collecting only non-flowering slips that, it is the current situation is the number of slips is insufficient. Reports studying the effect of non-flowering or flowering slips on tuberous root have yet to be published in sweet potato, although the physiological condition of the slips is known to be different between the vegetative and generative stages. Thus, we investigated the number and weight of the tubers grown from non-flowering or flowering slips and then estimated those tuber yields.

On the other hand, the sweet potato weevil, *Cylas formicarius* (Fabricius) and the West Indian sweet potato weevil, *Euscepes postfasciatus* (Fairmaure) are major pest of the genus Ipomoea. In particular, two spices of weevils have caused enormous economic damage to farmers cultivating the sweet potato, in countries in Central and South America, the South Pacific Islands (Sherman and Tamashiro, 1954), and the Nansei Archipelago, which includes Okinawa prefecture, Japan. In Japan, the shipping of sweet potatoes from infested to un-infested regions is restricted by Plant Protection Law in order to prevent the spread of these weevils. The existence of the weevil is an obstacle to Okinawa's agricultural advancement. These weevils can reduce tuber production by the plant to 0% in the worst cases (Talekar, 1988). Insecticides are the primary methods of control, although they are not always effective because of the cryptic behavior of the weevil (Jansson, 1992). The mode of damage is unique in that a weevil eating a tuber may cause relatively little physical damage to the tuber, mostly creating cosmetic problems on the surface or in the flesh. However, infestation by one weevil induces the production of secondary metabolites, ipomeamarones belonging to the sesquiterpene class, which reduce the tuber value. The ipomeamarones not only cause the tuber to taste bitter and astringent, but also are toxic to animals (Uritani, 2001). Damaged tubers, therefore, cannot be used for any purpose (Jansson and Raman, 1991; de Menezes, 2002). Therefore, we also investigated tuber root damage by two species of weevil, which can lead to significant decreases in sweet potato yield in subtropical and tropical areas.

MATERIALS and METHODS

Plant materials and experimental site

Sweet potato cultivar *Churakoibeni*, which is found in > 50% of Okinawa, was used as the plant material. This cultivar contains high amounts of purple pigments and is mainly used as a raw material for processing paste, which is used for souvenir sweets. Field experiments were carried out at Okinawa Prefectural Agriculture Research Center in Itoman, Okinawa, Southern Japan, located in a subtropical area. The soil in the experimental field is alkalescent, rich, clay soil called the *Jahgaru* in Okinawa, which is suitable for agricultural activities.

Experimental design

Planting and harvesting were done on April 27, 2017, and October 6, 2017, respectively. The sweet potato plants were grown for 162 days. The slips prepared were 120 vine cuttings, each about 30 cm long; the slips from non-flowering vines are referred to as *normal slips* and those from the flowering vines as *flowering slips* as shown in Figure 1. The slips were planted on ridges by inserting the basal portions at a depth of 10 cm into the soil and a distance of 30 cm between plants and 80 cm between rows. The ridges were at a height of 30 cm and a width of 80 cm and were 32 m long. The experiment was performed using a split-plot design with two treatment plots of different growth phase slips (vegetative growth, normal slip and generative growth and flowering slip) and replicated six times on the two ridges. Each plot consisted of 20 plants, and each treatment plot was alternately assigned to two ridges as a checkered pattern. Therefore, a total of 240 slips were planted.

Yield analysis

The tuber number and weight were determined for all plants. The tubers of interest were those >1 cm in diameter. The harvested tubers were first sorted by the below sizes in every replication of each plot after taking them out of the soil. The size of tuber was investigated and classified as follows; S: ~50 g, M (m and 2 m): 51-150 g; (51-100 and 101-150 g, respectively), L: 151-250 g, 2L: 251-350 g and 3L: ≥ 351 g. The reason for dividing the M size, which is a general standard in Japan, into m and 2 m is because the processers in Okinawa can mostly use tubers > 100 g. The number and weight of tubers were measured in each sorted size, and then the yield per hectare was estimated using the average weight per plant. To statistically evaluate the different tuber numbers or weight

