INTRODUCTION

Recently tomatoes are one of the popular and important vegetables for human food and/or health in lots of countries (Bhowmik et al., 2012; Canene-Adams et al., 2005; Doralis et al., 2008). Among them, processing tomatoes are cultivated for using processed products such as juice, ketchup, sauce, paste, and puree etc. Growers are produced them generally under contract with a processing company (Takemoto, 1992), and have the characteristics of determinate-type plant, having a low plant height, and evenly fruited and mature, and having a hard skin (Ito, 1976). Most of them are generally cultivated without support in the open field (Yanokuchi, 1997). This cultivation method has the advantage of requiring less labor and materials (Ito, 1992; Sato et al., 2004). In the future, it is necessary to increase fruit productivity; saving more labor and cost by mechanized cultivation (Mitchell et al., 2012), expanding the scale of management, high labor productivity, and align the flowering period that is convenient for almost one-time harvesting (Ohata and Ikeda, 2017). When the ripening period would be longer, labor productivity is higher, and the efficient management for growers due to work such as the weeding, side dressing, chemical spraying for diseases and pesticides is difficult (Ito, 1976).

In general processing tomatoes are grown in the open field, however, there are some problems that the fruits are apt to contact with the surface of the soil and mulch and the incidence of disorders such as rotten and cracked fruits, and disease such as plague and leaf mold are likely to increase due to rainfall during harvest periods. Oda et al. (2008) reported the differences between stem direction and lateral shoot growth in tomato plants. In previous reports (Ahmad and Singh, 2005; Muhammad and Singh, 2007), the vegetative growth, fruit yield, and marketable fruit rate could be increased by staking some tomato cultivars. Also, Ohta and Makino (2019) were reported the influence of stem directions on the fruit yield, plant growth and physiological characteristics in processing tomato cultivation. As a result, in the vertical double-shoots cultivation the translocation of nutrients and photosynthetic products were increased significantly compared to the control, we guessed the fruit productivity of one lateral shoot in the vertical cultivation would be increased compared to the untreated cultivation.

Effects of Double-shoots Training Cultivation on Plant Growth and Fruit Productivity in Processing Tomato (Solanum lycopersicum L.)

Katsumi OHTA, Goro TAKAMORI and Masayuki KADOWAKI

Graduate School of Natural Science and Technology, Shimane University, Matsue, Shimane 690-8504, Japan

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Since the fruits would be apt to perishable and disease in open field cultivation of processing tomatoes, we attempted vertical double-shoots attracting cultivation to secure a stable yield in this experiment. The control plot (untreated plants) and double-shoots (cultivated by attracted 1st and 2nd lateral shoots below the top flower truss) plot were set. There was no difference between the both plots on the first flowering date. Although the number of flowers per plant was decreased significantly in the double-shoots plot compared to the control plot, there were no differences in total yield and the number of fruits. The cracked, worm-eaten, and blossom-end-rot fruits were decreased significantly in the double-shoot plot. The stem diameter, SPAD value, leaf area, and dry weight per lateral shoot were significantly larger in the double-shoots plot than in the control, but there was no difference between the both plots in the photosynthetic rate and mineral nutrient contents per plant. Since in the vertical double-shoots cultivation the translocation of nutrients and photosynthetic products were increased significantly compared to the control, we guessed the fruit productivity of one lateral shoot in the vertical cultivation would be increased compared to the untreated control cultivation.

Keywords : double-shoots, vertical attracting cultivation, mineral nutrient, fruit setting rate, Solanum lycopersicum, processing tomato
and Ikeda, 2017). In the preliminary experiment, the yields when cultivated with 2, 4 and 6 lateral shoots were 2.6 kg, 3.3 kg and 3.6 kg, respectively, but no significant difference was recognized. Based on the result this experiment was conducted as a double-lateral shoot training that requires less time for management work and is expected to attract cultivation with better productivity in processing tomatoes.

