ジネンジョの新芋と花穂の発育に及ぼす日長と植物生長調整物質の組み合わせ処理の影響

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Interaction between Effects of Photoperiod and Plant Growth Regulators on the Development of Tubers and Inflorescences in Japanese Yams (*Dioscorea japonica*)

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Summary

The interaction between 8- and 24-hr photoperiods and plant growth regulators (PGR) (gibberellin A_3 (GA_3) and uniconazole-P (Uni)) on the development of the main shoots, aerial tubers (bulbils) and new tubers (below ground), and inflorescences (spikes) in Japanese yam (*Dioscorea japonica* Thunb.) plants was examined. Within the same PGR treatment, the main shoots of plants grown under the 24-hr photoperiod (constant light, LD) were longer than those grown under the 8-hr photoperiod (SD) in all season; under LD and SD, the main shoots of the GA_3-treated plants were the same size as shoots sprayed with water (control), whereas the main shoots of the Uni-treated plants were significantly shorter. Under LD, whereas the control and PGR-treated plants produced a negligible amount of aerial tubers, under SD, their development was severely inhibited by GA_3 treatment. During the early growing period, the fresh weight of new tubers and that of the combined fresh weight of aerial and new tubers in plants grown under SD were heavier than those grown under LD. From the middle to the end of the growing period, the development of aerial and new tubers in plants grown under LD accelerated so that the difference between the final fresh weights of the combined fresh weight of aerial and new tubers in plants grown under SD and those grown under LD at harvest became small. Although, there was not such LD promoting effect of those growth as would be observed in *D.opposita* cv. Ichoimo and Nagaimo. Under SD, the new tubers development were significantly promoted by GA_3 treatment because the inhibition of aerial tubers development by GA_3 treatment promotes the diversion of photosynthates stored in shoots to growth of new tubers. Under SD, plants grown developed one flush of inflorescences in June, whereas those grown under LD developed a flush in June and again in August through October. We conclude that the GA_3 and Uni had no significant effects on the ratio of plants that initiated flowers, the nodal position of the first and final spikes, and the total number of spikes per plant in both season of spikes development in the main shoots were not clear.

Key Words: *Dioscorea japonica*, photoperiod, plant growth regulator, spike, tuber.

Introduction

The combined effects of photoperiods, temperature, seed tuber weights, and plant growth regulators (PGR) on the growth of main shoots and the formation of aerial tubers (bulbils) and new tubers (below ground) and inflorescences (spikes) were previously examined (Yoshida, 2002; Yoshida et al., 2001, 2002) in Chinese yam plants (*Dioscorea opposita* Thunb.). We found that the yield of new tubers was increased by the gibberellin treatment, because the diversion of photosynthates stored in shoots to new tubers was promoted by the inhibition of aerial tuber and spike development, especially when combined with a 24-hr photoperiod. Japanese yam (*D. japonica* Thunb.) is the most expensive root vegetable in Japan because of its high viscosity and nutritional value, but because of its low yield of the new tubers, little or no efforts have been made to improve the species. The plants usually develop a large number of aerial tubers. Thus, we postulated that the yield of new tubers might be improved by gibberellin treatment by inhibiting bulbils development as in *D. opposita* cv. Ichoimo and Nagaimo. Yoshida et al. (2001, 2002) showed that the combined effect of photoperiod and PGR was greater than the effect of any single factor alone in Chinese yam plants. Therefore, in this study, the interactive effects of photoperiods and PGR on the development of the main shoots, and on the aerial and new tubers and spikes of the *D. japonica* plants were examined and the results compared with our previous findings with *D.opposita* cv. Ichoimo, Nagaimo, and Tsukuneimo.

