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Branch Formation and Yield by Flower Bud or Shoot Removal in Tomato

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Additional information is available at the end of the chapter

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Abstract

Branch formation might be used as indices for improving productivity in tomatoes. However, there has been little research to elucidate the relationship between the emergence of terminal flower bud (TFB) and the elongation of lateral shoots. Therefore, the effects of flower bud or shoot removal on plant growth, flowering, and yield were investigated. In indeterminate cultivar, the lateral shoot of the second node below TFB was suppressed by flower bud removal but not by shoot removal compared with untreated plants. In determinate cultivar, the opposite results were observed. TFB emergence was affected and not affected during lateral shoot elongation of both type cultivars, respectively. In determinate-type tomato, growth, dry weight, and the distribution of nitrogen and calcium in the lateral shoots in the pinching treatments (shoot removal) were greater than those in the control. The flowering periods and number of flowers per lateral shoot in the pinching treatments were shorter and greater, respectively, than those in the control. Initial weekly yields in the pinching treatments were increased compared with those in the control. From these results, since the branch formation and productivity by flower bud or shoot removal was clarified, it would be useful information for future tomato production.

Keywords: flower bud, lateral shoot, morphogenesis, *Solanum lycopersicum*, yields

1. Introduction

Tomatoes are an important fruit vegetable in many countries. Tomato plants differentiate terminal flower buds (TFB) on the apex of the main stem and formed flower truss, known as the determinate pattern with branching characteristics [1, 2]. The axillary bud (AB) adjacent to TFB differentiates and forms a lateral shoot as a sympodial branching. As mentioned above, the lateral shoot that grows as a main branch is a characteristic of indeterminate-type

tomatoes that are cultivated mainly for the fresh market. On the contrary, determinate-type tomatoes with a self-pruning growth habit with only short sympodial branches form a few flower trusses [3]. These cultivars are mainly grown for processing and cooking tomatoes [4].

In general, the lateral shoots of indeterminate tomato cultivars are periodically removed to prevent nutrient competition between vegetative and reproductive organs during cultivation period. Several lateral shoots extends greatly unless all the lateral shoots are removed [5]. Since the sink strength of lateral shoots with flower buds and trusses is stronger than that of the main stem or lateral shoot without flower buds and trusses [6], strong growth of some lateral shoots may cause uneven distribution of photosynthetic products, resulting in undesirable effects on fruit production. As an example of using lateral shoots, during tomato cultivation during winter in the Netherlands, lateral shoots generated from the first or second nodes below TFB are used to increase stem numbers per area in indeterminate cultivars and increase tomato yield [7]. The utilization of lateral shoots can both promote high-quality fruit production [8–10] and also increase crop yield [11]. In contrast, for determinate tomato cultivars, lateral shoots are generally not removed to save labor and ensure yield [12–15]. However, lack of fruit set on the first flower truss due to low or high temperatures or rainfall or due to pinching at the seedling stage could affect the lateral shoot lengths and flowering periods of determinate processing tomatoes.

Differentiation of AB occurs at every node during the growth of most commercial cultivars. Although AB at lower nodes extends during the vegetative stage, AB at the upper nodes below TFB does not extend much due to apical dominance [1, 16]. When TFB at the shoot apex emerges and grows, the entire AB in general begins to elongate. Branch formation in indeterminate cultivars differs from that in determinate ones because of generally remaining the lateral shoots. Also, to investigate the growth properties of lateral shoots generated from each node could be used to increase productivity in tomato cultivation.

The growth of lateral shoots in the indeterminate cultivars can be extended by pinching (shoot removal) from the results of the previous reports [17–20]. In some tomato cultivars, the numbers and weights of fruits that grew on double-stemmed plants created by pinching treatments were greater than those that grew on single-stemmed plants [21–23]. Pinching at the seedling stage can increase the number of double clusters and flowers on lateral shoots of cherry tomatoes [24, 25]. Pinching is often performed to increase initial tomato yield, but there are differences among cultivars as to the effects of pinching [26, 27]. In addition, the lengths of the lateral shoots at each node do differ depending on the pinching position [14]. As the number of remaining true leaves is increased by pinching, there is a difference among the lateral shoot lengths. Since a relationship among the lengths of lateral shoots, the number of flowers per plant, and per lateral shoot is expected to be changed by pinching in determinate processing tomatoes, growth of the lateral shoot would be influenced by the uptake and distribution of mineral nutrients in each organ. Furthermore, because pinching can enhance the uniformity of fruit maturity [14], pinching could shorten the harvest term while also, due to this shorter flowering period, leading to harvest periods with more than 80% total fruit yield.

However, there has been little research to elucidate the relationships between the TFB and the elongation of lateral shoots in indeterminate and determinate-type tomatoes. Furthermore,

there has been little information about the effects of pinching treatments on the harvest term, yield, growth of lateral shoots, flowering, and number of flowers in determinate processing tomatoes, and about the relationship between the growth of lateral shoots and the uptake of mineral nutrients. Therefore, the objective of this study was to clarify and summarize the effects of flower bud or shoot removal on these parameters based on the previous research [28, 29].