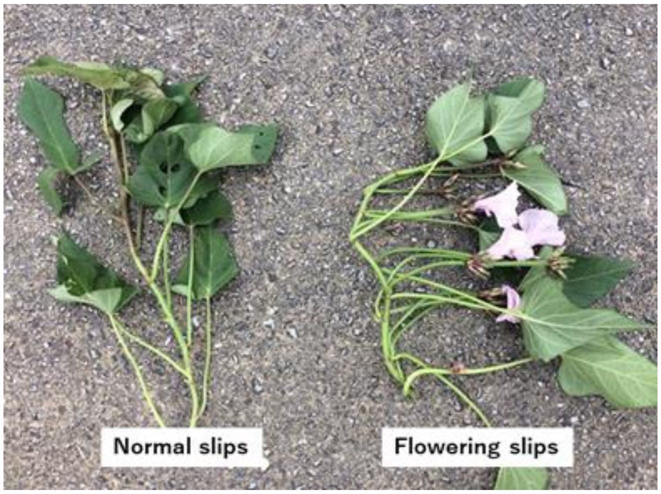

Figure 1. Normal (non-flowering) and flowering slips used for experiment.

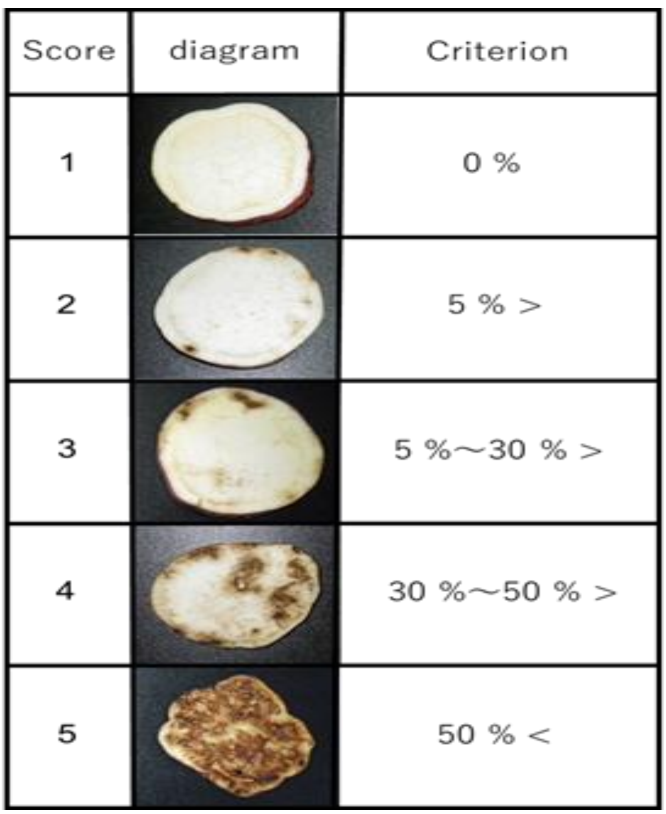

Figure 2. Score of tuber damage according to the maximum damaged area on the cross section of the tuber. 1. No symptoms of weevil infestation. 2. Less than 5% damaged. 3. 5 to 30%. 4. 30 to 50%. 5. Above 50%.

by whether the slip has flowers or not, data were analyzed using a one-way analysis of variance (ANOVA; α = 0.05) using the square root of the number or weight in each replication of each plot.

Weevil damage analysis

Damage by weevil was investigated using the tuber damage rate and the damage score ranging from 1 (healthy) to 5 (serious damage). The tubers were randomly selected (10 from every size of each plot); thus, a total 50 tubers per plot were investigated. To verify fresh weevil damage, each tuber was sliced into 3 mm thick segments. When weevil damage was verified in at least one of the segments, that tuber was considered *damaged*. The damage rate was calculated by the number of damaged tubers of the total number of tubers (50). The damage score was rated in five ranks as presented in Figure 2. To statistically evaluate the different weevil damage rate by whether the slip had flowers or not, data were analyzed using chi-squared test (α = 0.05). The mean score was then calculated in each plot. To statistically evaluate the different weevil damage score by whether the slip has flowers or not, data were subjected to one-way ANOVA (α = 0.05).