MATERIALS AND METHODS

Experimental site, plant materials, growing conditions, and treatments

The processing tomato ‘Shuho’ (Solanum lycopersicum L.) (Nagano Chushin Agricultural Institute Experimental Station, Shiojiri, Japan) was used for these experiments. Seeds were sown in yellowish pumice (diameter 2-5 mm) in plastic containers (34.5×27.0×7.5 cm) on 2018 Apr. 3. All containers were placed in a greenhouse at Shimane University, Matsue, Japan (lat. 35°49′N, long. 133°07′E, 3 m a.s.l.). One plant was potted in 9 cm diam. ×10 cm deep (0.37 L) black plastic pots in potting medium containing 50% sandy loam and 50% bark compost on Apr. 20. When the fifth true leaf of the control plants which was no training that was untreated had fully expanded, the tomato plants were transplanted into the experimental field with the soil surface covered with black 0.02-mm polyethylene film and with the addition of 8.0 kg a⁻¹ of 16-3.9-8.3 NPK solid fertilizer before mulching on May 21 at Yatsuka-cho, Matsue, Japan (lat. 35°29′N, long. 133°10′E, 24 m a.s.l.). After the seventh true leaves had expanded, the double-shoots training plants with using twine were trained two lateral shoots on June 4 (Fig. 1). No training treatments were performed as in the untreated control. Soil moisture was maintained between 0.18 and 2.5 using furrow irrigation twice per week and tensiometers (DM-8, Takemura Electrical Factory Co., Ltd., Tokyo, Japan). The experimental plot was 35 m², and planted in a single row 1.7-m wide, with 0.8-m spacing between rows, with 0.45-m spacing between plants, and a planting density of 1.3 plants m⁻². Experiments were arranged in a randomized complete block design with three replications. Ten plants were used for each treatment. Eight plants per treatment were used for the measurement of the growth parameters, flowering and yields, and the remaining plants were used for the measurement of the dry matter and the analysis of mineral nutrient contents. The average, maximum, minimum air temperatures, cumulative solar radiation and precipitation during the tomato growing season in the open field were 25.4°C, 37.9°C, 12.9°C, 1,954 MJ m⁻², and 442.0 mm, respectively. No insecticides and fungicides were used.

Analysis of plant growth and mineral contents

At 58 days after transplanting (DAT), the plants were sampled and divided into stems, leaves and fruits on the main shoot and lateral shoots. The leaf areas were measured using a leaf area meter (LI-3100, LI-COR, Lincoln, NE, USA). And then, plants were washed with deionized water. Two plants were sampled from each plot, and there were three replications. After being oven dried at 80±5°C for 72 h, the dried plants were ground in an electric mill (WB-1, AS ONE Corp., Osaka, Japan) to a fine powder with three replications. Total nitrogen (N) contents were analyzed using a CN coder (Simigraph NC-90A, Suntom Chemical Analysis Center Corp., Tokyo, Japan). After dry ashing, the phosphorus (P) contents were determined by vanadomolybdate absorption spectrometry, and the potassium (K), calcium (Ca), and magnesium (Mg) contents were determined using an atomic absorption spectrophotometer (AA-680, Shimadzu, Kyoto, Japan). The content of mineral nutrients in each plant was calculated from these data.

Measurements of flowering, photosynthetic rate, and SPAD value

The first flowering dates of the main stem and the first truss of each lateral shoot, and the numbers of flowers and secondary or other lateral shoots were recorded. At 63 DAT, the photosynthetic rate of the top leaflet of leaves at the same positions as those evaluated for dimensions were measured using a portable photosynthesis meter (LI-6400, LI-COR, Lincoln, NE, USA). The stem diameter below the terminal flower truss on the main stem and below the terminal flower truss on the lateral shoot of second node below the terminal truss and SPAD values of the top leaflet of below true leaves at the same positions as those evaluated for them were measured using a digital caliper (CD-15CPX; Mitutoyo Corp., Kawasaki, Japan) and a chlorophyll meter (SPAD-502; Konica Minolta Inc., Tokyo, Japan), respectively.

Measurements of fruit yield, number, and fruit quality

Mature red fruits were harvested twice per week for 6 weeks, and the fruit number, fruit weight and the number of marketable fruits (i.e., except for cracked, blossom-end rot, sunburn, insect damage and rotten fruits) were recorded. The soluble solids content (SSC) and titratable acidity (%) of citric acid) contents of 30 marketable fruits that were harvested during the second and third weeks after the start of harvest in each plot were estimated. SSC was measured using digital refractometers: APAL-1 (AS

Fig. 1 Schematic diagram of extensive cultivation (a, control) and the double-shoots training cultivation (b, double-shoots training). A is terminal flower truss. B is lateral shoot. C is stake.
TOMATO DOUBLE-SHOOTS TRAINING

ONE Corp., Osaka, Japan), and lycopene content was measured according to the previous report (Nagata and Yamashita, 1992), respectively.