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Materials and Methods

Plant materials and culture practices

Japanese yam (*Dioscorea japonica* Thunb.) tubers

were purchased from a seedling company and were selected by weight (0.8-1.2 kg) in early April 2001, when they were cut into 50 g (FW) pieces. These pieces of seed tubers were allowed to sprout for about one month in an unheated glasshouse at the Akita Prefectural College of Agriculture, and then transplanted into plastic pots (35 cm diam. × 50 cm height) on May 21, 2001. The most vigorous shoots were retained as the main shoot and were entwined on a 240 cm pole. The terminal 30 to 100 cm of the shoot was supported vertically; the remaining main shoots were coiled around the base of the pole. Initially, 0.3 g of magnesium lime and 0.6 g of NPK fertilizer (15 N-15 P_2O_5-15 K_2O) were added to each pot per liter of potting soil. Two grams per pot of the above fertilizer was supplied at the end of July and the end of August. Plants were irrigated as needed.

Treatment

The plants were grown in an unheated plastic house in which the photoperiod treatments were started on June 4, 2001. The plants, exposed to both an 8-hr photoperiod (SD) and 24-hr photoperiod (constant light, LD), were grown under natural sunlight between 8:40 and 16:40 and covered with silver polyethylene film (100% shading material) between 16:40 and 8:40. The plants in the LD were irradiated by incandescent lamps (about 2.0 μmol· m^{-2}· s^{-1}) between 16:40 and 8:40. These treatments were continued until the end of November (SD) and mid-December (LD), when shoots became dormant and underwent dieback. A combination treatment of photoperiod and PGR was started on June 11, when the main shoots reached 100 cm. The plants were sprayed at weekly interval with the gibberellin A_3 (100 ppm GA_3) and uniconazole-P (25 ppm Uni) containing 0.01% Tween 20 until run-off. The PGR treatment were stopped when the main shoots ceased elongating on August 27 in the SD group and November 11 in the LD group. The control plants were sprayed to run-off with distilled water plus 0.01% Tween 20. Each treatment group consisted of 12 plants.

The fresh weights of the aerial and new tubers were recorded three times: 1) on August 15, when the main shoots stopped growing in the SD group, 2) October 8, when the main shoots stopped growing in the LD group, and 3) at the end of December, when the shoots of both groups had died. Three or four plants were harvested on each sampling date.

Results and Discussion

Shoot growth

The main shoots of plants grown under SD stopped growing in early August, whereas those grown under LD stopped elongating in mid-October (Fig. 1). The period by cessation of shoot growth under SD was intermediate between that of *D. opposita* cv. Ichoimo and Nagaimo grown under SD, however, the shoot elongation period under LD was significantly extended compared with cv. Ichoimo, Nagaimo, and Tsukuneimo grown under LD (Yoshida, 2002; Yoshida et al., 2001, 2002). Under SD, the shoots of GA_3-treated plants died back after the leaves turned yellow on November 12, followed by the control and Uni-treated plants on November 19 (Table 1). Under LD, the shoots died back before the leaves turned yellow in the control and PGR-treated plants on December 17. The process of the shoots dieback in *D. japonica* under LD seemed to reflect the continued elongation of the main shoots until the end of the growing stage. Under SD and LD at the time of shoot dieback, the lengths of the main shoots of the control and GA_3-treated plants were longer than those of the Uni-treated plants, but within the same PGR treatments, the main shoots of the plants grown under LD were longer than those grown under SD. This result corresponded to our previous findings with cv. Ichoimo, Nagaimo and Tsukuneimo (Yoshida, 2002; Yoshida et al., 2001, 2002).

The number of leaves in the plants grown under SD stopped increasing after early August, whereas those grown under LD stopped increasing after mid-October (Fig. 2). Within the same PGR treatments, plants grown under LD had more leaves than those grown under SD. At the time of shoot dieback, the number of leaves on the main shoots was decreased by GA_3 treatment of