RESULTS AND DISCUSSION

In tropical and subtropical areas, sweet potatoes can be grown throughout the year; however, this requires preparation of planted slips, and preparation of nurseries every time requires a great deal of effort. Therefore, in these areas, it is common practice to take slips from a field under cultivation or from a field just before harvest. However, when the sweet potato is harvested in autumn or spring, it overlaps with the sweet potato flowering time, and flowering is seen in many fields. At the time of harvesting from these fields, farmers choose to harvest slips that have not flowered. These operations are very complicated, and sufficient slips cannot be secured by only selecting slips that have not flowered. The disadvantages of using flowering slips for planting have not been scientifically proven, and the effect of flowering on sweet potato yield has not been elucidated.

The average tuber numbers of normal and flowering slips were 81.3 and 83.3, respectively, and the average numbers of tubers weighing >100 g, for shipping to customers were 46.3 and 43.0, respectively. The flowering slip of the 2 m size was significantly ($P < 0.05$) higher than the normal slip; however, there was no significant difference among all the other sizes as shown in Table 1. Next, the average tuber weight of the normal and flowering slips were 12.1 and 10.8 kg, and the average number of tubers weighing >100 g, for shipping to customers, were 10.1 and 8.65 kg, respectively. As well as tuber number, the flowering slip of the 2 m size was significantly ($P < 0.05$) higher than the normal slip; however, there was no significant difference among all the other sizes as described in Table 2. The number of plants investigated for the normal and flowering slips were 117 and 111, respectively, due to missing plants. The total putative yield per hectare of normal and flowering slips were 28.7 and 30.4 t, respectively, and the total putative yield per hectare of tubers weighing >100 g, for shipping to customers, were 24.1 and 24.3 t, respectively. As you can see from the standard ratio line, these yields were not fairly varied between the plots as

Table 1. The average number of tuber and statistical analysis (P > 0.05) in each size.

Tuberous size		Average		$F_{1,10}$	*P*
		Normal	Flowering		
S		15.3	19.0	1.285	0.283
M	m	19.7	21.3	0.123	0.733
	2m	14.8	19.8	5.531	0.041
L		18.7	14.3	1.032	0.334
2L		7.67	6.00	0.928	0.358
3L≦		5.17	2.83	1.018	0.337
S-3L≦		81.3	83.3	0.043	0.840
M2-3L≦		46.3	43.0	0.248	0.629

Normal and flowering of number of samples were 117 and 111, respectively.

Table 2. The average tuber weight (kg) and statistical analysis (P > 0.05) in each size.

Tuberous size		Average		$F_{1,10}$	*P*
		Normal	Flowering		
S		0.51	0.60	0.976	0.347
M	m	1.45	1.58	0.147	0.709
	2m	1.81	2.48	5.239	0.045
L		3.61	3.15	0.322	0.583
2L		2.27	1.75	0.958	0.351
3L≦		2.43	1.26	1.210	0.297
S-3L≦		12.1	10.8	0.361	0.561
M2-3L≦		10.1	8.65	0.541	0.479

Normal and flowering of number of samples were 117 and 111, respectively.

Table 3. The putative yield (t/ha) in each size.

Tuberous size	S	M		L	2L	3L≦	S-3L≦	M2-3L≦
		m	2m					
Normal	1.21	3.44	4.30	8.60	5.40	5.78	28.7	24.1
Flowering	1.69	4.44	6.98	8.86	4.93	3.53	30.4	24.3
Standard ratio	140%	129%	162%	103%	91%	61%	106%	101%

presented in Table 3. Although it is not significantly different, the flowering slip tend to give higher yield of tubers under the L size than the normal slip and lower yield of those over 2 L. However, the significant difference observed was only 2 m size. The weevil damage rates of the normal and flowering slips were 14.0 and 18.0%, and the damage scores were 1.22 and 1.36, respectively. The difference in damage rate and score was not significant between the plots. In other words, the yield did not significantly decrease by weevil damage between normal and flowering slips (Table 4).