Statistical analysis
Data were analyzed using an analysis of t-test at \( P < 0.05 \) in SPSS ver. 25.0.0 (SPSS, Chicago, IL, USA).

RESULTS AND DISCUSSION

Flowering date and number of flowers
Table 1 shows the number of days from sowing to first flowering of the terminal flower truss and the number of flowers. No differences of the days from sowing to first flowering were observed between the control and the double-shoots training plots. The number of flowers per whole plant in the double-shoots training plot was significantly lower, at 165.4 flowers, than that in the control plot at 213.7 flowers. However, it per lateral shoot in the double-shoots training plot was significantly higher, at 78.7 flowers, than that in the control plot at 24.8 flowers. On the first flowering day, there was no difference between the two treatment plots in the first flower truss, the first flower truss under the first flower truss, and the second flower truss under the first flower truss, so it was confirmed that there was no difference on the flowering day in the both treatments. This first flowering day in the first flower truss is consistent with the result of previous report (Ohta and Makino, 2019) in which the flowering dates did not change between the vertical and horizontal plots. We propose that the numbers of dropped flowers in the control plot were greater than in the double-shoots training plot because of the excessive number of flowers per plant. These findings are in agreement with those of earlier studies (Ito et al., 1980; Ohta and Ikeda, 2017).

Fruit yield, physiological disorder, and fruit quality
Table 2 shows the fruit yield, number of fruits, fruit weight, and fruit set ratio. There was no significant difference in the total fruit, marketable fruit yield, and fruit weight between the both plots. There was no difference in total yield and normal fruit yield between the two treatment plots, which was consistent with the result of no difference in yield between vertical and horizontal plots (Ohta and Makino, 2019). However, the not marketable fruit yield in the double-shoots training plot was significantly higher, at 1,134 g plant\(^{-1}\) than in the control plot at 812 g plant\(^{-1}\). Since there was no differences of the number of fruits per whole plant, fruit set ratio in the double-shoots training plot was significantly higher, at 22.2%, compared to that in the control plot at 15.2%. In addition, the fruit setting rate in the double-shoots plot was higher compared to the control plot, so there was no difference in the number of fruits between the two treatment plots. It is expected that the translocation of photosynthetic products for flower bad differentiation and fruit growth in the double-shoots plot was concentrated compared to the control plot. It seems that in this plot the fruit setting rate increased and the number of fruits became the same as that of the control plot. However, Cockshull (1995) and Cockshull et al. (2001) reported that an increase in the number of lateral shoots does not increase the yield, however, has the effect of increasing the number of fruits and regulating the size of the fruits. Therefore, it is suggested that the yield did not increase even if the number of lateral shoots was increased. It was also considered that when the number of stems was increased by using the lateral shoots, the LAI increased but the integrated light-receiving amount did not increase, as a result, although the cumulative tuition fee did not increase, the amount of photosynthetic products per plant would not increase. From this experiment data, although these reason could not be explained because the translocation and partition rates of the photosynthetic products was not measured, the double-shoots training plot would be presumed to be equal to the control plot with the fruit productivity. SSC, titratable acidity, and lycopene contents in fruits did not differ significantly, at about 5.0°Brix and 0.27% between the both treatments.

Table 3 shows the incidence of physiological, pathological disorders, and insect damage. There was no differ-

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**Table 1** Effect of double-shoots training on the days from sowing to first flowering of the terminal flower truss, and the number of flowers in processing tomato.

| Treatment          | Days from sowing to first flowering of the terminal flower truss | Number of flowers |
|--------------------|----------------------------------------------------------------|-------------------|
|                    | The main stem | The lateral shoot of first node below the terminal flower truss | Per whole plant | Per lateral shoot |
| Control            | 61.0a         | 65.9a                                                 | 71.4a           | 235.7b          | 24.8a          |
| Double-shoots      | 60.4a         | 65.4a                                                 | 71.7a           | 165.4a          | 78.7b          |

Double-shoots training indicates attracting two lateral shoots for upright. Different lowercased letters within each column indicate significant difference at \( P < 0.05 \) (t-test).

| Treatment          | Fruit yield (g plant\(^{-1}\)) | Number of fruits per plant | Fruit weight (g) | Fruit set ratio (%) |
|--------------------|-------------------------------|----------------------------|------------------|--------------------|
|                    | Total | Marketable | Not marketable | 34.2a | 106.8a | 15.2a |
| Control            | 3,401a | 2,266a | 1,134b | 32.4a | 106.8a | 15.2a |
| Double-shoots      | 3,504a | 2,692a | 812a   | 34.2a | 104.6a | 22.2b |