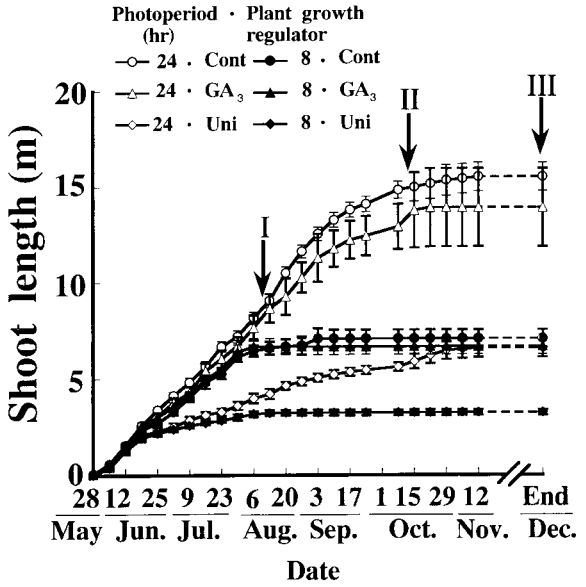

Fig. 1. Growth curves of the main shoots of Japanese yam (*D. japonica*) plants treated with GA_3 and Uni and grown under 8- and 24-hr photoperiods. Vertical bars represent SE (n= 10 to 12 (May 28 to Aug. 13), 7 to 9 (Aug. 20 to Oct. 8), and 5 to 7 (Oct. 15 to end of Dec.)). Arrows indicate harvest dates of aerial and new tubers; I: August 15. II: October 8. III: at the time of shoot dieback at the end of December. Cont, (control plants sprayed with distilled water); GA_3, gibberellin A_3 (100 ppm); Uni, uniconazole-P (25 ppm).

Table 1. Interaction between photoperiod and plant growth regulators on the development of spikes (inflorescences) in Japanese yam (*D. japonica*) plants.

Photo-period (hr)	Plant growth regulator[x]	No. of plants observed	The first spike group[z]				The second spike group[y]				Date of shoot dieback
			Occurrence of plants with a spike (%)	Nodal position of the first spike	Nodal position of the final spike	Total no. of spikes / Plant	Occurrence of plants with a spike (%)	Nodal position of the first spike	Nodal position of the final spike	Total no. of spikes / Plant	
8	Cont	12	10 (83)	19.9 a[w] (Jun. 18[v])	51.4 ab (Jul. 16[u])	23.8 b	0 (0)	-	-		Nov. 19
8	GA_3	12	11 (92)	17.1 a (Jun. 18)	43.5 b (Jul. 16)	30.4 ab	0 (0)	-	-	-	Nov. 12
8	Uni	12	12 (100)	17.8 a (Jun. 18)	65.8 a (Jul. 16)	49.2 a	0 (0)	-	-	-	Nov. 19
24	Cont	12	12 (100)	17.1 a (Jun. 18)	50.4 ab (Jul. 9)	34.3 ab	4 (33)	152.0 a (Aug. 20)	209.3 a (Oct. 8)	58.3 a	Dec. 17
24	GA_3	12	10 (83)	19.0 a (Jun. 18)	59.2 ab (Jul. 2)	40.5 ab	4 (33)	106.0 a (Aug. 6)	134.3 a (Sep. 17)	37.7 a	Dec. 17
24	Uni	12	11 (92)	17.5 a (Jun. 18)	55.2 ab (Jul. 9)	41.9 ab	3 (25)	142.3 a (Sep. 3)	181.3 a (Oct. 8)	40.0 a	Dec. 17

[z,y] There were two flushes of spike development in the main shoots of Japanese yam plants. The June flush is referred to as the first; that of August, September, and October is referred to as the second spike group.

[x] Cont, (control plants sprayed with distilled water); GA_3, Gibberellin A_3 (100 ppm); Uni, Uniconazole P (25 ppm).

[w] Values in the same column followed by the same letter are not significantly different as determined by Tukey's compromise test ($P \leqq 0.05$).

[v,u] Date indicates the emergence of flower buds on 50% or more plants.