2. Materials and methods

2.1. Lateral shoot elongation after terminal flower buds (TFB) and shoot (including TFB and axillary bud (AB) at the first node below TFB) removal

2.1.1. Plant materials, cultivation, and treatments

Indeterminate-type “Mini Carol” (*Solanum lycopersicum* L.) (Sakata Seed Co. Ltd., Japan) and determinate-type “Suzukoma” (Tohoku Agricultural Research Center, National Agriculture and Food Research Organization and ZEN-NOH, Japan) were used for this experiment. Seeds were sown in plastic containers (34.5 × 27.0 × 7.5 cm). One plant was potted black plastic pots at a ratio of sandy loam:bark compost of 1:1 (v/v). Tomato plants were transplanted into Wagner pots (1/5000 a) in the same potting substrate described above. All pots were placed in a greenhouse at Shimane University, Matsue, Japan. TFB (maximum bud length of about 1 mm) were removed by pinching them off, and the stems were decapitated at the upper portions of shoots of the second node below TFB (**Figure 1**). Ten plants per treatment were evaluated.

2.1.2. Measurements

The lateral shoot length of the second node below TFB was measured at 0, 3, 6, and 9 days after the treatments.

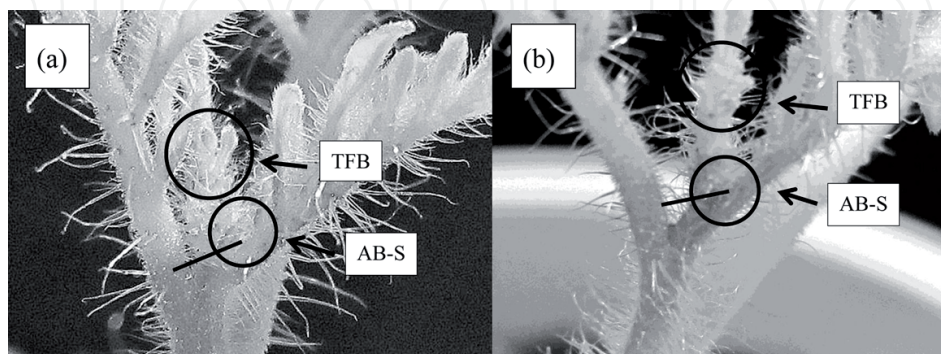


Figure 1. Axillary bud of the second node (AB-S) below the terminal flower bud (TFB) in indeterminate-type cultivar “Mini Carol” (a) and determinate-type cultivar “Suzukoma” (b) tomatoes. Axillary buds (AB) of the first node below TFB exist behind TFB. Flower bud removals are shown by bars (Source: Ohta and Ikeda [28]).

2.2. Effects of pinching treatment (shoot removal) on plant growth, flowering, and yield in determinate tomato

2.2.1. Experimental site, plant materials, growing conditions, and treatments

The determinate-type “Shuho” (Nagano Chushin Agricultural Institute Experimental Station, Shiojiri, Japan) was used for this experiment. Seeds were sown in plastic containers. All containers were placed in a greenhouse at Shimane University, Matsue, Japan. One plant was potted black plastic pots at a ratio of sandy loam:bark compost of 1:1 (v/v). After the third and sixth true leaves had expanded, the plants were pinched at the stem above the third and sixth true leaves (**Figure 2**). No pinching treatments were performed in the untreated control. The tomato plants were transplanted into the experimental field with the soil surface covered with black 0.02-mm polyethylene film at Yatsuka-cho, Matsue, Japan. The plants were arranged in a single 1.6 m wide row, with 0.8 m spacing between rows, 0.45 m spacing between plants, and a planting density of 1.39 plants m⁻². A randomized complete block design was used with three replicates. In total, eight plants per treatment were used. Six plants were used to measure the lateral shoot growth, flowering, and fruit yields, and the remaining plants were used to analyze the mineral nutrient contents.

2.2.2. Measurements

At 18 and 59 days after transplanting (DAT), the lengths of the lateral shoots generated from each node were measured. At 18 DAT, the plants were sampled and divided into stems, leaves on the main shoot, and lateral shoots, and then washed with deionized water. After being air-dried at 80°C for 72 h, the dried plants were ground using an electric mill (WB-1; AS ONE Corp., Osaka, Japan). Total nitrogen (N) contents were determined using a CN