Double-shoots training indicates attracting two lateral shoots for upright. Different lowercased letters within each column indicate significant difference at \( P < 0.05 \) (t-test).
ence of cracked fruit ratio between the both treatments. Although blossom-end rot ratio in the double-shoots training plot was significantly higher, at 13.6%, compared to that in the control plot at 6.7%, rotten fruit and insect damage in the double-shoots training plot were significantly lower, at 6.3 and 6.2%, respectively, than those in the control plot at 10.9 and 10.9%, respectively. It is considered that the reason why these fruits in the double-shoot plot were reduced because of be prevented to attach the ground or mulching film. In contrast, as for the factors that the reason which blossom-end rots in the double-shoot training plot was increased compared the control plot, this disorder generally appear when Ca is deficient at the tip of the fruit, that is, when the fruit grows rapidly in the early stage (Peet, 2012; Sato et al., 2004). Although sunburn fruits were not observed in the double-shoots training plot, they were observed only in the control plot. It is described that when the sunburn fruits are suddenly exposed and exposed to direct sunlight (Yanokuchi, 1997). It is speculated that this is the reason the fruits did not receive direct sunlight because of increased the leaf area. Ohta and Makino (2019) reported that the in determinate-type tomato the leaf area in the vertical plot was larger than that of the horizontal plot, and the dry matter weight of the whole plant including the leaves, stems and lateral shoots was also increased. The results of previous results suggested the positive influences of vertical attraction in processing tomatoes.

Photosynthetic rate, SPAD value and stem diameter

Table 4 shows the photosynthetic rate, SPAD value in the tip leaflet of true leaf and stem diameter in the main stem and on the lateral shoot. The sunburn fruits were observed clearly. SPAD values of tip leaflet of the true leaves in the double-shoots training plot were also significantly higher, at 41.7 and 45.4, respectively, compared to those in the control plot at 34.9 and 39.8, respectively. SPAD values were higher in the both plots than in the control plot in the true leaves and lateral shoots. SPAD values were shown to be proportional to the chlorophyll contents in the previous report (Udding et al., 2007). Since it is guessed that its content would be highly related to photosynthetic ability, it is speculated that the plants in the double-shoots plot have higher leaf photosynthetic ability than those in the control plot. Stem diameter at the main stem and lateral shoot in the double-shoots training plot were significantly higher, at 21.3 and 17.2 mm, respectively, compared those in the control plot at 18.6 and 13.8 mm, respectively. These data was the same tendency with the previous report (Ohta and Makino, 2019).

Leaf area, dry weight (DW) and contents of N, P, K, Ca, and Mg

Figure 2 shows the leaf area of main stem and lateral shoots at 58 DAT. The leaf area of the main stem and lateral shoot per whole plant were not different between the treatments. Although the photosynthetic rate of the seventh true leaf in the vertical stem direction was significantly higher than that in the horizontal direction, that of the third true leaf in the vertical stem direction was significantly lower than that in the horizontal stem direction (Ohta and Makino, 2019). Net photosynthetic rates of erect leaves were higher than those of bent ones in rose (Kim et al., 2004). In this study, since the untreated control plot was not a strongly attracted treatment compared to the horizontal stem direction plot, it was assumed that the differences of the photosynthetic rate between the upper part leaves and the lower ones were not observed clearly. SPAD values of tip leaflet of the true leaves in the double-shoots training plot were also significantly higher, at 41.7 and 45.4, respectively, compared to those in the control plot at 34.9 and 39.8, respectively. SPAD values were higher in both plots than in the control plot. Stem diameter at the main stem and lateral shoot in the double-shoots training plot were significantly higher, at 21.3 and 17.2 mm, respectively, compared those in the control plot at 18.6 and 13.8 mm, respectively. These data was the same tendency with the previous report (Ohta and Makino, 2019).