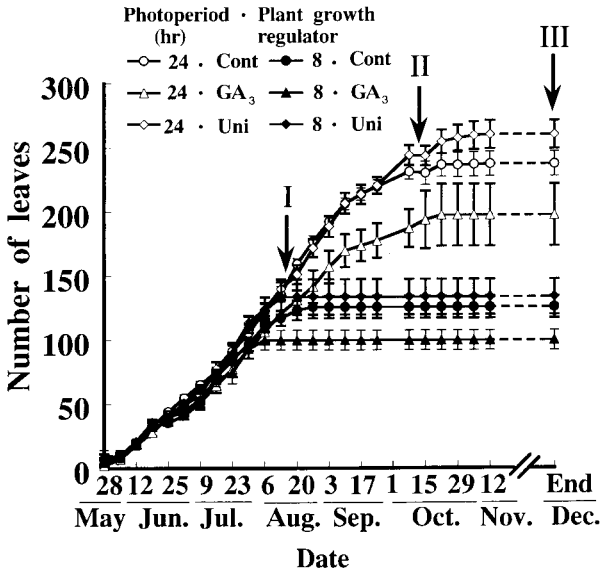

Fig. 2. Cumulative increase in the number of leaves in the main shoot of Japanese yam (*D. japonica*) plants treated with GA_3 and Uni and grown under 8- and 24-hr photoperiods. Vertical bars represent SE (n= 10 to 12 (May 28 to Aug. 13), 7 to 9 (Aug. 20 to Oct. 8), and 5 to 7 (Oct. 15 to end of Dec.)). Arrows indicate harvest dates of aerial and new tubers; I: August 15. II: October 8. III: at the time of shoot dieback at the end of December. Plant growth regulator treatments are as described in Fig. 1.

plants grown under SD and LD, similar to *D. opposita* plants (Yoshida, 2002; Yoshida et al., 2001, 2002) and *D. alata* plants (Onjo and Hayashi, 2001; Onjo et al., 1999). To reverse the negative effect of the GA_3 treatment, we need to investigate the method of GA_3 application, its timing, frequency, and intervals.

Aerial and new tuber development

At the initial harvest on August 15, when the main shoots under SD had ceased to elongate, the control and Uni-treated plants grown under SD had produced a few aerial tubers, while the GA_3-treated plants produced even less (Fig. 3). Under LD, the control and PGR-treated plants produced a negligible amount of aerial tubers. There were small differences in new tuber yields among the control and PGR-treated plants in both photoperiod. Within the same PGR treatment, the fresh weight of new tubers and that of the combined fresh weight of aerial and new tubers per plants under SD were heavier than those under LD. Thus, LD severely delayed the start of aerial and new tuber development which coincides with the cessation of shoot growth in *D. opposita* and *D. japonica* (Hori, 1984; Yoshida, 2002). These results indicate that *D. japonica* plants are quantitative short-day plants on the development of aerial and new tubers, similar to *D. opposita* plants (Garner and Allard, 1923; Sato, 1964; Yoshida, 2002; Yoshida et al., 2001, 2002) and *D. alata* (Hayashi and Ishihata, 1991; Shiwachi et al., 1999, 2000).

By the second harvest of tubers on October 8, the main shoots under LD had ceased to elongate. Under SD, the largest aerial tuber on a Uni-treated plant

weighed 64.4 g, while that of the control weighed 49.5 g; none were available from the GA_3-treated plants. Under LD, the control and PGR-treated plants produced few aerial tubers. Under SD and LD, the fresh weights of new tubers in the GA_3-treated plants seemed heavier than those in the control and Uni-treated plants, but within plants exposed to the same PGR treatment, the fresh weights of new tubers under SD were heavier than those grown under LD.