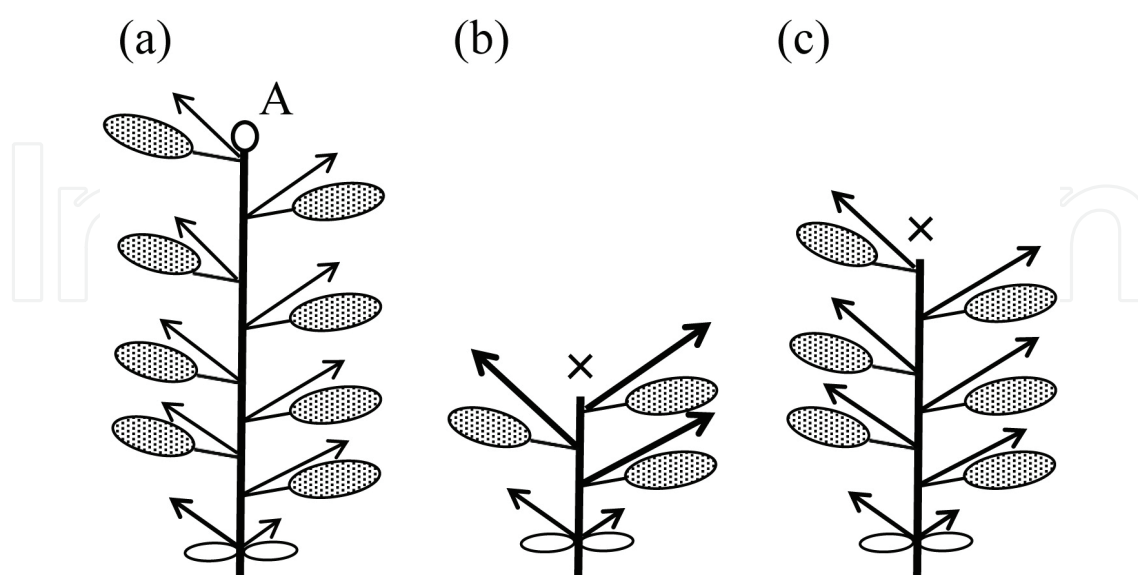


Figure 2. Pinching treatments (shoot removal) in determinate-type tomato (schematic diagram). Left is control (a), center is Pinch-3 (b), and right is Pinch-6 (c). Pinch-3 or -6 indicates pinching treatment with the plant left with three or six true leaves, respectively. A is terminal flower bud (TFB) of main stem. X is pinching position.

coder (Sumigraph NC-22F, Sumitomo Chemical Analysis Center Corp., Tokyo). The phosphorus (P) contents were measured by vanadomolybdate absorption spectrometry. The potassium (K), calcium (Ca), and magnesium (Mg) contents were measured by an atomic absorption spectrophotometer (AA-630, Shimadzu, Kyoto, Japan). The contents of mineral nutrient in each organ of plant were calculated from dry weight and mineral nutrient concentrations. The first flowering dates of the main stem and the lateral shoots were recorded, and the numbers of flowers, and the number of secondary and higher lateral shoots per primary lateral shoot were counted. Full ripe fruits were harvested twice per week during 6 weeks, and the number of fruits, fruit weight, and the number of marketable fruits were recorded. The soluble solids content (SSC) values of 20 marketable fruits were evaluated using a digital refractometer (APAL-1; AS ONE Corp., Osaka, Japan) to measure the Brix values of fresh juice samples.

3. Results

3.1. Lateral shoot elongation after TFB or shoot removal in indeterminate tomato

The lateral shoot length at the second node below TFB in the indeterminate-type cultivar “Mini Carol” was significantly suppressed by flower bud removal at 6 and 9 days after treatment, compared to that in untreated plants (Figure 3). On the other hand, lateral shoot lengths at the second node below TFB did not differ after shoot removal compared with untreated plants.

Indeterminate-type

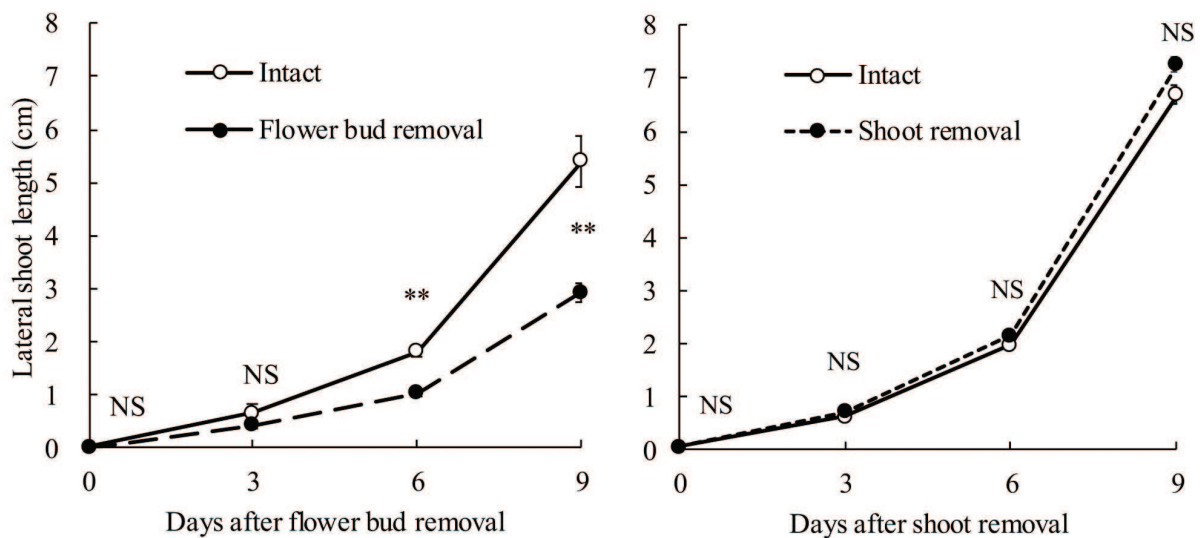


Figure 3. Lateral shoot length of the second node below the terminal flower bud (TFB) after flower bud removal and shoot removal at the upper position of second node below TFB of indeterminate cultivar, “Mini Carol”. Significant difference was shown as **: $P < 0.01$, NS: not significant (t -test). Vertical bars indicate standard error (Source: Ohta and Ikeda [28]).

3.2. Lateral shoot elongation after TFB or shoot removal in determinate tomato

The lateral shoot length at the second node below TFB in the determinate-type cultivar “Suzukoma” was not significantly different between plants with flower buds removed and untreated plants (Figure 4). However, the lateral shoot length at the second node below TFB increased significantly at 6 and 9 days after shoot removal compared with that of untreated plants.