Our study revealed that there is no significant difference between the normal and flowering slips in total number, total weight, yield and weevil damage as shown in Figure 3. Furthermore, the only difference was with the 2 m size, where the flowering slip had a significantly higher tuber number and weight than the normal slip; however, the difference in all the other sizes was not significant. The

Table 4. The weevil damage rate (%), average damage score and statistical analysis (P > 0.05).

	Damage rate		Damage score		
	%	**X^2**	**Average**	**$F_{1,98}$**	***P***
Normal	14.0	0.415	1.22	0.998	0.320
Flowering	18.0		1.36		

Figure 3. Comparison with normal (non-flowering) and flowering slips of yield in the each size. *The size to sort was S: ~50 g, M (m and 2m): 51 g~150 g (51-100 g and 101-150 g, respectively) L: 151-250 g, 2L: 251-350 g and 3L: ≦351 g. 20 plants / quadra × 6 replications: total of 120 plants.

reason the 2 m size was significantly different may be due to its 162-day plantation period. If the plants are harvested before this period, this significant difference may occur in sizes smaller than the 2 m size. The most important point is that there is no significant difference in the total tuber number, weight, and yield. However, in the putative yield, flowering slip seemed to be higher in sizes under the L size compared with the normal slip and seemed to be lower in sizes over 2 L as shown in Table 3. Therefore, we considered that the final yield of flowering slip was the same as that of the normal slip because the tuber number in the smaller sizes was higher compared with the normal slip.

Flowering cultivars turn nutrients into flowers and seeds, so it may not be good to grow larger tubers in root crops. Tuber yield and quality are the primary characteristics of interest in a potato cultivar. Literature on potatoes and other crops indicates that there is often an inverse relationship between growth of floral parts and vegetative organs. Reports of fruit and seed production inhibiting vegetative growth have been published on tomato (Murneek, 1932), cotton (Eaton, 1931) and potato (Proudfoot, 1965). However, some reports on potato suggest there is no consistent relationship between fruit production and tuber yield (Kidane-Mariam and Peloquin, 1974). In addition, Gonzalez-Schain and Suarez-Lopez (2008) reported that tuber yield, a trait of high agronomic relevance, was significantly increased in pACo plants expressing moderate CONSTANS (CO) level. These results indicate that CO affects flowering and stem elongation through distinct mechanisms and suggest that its effects on flowering and tuberisation in potato are photoperiod-independent. Onoda (1965), using past data, showed that the yield of varieties varied based on the degree of flowering in sweet potato. As a result, 88% of all varieties are flowering, and they include low and high yields of both flowering and non-flowering varieties (Onoda, 1965). It became clear that there is no relationship between the presence or absence of flowering and yield. Kandiannan et al. (2015) reported that fresh and dry yield, dry recovery and curcumin content did not differ between flowered and non-flowered plants and it is concluded that flowering in turmeric would not have any impact on yield and quality. Our report also confirms that there is no significant difference in yield when using flowering slips as compared with when using non-flowering slips. Therefore, we reason that the distribution of nutrients sent to flowers and seeds, and stored nutrients sent to roots occurs through two non-competing mechanisms.

Conclusion

In conclusion, in tropical and subtropical areas, such as Okinawa and Thailand, sweet potato flowers bloom in preparation of the slips for planting. Using flowering slips however may negatively affect yield; thus, sweet potato farmers prepare non-flowering slips, spending much time and labor. Our study revealed that there is no significant difference between non-flowering and flowering slips in the amount of yield. From these results, we suggest that farmers can efficiently cultivate sweet potato without spending excessive time preparing non-flowering slips. It contributes significantly in the field of sustainable agriculture and food security.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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