Table 4 Effect of double-shoots training on the photosynthetic rate, SPAD value in the tip leaflet of true leaf on the first node and lateral shoot on the second node below the terminal flower truss and stem diameter below the terminal flower truss in processing tomato.

| Treatment               | Photosynthetic rate in the tip leaflet of the true leaf \(\mu mol CO_2 m^{-2}s^{-1}\) | SPAD value of tip leaflet of the true leaf | Stem diameter below the terminal flower truss (mm) |
|-------------------------|-------------------------------------------------|-----------------------------------------|-------------------------------------------------|
|                         | First node below the terminal flower truss | First node below the terminal flower truss | The main stem                                    |
|                         | Lateral shoot of second node below the terminal flower truss | Lateral shoot of second node below the terminal flower truss | Lateral shoot of second node below the terminal flower truss |
| Control                 | 4.6a                                           | 34.9a                                  | 18.6a                                           |
| Double-shoots training  | 7.5a                                           | 41.7b                                  | 21.3b                                           |

Double-shoots training indicates attracting two lateral shoots for upright. Different lowercase letters within each column indicate significant difference at \(P < 0.05\) (t-test).
both treatments, but it per lateral shoot in the double-shoots training plot was significantly higher, at 7,406 cm², than that in the control plot at 2,499 cm². There was no difference in the leaf areas of the main stem and lateral shoots between the two treatments, however, there was a large difference between the both treatments per lateral shoot.

Figure 3 shows the DW of main stem and lateral shoots. The stem, leaf, and fruit of the main stem were not different between the both plots. In the stem and fruit weight in the double-shoots training plot were significantly lower than those in the control plot. Those parts per lateral shoots in the double-shoots training plot were significantly larger than those in the control plot.

Figure 4 shows the content of N, P, K, Ca, and Mg of main stem and lateral shoots. In the main stem, N in the double-shoots training plot was significantly higher compared to that in the control plot. In the total lateral shoot, P, K, Ca and Mg in the double-shoots training plot were significantly lower than those in the control plot, respectively. On the contrast, N, P, K, Ca and Mg per lateral shoots in the double shoots training plot were significantly higher than those in the control plot. The growth of one lateral shoot, in the double-shoots training plot, was greater than that in the control, which was likely due to the increased uptake of all mineral nutrients because the distribution of mineral nutrients was concentrated to the lateral shoots by restricting the number of ones. The reason of the differences of leaf area and dry weight is considered that the translocations of nutrients absorbed from the roots and photosynthetic products produced in the leaves were concentrated in the two lateral shoots. In previous study (Ohta and Ikeda, 2017), the mineral contents in the lateral shoots of the 3-true-leaf pinching treatment was increased compared those in the 6-true-leaf pinching ones. Therefore, the vegetative growth of the lateral shoots were increased in the double-shoots training plot than in the control plot. About this result, suggesting that the plant growth regulator in the both treatment-plants might also be related to the differences. This seems to be a point for further study.

Since apical dominance was influenced by the relation between auxin and cytokinin, it is possible that the role of these inner plant growth regulators promote shoot branching (Dun et al., 2006; Ferguson and Beveridge, 2009; Renton et al., 2012; Waldie and Leyser, 2018). To reduce the number of apical buds in the tomato plants by removing lateral shoots such as this experiment suggest that the metabolic sinks would be decreased in the plants (Cline et al., 1991). This results in auxin production in the apical bud of the lateral shoots and nutrient distribution concentrated into them, and as a result, their growth of the lateral shoots was increased (Aoki, 2007; Hillman, 1984). The levels and distribution of N, P, K, Ca and Mg in the vertically trained plants were increased in the leaf, stem and
upper lateral shoots of tomatos (Hawkesford et al., 2012; Ohta and Makino, 2019). Fukui et al. (1990) reported that the number of flowers per lateral shoot were increased due to the relatively greater availability of photosynthetic products in tomato plants with large leaf areas. Therefore, increased flower numbers in tomato plants is also by increased higher contents of N and P (Saito et al., 1963). Thus, the restriction of the lateral shoots and vertically trained shoots likely increase the photosynthetic products and mineral nutrient uptake by increasing the leaf areas of laterals shoot, and also likely lead to increased numbers of flowers.

**CONCLUSION**

From this experiment, in the double-shoots training cultivation, there was a tendency for the number of obstructed fruits to decrease, and the translocation of nutrients and photosynthetic products absorbed from the roots was concentrated due to the limitation of the number of lateral shoots, and the productivity of the fruit per lateral shoot was increased. Therefore, it is estimated that the fruit productivity of the whole plant is the same as that of the conventional unsupported strutless cultivation. The results of these experiments indicate that further studies should be undertaken to elucidate the relationships among lateral shoot growth, the number of flowers, second and further lateral shoots, physiological factors such as the nutritional status of lateral shoots after flower bud differentiation and the distribution of photosynthetic products in processing tomato plants.

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