Figure 5 summarizes the results of Figures 3 and 4. Lateral shoot (C_1) growth at the second node below TFB was analyzed in indeterminate-type cultivars in the presence of either TFB (A_1) or AB (B_1). The growth of C_1 was suppressed in the presence of only B_1 , and the growth of C_1 did not change even if both A_1 and B_1 were removed. Therefore, the presence of A_1 promoted the growth of C_1 in indeterminate-type cultivars. On the contrary, when the growth of lateral shoot (C_2) was analyzed in determinate-type cultivars in the presence of either TFB (A_2) or AB (B_2), the growth of C_2 in the presence of only B_2 did not change (growth was suppressed). However, the growth of C_2 was accelerated if both A_2 and B_2 were removed. Thus, the presence A_2 did not promote the growth of C_2 in determinate-type cultivars.

3.3. Effects of pinching treatment (shoot removal) on plant growth, flowering, and yield

At 18 DAT, the mean lateral shoot lengths in the three-true-leaf pinching treatment had extend significantly longer, at 14.7 cm, than those in the control, at 5.5 cm. CVs of mean lateral shoot length did not differ among the all treatments, at 50–55%. The lateral shoot lengths generated from the lower nodes in the six-true-leaf pinching treatment was no difference compared

Determinate-type

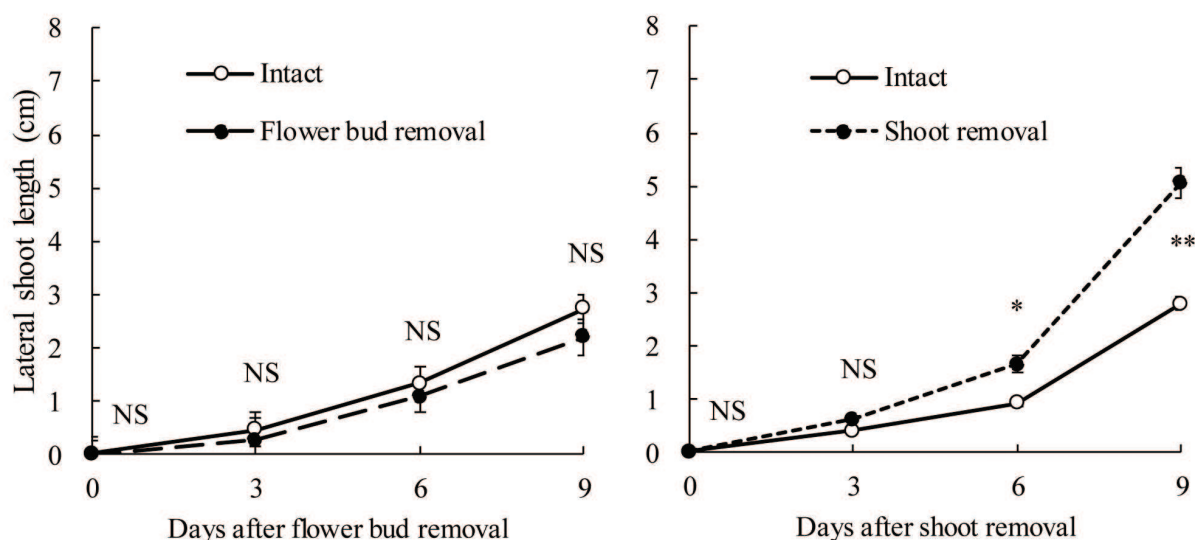


Figure 4. Lateral shoot length of the second node below the terminal flower bud (TFB) after flower bud removal and shoot removal at the upper position of the second node below TFB of determinate cultivar, “Suzukoma”. Significant difference was shown as **: $P < 0.01$, *: $P < 0.05$, NS: not significant (t -test). Vertical bars indicate standard error (Source: Ohta and Ikeda [28]).