At final harvest at the end of December, plants grown under LD had produced only a negligible amount of aerial tubers (Fig. 3), whereas under SD, the fresh weights of aerial tubers in the control plants were heavier than those of Uni-treated plants; those from GA_3-treated plants were negligible. However, the fresh weights of new tubers in the GA_3-treated plants were heavier than those of control and Uni-treated plants. The inhibition of aerial tubers by the GA_3 treatment is thought to have partitioned the photosynthates stored in shoot to growth of new tubers, similar to *D. opposita* cv. Ichoimo and Nagaimo (Yoshida et al., 2001, 2002). To increase the yield of new tubers in *D. japonica* plants, this GA_3 treatment would be a very useful practical cultural technique. Furthermore, the reduction on the formation of aerial tubers would decrease the vegetation control (weed) problem. However, under LD, the fresh weight of new tubers with the GA_3-treated plants was equal to the control plants so there was no economic advantage. We attribute this to the LD inhibition of aerial tubers development. Within the same PGR treatments, except for the control plants, the fresh weight of new tubers and that of combined fresh weight of aerial and new tubers in plants grown under SD was heavier than those grown under LD. These results differ from our previous findings with cv. Ichoimo and Nagaimo in which the total yield under the 24-hr photoperiod at final harvest was equal to or heavier than those grown under the 8-hr photoperiod (Yoshida et al., 2001, 2002). The difference in the effect of photoperiod on the development of aerial and new tubers between *D. japonica* plants and both cv. Ichoimo and Nagaimo is attributed to the continued elongation of the main shoots in the former under LD, unlike that in SD plants. We supposed that the continued vegetative growth severely delayed tubers growth under LD.

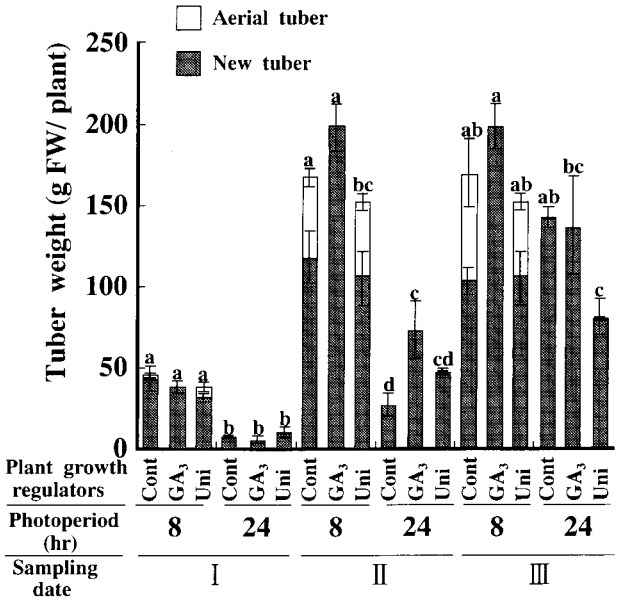

Fig. 3. Interaction between photoperiods and plant growth regulators on the fresh weight of aerial and new tubers in Japanese yam (*D. japonica*) plants. Harvest was conducted on August 15 (I), October 8 (II), and at the time of shoot dieback at the end of December (III). Vertical bars represent SE (n= 3 (I), 3 (II), 3 or 4 (III)). Mean separation for the total fresh weight of aerial and new tubers in each sampling date by Fisher's protected LSD test ($P \leq 0.05$). Plant growth regulators treatments are as described in Fig. 1.

Spike development

That plants grown under SD had only one flush of spike development in June, whereas plants grown under LD had a flush of spike developments in June and again August through October (Fig. 4) differs significantly from our previous findings regarding cv. Ichoimo, Nagaimo, and Tsukuneimo, which exhibited only one flush of spike development (Yoshida, 2002; Yoshida et al., 2001, 2002).

In the first season (June) of spike development, the ratio of plants that developed spikes in the plants grown under SD and LD was 10 to 12, respectively out of 12 plants (83 to 100%). The nodal position of the first spikes was about 20 nodes in all treatments and they emerged on June 18 (seven days after the combination treatments) in plants grown under both photoperiods.