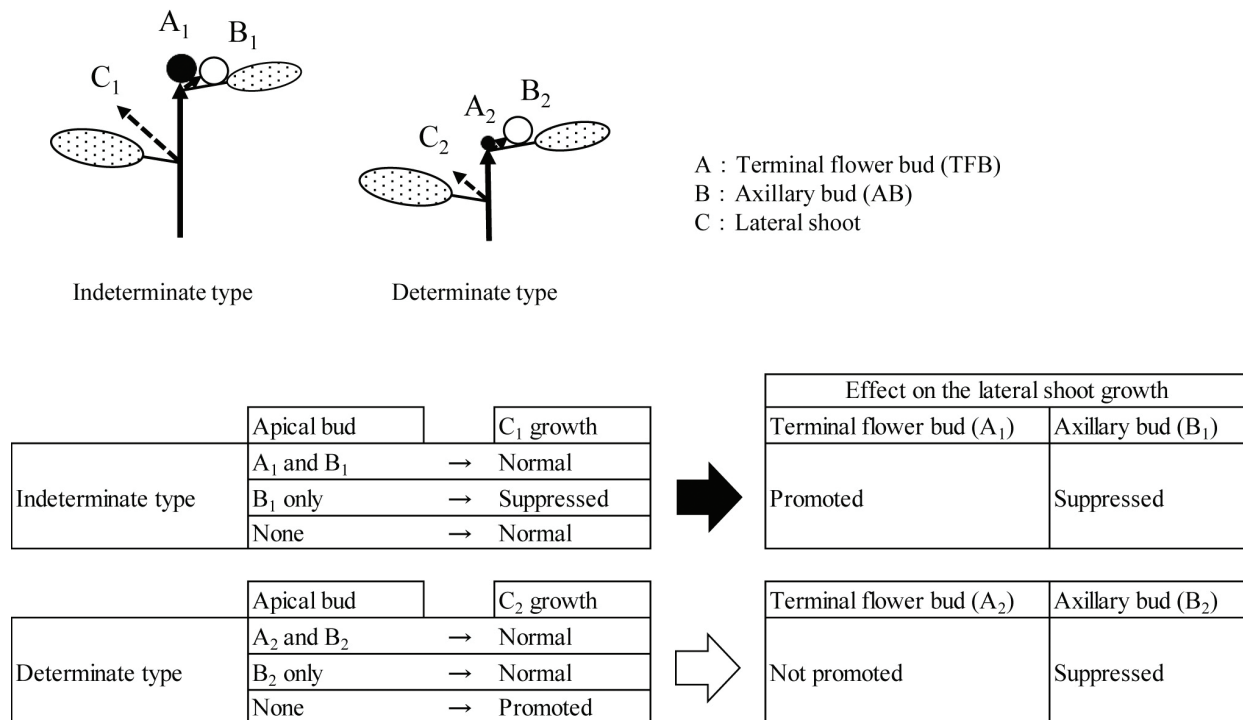


Figure 5. Relationships among terminal flower bud (TFB) (A₁, A₂), axillary bud (AB) (B₁, B₂) and lateral shoot growth (C₁, C₂) of indeterminate and determinate-type tomatoes (Source: Ohta and Ikeda [28]).

with those in the control, however, the lateral shoots generated from the second to sixth true leaf nodes had extended significantly longer than those in the control (data not shown). At 59 DAT, the lateral shoot lengths in the pinching treatments showed the same tendencies as seen at 18 DAT. The mean lateral shoot lengths in the both pinching treatments were significantly longer, at 44.6 and 35.5 cm, than those in the control, at 27.8 cm. CV of the mean lateral shoot length in the three-true-leaf pinching treatment was smaller, at 28%, than the other treatments, at 33 and 37%.

Figure 6 shows the effect of pinching treatments (shoot removal) on the dry weight (DW) of the plants. Although total DW did not differ among the all treatments, DW in the stem in the three-true-leaf pinching treatment were significantly less compared with those in the six-true-leaf pinching treatment and the control. DW in the leaves in the three-true-leaf pinching treatment was significantly less compared with that in the control. However, DW in the lateral shoots in the three-true-leaf pinching treatment was highest among the all treatments.

Table 1 shows the effect of pinching treatments (shoot removal) on the content and distribution of N, P, K, Ca, and Mg at 18 days after transplanting (DAT) in each organ of plant. Although in the stem the contents of P and K in the three-true-leaf pinching treatment were significantly lower than that in the control, the contents of these mineral nutrients in the six-true-leaf pinching treatment did not differ compared with that in the control. In the leaves, the contents of all the mineral nutrients were no differences among the all treatments. In the lateral shoots, the contents of N, P, K, Mg, and Ca in the three-true-leaf pinching treatment were significantly increased compared with those in the control. In the lateral shoots, the

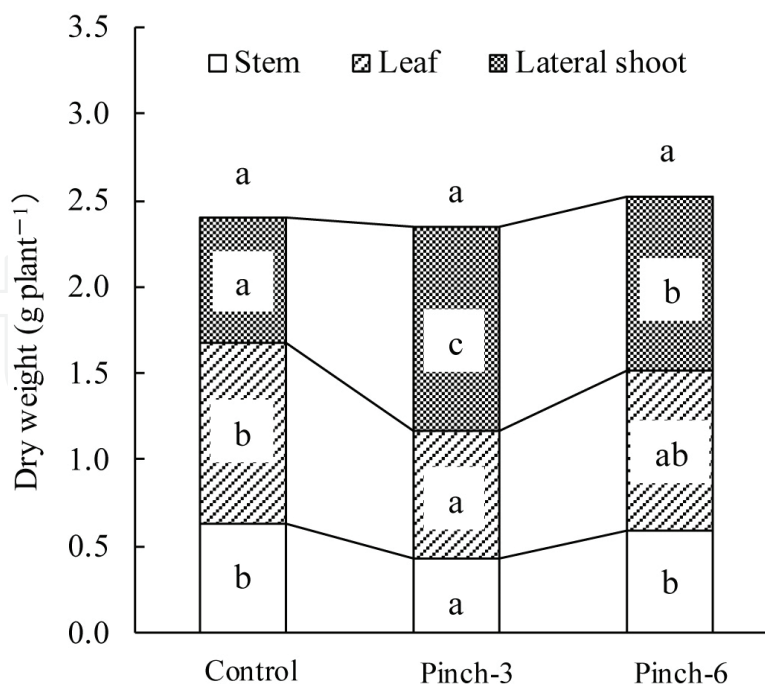


Figure 6. Effect of pinching treatments (shoot removal) on the dry weight (DW) at 18 days after transplanting (DAT) in determinate-type tomato. Pinch-3 or -6 indicates pinching treatment with the plant left with three or six true leaves, respectively. Different letters within each organ indicate significant difference at $P < 0.05$ (Tukey's test) (Source: Ohta and Ikeda [29]).

contents of N, K, and Ca in the six-true-leaf pinching treatment were significantly greater than that of the control. The total contents of N and Ca in the three-true-leaf pinching treatment were greater than those of the control. Although the distributions of P and K to the stem in the three-true-leaf pinching treatment were decreased compared with those in the control, the distributions of all the mineral nutrients to the lateral shoots in the three-true-leaf pinching treatment were increased compared with those in the control.

The first flowering days from sowing in the control was decreased, at 57.5 days, compared with those in the both pinching treatments, at 64.5 and 64.6 days, respectively. The number of days between the both pinching treatments and the control to the first flowering of the lateral shoots did differ. The number of days between the first and last flowering of the terminal flower truss of main and/or each the lateral shoots in the three-true-leaf pinching treatment was significantly lower, at 13.1 days, than that in the control, at 18.7 days, but the number of days between the first and last flowering of the terminal flower truss of each lateral shoot did not differ between the six-true-leaf pinching treatment and the control.

Table 2 shows the effect of pinching treatments (shoot removal) on the number of flowers per plant, per primary lateral shoot, and flowered lateral shoots. Although the number of flowers per whole plant in the six-true-leaf pinching treatment was significantly higher than that of the control, the number of flowers per plant in the three-true-leaf pinching treatment was significantly lower compared with that of the control. The total numbers of flowers per lateral shoot in both pinching treatments were significantly higher than that in the control. The number of flowers per primary lateral shoot did not differ among the all treatments; whereas, the

Organ	Treatment	N	P	K	Ca	Mg
Stem	Control	7.9 a ^a (13) ^b	2.9 b (25)	16.5 b (31)	17.8 a (24)	4.3 a (30)
	Pinch-3 ^c	6.8 a (8)	1.9 a (16)	10.4 a (19)	17.0 a (19)	3.5 a (21)
	Pinch-6	8.2 a (11)	2.6 b (20)	15.8 b (26)	16.3 a (23)	4.2 a (29)
Leaf	Control	26.2 a (42)	4.2 a (36)	14.4 a (27)	40.0 a (55)	5.9 a (42)
	Pinch-3	21.6 a (25)	3.1 a (25)	11.9 a (22)	44.4 a (49)	6.5 a (40)
	Pinch-6	23.3 a (31)	3.6 a (28)	13.7 a (23)	36.6 a (50)	5.3 a (36)
Lateral shoot	Control	28.2 a (45)	4.6 a (39)	22.4 a (42)	15.0 a (21)	3.9 a (28)
	Pinch-3	56.8 c (67)	7.2 b (59)	31.8 b (59)	29.1 c (32)	6.3 b (39)
	Pinch-6	42.9 b (58)	6.7 b (52)	30.3 b (51)	19.9 b (27)	5.2 ab (35)
Total	Control	62.3 a (100)	11.8 a (100)	53.4 a (100)	72.7 a (100)	14.1 a (100)
	Pinch-3	85.2 b (100)	12.2 a (100)	54.1 a (100)	90.5 b (100)	16.3 a (100)
	Pinch-6	74.4 ab (100)	13.0 a (100)	59.8 a (100)	72.8 a (100)	14.7 a (100)
<i>P</i>						
Organ (A)		NS	NS	NS	*	NS
Treatment (B)		**	**	**	**	*
A × B		NS	NS	NS	NS	NS

^aDifferent letters within each column indicate significant difference at $P < 0.05$ (Tukey's test).

^bValues are the ratio of the nutrient amount in each organ to the total in each treatment.

^cPinch-3 or -6 indicates pinching treatment with the plant left with three or six true leaves, respectively.

**NS: significant at $P < 0.05$ and $P < 0.01$ or not significant, respectively (ANOVA).

Table 1. Effect of pinching treatments (shoot removal) on the content and distribution of N, P, K, Ca, and Mg (mg plant⁻¹) at 18 days after transplanting (DAT) in determinate-type tomato (Source: Ohta and Ikeda [29]).

Treatment	Number of flowers per whole plant		Number of flowered lateral shoots per whole plant		Number of flowers per lateral shoot				Number of secondary and higher lateral shoots per primary lateral shoot			
					Total	Primary	Secondary and higher					
Control	198.5	b ^a	9.2	b	21.6	a	5.4	a	16.2	a	4.5	a
Pinch-3 ^b	158.3	a	4.8	a	33.5	c	5.0	a	27.9	c	6.4	c
Pinch-6	239.6	c	9.0	b	26.8	b	5.1	a	21.8	b	5.4	b

^aDifferent letters within each column indicate significant difference at $P < 0.05$ (Tukey's test).
^bPinch-3 or -6 indicates pinching treatment with the plant left with three or six true leaves, respectively.

Table 2. Effect of pinching treatments (shoot removal) on the number of flowers, flowering lateral shoots, flowers per lateral shoots, and secondary and higher lateral shoots per primary lateral shoot in determinate-type tomato (Source: Modified from Ohta and Ikeda [29]).

parameter per secondary and higher lateral shoot in the three-true-leaf pinching treatment was highest among the all treatments. The number of flowered lateral shoots per whole plant in the three-true-leaf pinching treatment was significantly lower compared with those in the other treatments.