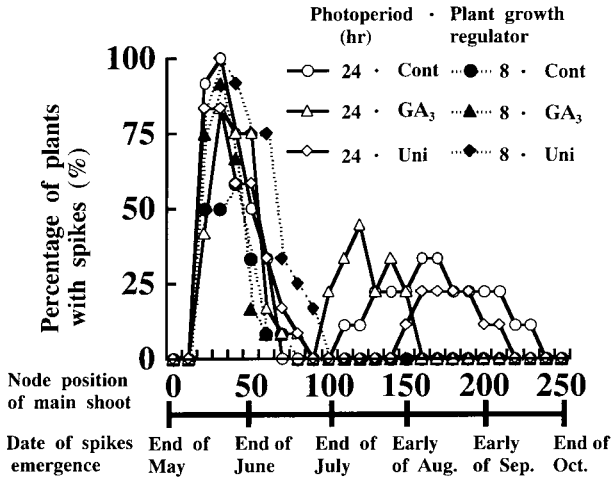

Fig. 4. Interaction between photoperiods and plant growth regulators on the percentage of plants with spikes per node on the main shoots in Japanese yam (*D. japonica*) plants. Plant growth regulators treatments are as described in Fig. 1. Data in the x-axis indicate date of emergence of spikes from plants grown under the 24-hr photoperiod.

These results indicate that the floral initiation was underway before the interactive effects of the photoperiod and plant growth regulators could come into play. As the difference of spikes development by photoperiod treatment was increased in plants from the smaller seed tubers in *D.opposita* plants (Yoshida, 2002), we should pursue this interactive aspect along with the effects of photoperiod and PGR. Furthermore, the nodal positions and the date of emergence of the first spikes in cv. Ichoimo, Nagaimo, and Tsukuneimo in the first season ranged from 41 to 65 nodes and 20 to 30 days after combined PGR treatment (Yoshida, 2002; Yoshida et al., 2001, 2002). These data indicate that flower bud initiation occurs very early in *D. japonica* plants. Under SD, the nodal position of the final spikes and the number of spikes per plant in Uni-treated plants tended to be higher but insignificant compared with the control and GA_3-treated plants. Likewise, under LD, the nodal position of the final spikes and the number of spikes per plant were the same. Hence, within the same PGR treatments, the nodal position of the final spikes and the number of spikes were not significantly different in plants grown under SD and LD.

During August to October, plants grown under LD developed spikes, but those under SD did not. This result could be attributable to the extend period of main shoots growth; that is, by August and October, elongation of the main shoots on plants grown under SD had already ceased. Temperature might be a factor with the two-peaks of spike development in plants grown under LD. Spike development in cv. Ichoimo was inhibited by high temperatures (Yoshida, 2002), so that heat stress might also inhibit spike development in *D. japonica* plants grown under LD, but induce regrowth as the weather cools. Hence, further study should investigate the effect of high temperature on spikes development. The ratio of plants that developed spikes in the control and PGR-treated plants was 3 to 4, respectively out of 12 plants (25 to 33%). With such large variances, no statistical differences among PGR treatments in the nodal position of first and final spikes, and in the number of spikes per plants could be established.

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ジネンジョの新芋と花穂の発育に及ぼす日長と植物生長調整物質の組み合わせ処理の影響

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摘　要

ジネンジョの主枝，むかご，新芋および花穂の発育に及ぼす日長とジベレリン (GA_3)またはウニコナゾール P (Uni)との組み合わせ処理の影響について調べた．その結果，同じ植物生長調整物質処理区間で比較した場合，主枝の長さは8時間日長より24時間日長で長く，8時間日長，24時間日長ともに，主枝は対照と GA_3 で同じ程度発育し，Uni で著しく抑制された．24時間日長では，むかごはほとんど発育せず，8時間日長でのむかごの発育は，GA_3 で著しく抑制された．新芋およびむかごと新芋を合わせた新鮮重は，発育初期には，8時間日長の方が24時間日長より大きかったが，24時間日長では，発育中期～後期の期間に，むかごと新芋の発育がかなり進行し，最終的には8時間日長との差は縮まった．しかしながら，‘ナガイモ’と‘イチョウイモ’でみられたような24時間日長の促進効果はみられなかった．8時間日長で，新芋の発育が GA_3 で著しく促進されたのは，GA_3 によりむかごの発育が抑制された結果，枝に蓄えられた光合成産物が新芋に効率よく転流されたためと考えられる．花穂発育の時期は，8時間日長で6月に認められたが，24時間日長では6月と8~10月の2回認められた．1回目と2回目の花穂発育時期において，花穂発育個体率，第1と最終花穂着生節位および1株当たり花穂数に及ぼす植物生長調整物質の影響は明瞭でなかった．