Figure 7 shows the effect of pinching treatments (shoot removal) on the weekly marketable fruit yield. At 0 week after the start of the harvest (WAH), the weekly yield in the control was higher than those in both pinching treatments. However, at 1 WAH in the three-true-leaf pinching treatment was higher compared with that in the control. The weekly yield in the six-true-leaf pinching treatment at 2 WAH was also higher compared with that in the

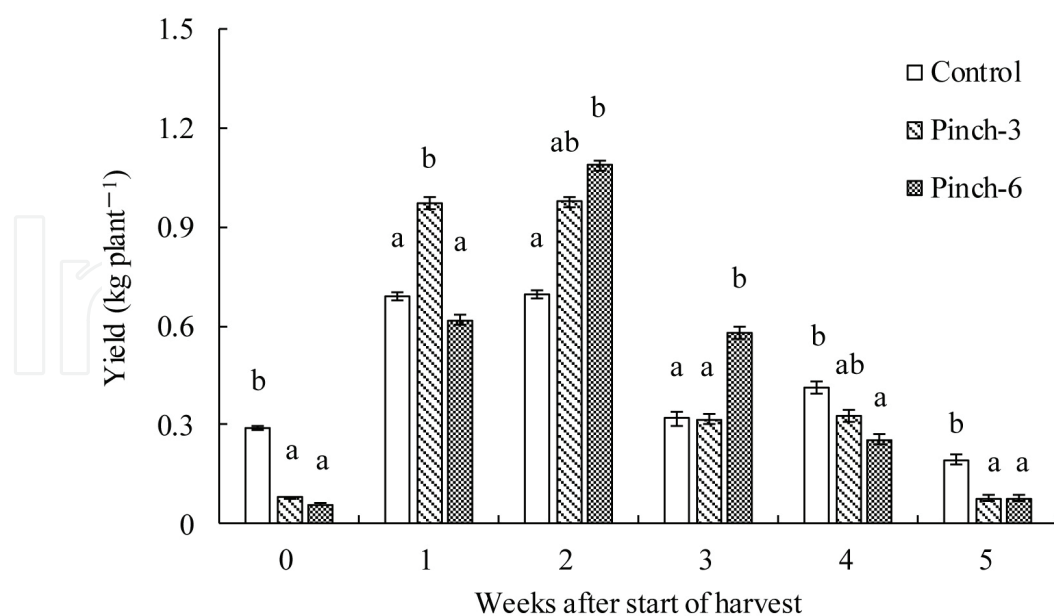


Figure 7. Effect of pinching treatments (shoot removal) on weekly marketable fruit yield in determinate-type tomato. Pinch-3 or -6 indicates pinching treatment with the plant left with three or six true leaves, respectively. Different letters within each week indicate significant difference at $P < 0.05$ (Tukey's test). Vertical bars indicate standard error (Source: Ohta and Ikeda [29]).

control. The harvest term in the both pinching treatments was shortened until 3 WAH compared with that in the control until 4 WAH. The fruit set ratio in the three-true-leaf pinching treatment was higher, at 20.4%, than in the other treatments, at 12.7 and 15.8%. However, the fruit yield per plant, at 2968–3018 g, the mean fruit weight, at 94.7–98.3 g, the number of harvested fruits per plant, at 30.3–31.7 fruits, the marketable fruits ratio, at 87.6–89.6%, and SSC, at 4.9–5.1°Brix, did not differ among the treatments. Although the numbers of flowers per whole plant in the six-true-leaf pinching treatment and the control were greater than those in the three-true-leaf pinching treatment, the numbers of harvested fruits were not different among the all treatments.

4. Discussion

Flower bud removal or shoot removal was carried out to clarify the roles of TFB and AB at the first node below TFB, and to clarify the reason that lateral shoots at the second node below TFB elongate. In indeterminate-type cultivar, the lateral shoot lengths at the second node below TFB were suppressed significantly at 6 and 9 days after flower bud removal, but these shoots did not elongate upon shoot removal (**Figure 3**). In determinate-type cultivar, growth of the lateral shoots at the second node below TFB was not suppressed by flower bud removal compared with untreated plants, but lengths of these shoots increased significantly at 6 and 9 days after shoot removal (**Figure 4**). Hence, these results suggest that TFB promoted the growth of lateral shoots at the second node below TFB in indeterminate-type cultivar, but not in determinate-type cultivar (**Figure 5**). In contrast, the presence of AB at the first node below TFB seemed to suppress elongation of AB at the second node in both types of cultivars. Because emergence of TFB occurred earlier than emergence of AB at the second node [28], the effect of TFB on lateral shoot growth might be stronger than that on AB in both types of cultivars.

In relation to the inner plant growth regulators, auxin is produced in the apical bud and young expanding leaves in *Arabidopsis*, Brussels sprouts, pea, and tomato [30–33]. In the indeterminate-type cultivars, if the auxin concentration that suppresses lateral shoot elongation decreases temporarily upon ablation of the apical meristem or emergence of TFB, the lateral shoot at the second node below TFB elongates due to high cytokinin concentrations in the main stem. According to Shimizu-Sato et al. [34], reduced auxin concentration in the apical organs is a factor involved in increased cytokinin concentrations. However, in determinate-type cultivars, emergence of TFB did not promote the growth of lateral shoots. The much shorter stem lengths in determinate-type cultivars compared indeterminate-type cultivars [28] suggests that auxin concentrations in the apical organs including TFB might differ much from those of non-flowering terminal buds. Furthermore, auxin concentrations in apical organs including TFB might be related to branching habit in tomato plants. Some researchers [35–39] reported that plant growth regulators such as auxin, cytokinin, and strigolactone are related each other to the outgrowth of AB in several plants. Further study is desired to clarify the differences between the two branching types in tomato and the fluctuations in plant growth regulator concentrations.

In the pinching treatments (shoot removal), the growth of lateral shoots, especially in the three-true-leaf pinching treatment, was greater compared with that in the control (**Table 1**), which would be due to the increase of mineral nutrients uptake since the distribution of some mineral nutrient elements was changed by the pinching treatment. The differences in lateral shoot lengths in the plants by the pinching treatment at four to six true leaves were larger than in the plants by the pinching treatment at zero to three true leaves in the determinate-type tomato “Wase Daruma” [14]. Almost the same result was obtained in regard to the lateral shoot lengths in the different pinching treatments in the present study. The shoot lengths of 3-scaffold shoots by pinching treatment were longer than those of 6-scaffold shoots because the nutrient competition among the remaining shoots reduced in watermelon (*Citrullus lanatus*) [39]. This might be the reason that at 59 DAT the mean lateral shoot lengths in the three-true-leaf pinching treatment were more uniform compared with those in the six-true-leaf pinching treatment. In this study, perhaps the emergence period of AB was shorter and the competition for absorbed mineral nutrients was reduced in the plants that underwent the three-true-leaf pinching treatment.

Since the flowering period in the three-true-leaf pinching treatment was significantly shorter than those in the other treatments, the decrease of fruit set ratio that could occur during periods of high air temperatures (over 35°C) might have been avoided by pinching treatment [40]. Although the number of flowers in the three-true-leaf pinching treatment was significantly decreased compared with the other treatments (**Table 2**), there was no difference in the total fruit yield among all the treatments because the fruit set ratio in the three-true-leaf pinching treatment was higher than that in the other treatments. The harvest term in the pinching treatments was shortened until 3 WAH compared with that in the control until 4 WAH (**Figure 7**). These findings are in agreement with those of earlier studies [26, 27, 41]. The possibility for both shortening the harvest term and increasing the early yield was recognized in the three-true-leaf pinching treatment. In particular, shortening of the harvest term would permit mechanical harvesting and save labor cost, as described previously [12, 42–44].

The number of flowers per primary lateral shoot was not different in all treatments, whereas the numbers of flowers per secondary and higher lateral shoots in the both pinching treatments were significantly higher compared with that in the control (**Table 2**). The flower numbers on the longer lateral shoots could be increased in processing tomato plants [45]. In eggplants, the flower numbers on pinched plants were higher than those on no pinched plants because the number of lateral shoots would be increased on the former [46]. Therefore, in this experiment, the increases in both the number of flowers and the number of secondary and higher lateral shoots in the both pinching treatments compared with the control might be due to the release of apical dominance in plants because of the extension of lateral shoots in the previous reports [17, 19, 20, 47].

Pinching (shoot removal) releases apical dominance and removes a metabolic sink in plants [38]. This results in decreased auxin production in the apical bud and increased nutrient distribution into and growth of the lateral shoots [48, 49]. The levels and distribution of N, P, and K were increased in the lateral shoots of bean plants in relation to apical dominance [50]. Ca, a structural component of the cell wall and membranes, is needed for tomato plant growth at early growth stages [51], and its uptake under high-growth conditions was increased in tomato shoots [52, 53]. Fukui et al. [13] also reported that increased the number of flowers were due to the relatively greater availability of photosynthetic products in tomato cultivars

with large leaf areas. The number of flowers in tomato plants is also increased by higher contents of N and P [54]. Decoteau [55] reported that topping enhanced axillary leaf development in processing tomato cultivars. Thus, pinching treatments likely increase the photosynthetic products and mineral nutrient uptake by increasing the leaf areas of lateral shoots, and also likely lead to increased numbers of flowers. Therefore, it was revealed that the numbers of dropped flowers in the control and six-true-leaf pinching treatments were greater than in the three-true-leaf pinching treatment because of the excessive number of flowers per plant.

5. Conclusion

In tomato plants, flower bud or shoot removal (pinching treatment) affected the branch formation and fruit yield. The emergence of TFB affected the growth of lateral shoots in indeterminate-type cultivar, whereas it did not affect the growth of lateral shoots in determinate-type cultivar. Therefore, it is suggested that the appropriate management of the lateral shoots would be necessary for improve fruit yield or fruit quality, and it would be different between indeterminate and determinate-type cultivars. In indeterminate-type cultivars, it would be important to consider both the position and timing of shoot pinching and the timing of lateral shoot removal. In determinate-type cultivars, it might be necessary to study the number of lateral shoots or the training direction of the vines in order to avoid plant diseases during the periods of high temperature and/or humidity conditions. The shortening of harvest term and increase of initial fruit production in the three-true-leaf pinching treatment would be due to elongated lateral shoots and shortening of the flowering periods per plant. Thus, the pinching treatment could permit machine harvesting and save labor costs for determinate tomato cultivation. From these results, further studies should be undertaken to elucidate the relationships among shoot growth of plant, number of flowers, and physiological factors such as the sink strength in each organ, the distribution of photosynthetic products, and the changes of nutritional status and some plant growth substances in plants after flower bud or shoot removal (pinching treatment).

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