Research Paper

Using a Water Nozzle for Disbudding Satsuma Mandarins

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ウンシュウミカンにおける水噴射ノズルを使った摘蕾方法

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A new disbudding method using a water jet nozzle was developed. An experiment was conducted on 32-year-old satsuma mandarin trees (cv. Okitsu wase) bearing many fruits. The disbudding treatment was applied to selected lateral shoots 1 day after budding (March 31, transverse bud diameter: 1.24 mm), 7 days after budding (April 6, transverse bud diameter: 2.30 mm), 16 days after budding (April 15, transverse bud diameter: 2.86 mm), or 24 days after budding (April 23, transverse bud diameter: 4.99 mm). Two types of nozzles with different discharge volumes (WJN1: 43.8 mL/s; WJN2: 29.3 mL/s) were considered for the bud removal rate and time required. As a result, NNZO12 was more successful for removing buds. When the nozzle with the higher discharge volume (WJN1) was used 1 day after budding, the time required was 49.5% of that needed for manual disbudding, and the removal rate was 96%. Because the peduncle became thick with time, the time required to remove buds increased; from these findings, it was considered that the treatment up to 7 days after the sprouting (bud diameter 2.3 mm) was effective for disbudding using the water jet nozzle. No significant difference was found in the required time when the treatment was applied more than 7 days after budding. The development of new shoots could be damaged if the water jet disbudding was applied to very small buds just after sprouting.

Key Words : bearing shoot, disbudding, sprouting, vegetative shoot, water jet nozzle

1. Introduction

Excessive fruiting in satsuma mandarin (*Citrus unshiu* Marcow.) can reduce the fruit size, weaken the tree, and inhibit flower formation the following

year. The damage as called “alternate bearing” can be serious especially in very early ripening cultivars (Kihara and Konakahara 2000). To prevent such damage, an effective countermeasure is to adjust the buds to an adequate number by removing excess buds (i.e., disbudding) (Kihara and Konakahara 2000).

Manual disbudding is laborious, and the period optimum for disbudding is short at just a few days to about 10 days before full bloom. A new disbudding method that saves the labor and time required. This is similar to persimmon, for which manually picking

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increases profits but has to be carried out in a short period of time, so the flowers are pruned to reduce the amount of labor (Fumuro 2003; Kumamoto *et al.* 2016; Matsuda *et al.* 2008).

In the present study, a customized water jet nozzle that can be attached to typical power-operated sprayers was developed for removing satsuma mandarin buds. The water jet disbudding and manual disbudding were compared to check the disbudding efficiency, time saved, and development of new shoots.

2. Materials and Methods

In order to examine how the use a water jet nozzle can reduce the time spent on disbudding, an experiment was performed in 2015 using 32-year-old satsuma mandarin (cv. Okitsu wase) planted in the experimental field of the Kinan Fruit Tree Science Branch of the Mie Prefecture Agricultural Research Institute (Figure 1). Three trees bore too much fruit (tree height: 2.4 ± 0.14 m, tree width: 3.4 ± 0.20 m) were used. The 30th of March, when about half of the previous shoot sprouted, was taken as the reference date for budding.

The water jet disbudding treatment was performed 1 (March 31, bud size [i.e., transverse diameter]: 1.24 mm), 7 (April 6, bud size: 2.30 mm), 16 (April 15, bud size: 2.86 mm), or 24 (April 23, bud size: 4.99 mm) days after budding (DAB) (Figure 2). The treatment was done for each lateral branch (average number of old leaves: 65.5 ± 24.6) by using a custom water jet nozzle manufactured by Yamaho Industry. The water jet nozzle was characterized by an ability to produce a narrow fan-shaped spray. The water jet could reached the buds on the shoots with pinpoint accuracy at a much higher impact and lower discharged volume compared to the wide-angle mist spray nozzles used for pesticide spraying (Figure 3).

The spraying nozzle was attached to the end of a pesticide spraying hose (inner diameter: 8.5 mm) connected to a power-operated sprayer that was driven by an engine manufactured by Honda Motor (GX120, maximum output: 2.6 kW/3600 rpm) and a dedicated pump manufactured by Olympia Kogyo (G420, maximum pressure: 4.9 MPa, pump volume:

Fig. 1 Using 32-year-old satsuma mandarin (cv. Okitsu wase) (2015.5.5)

1DAB ^x	7DAB	16DAB	24DAB
1.24 mm ^y	2.30 mm	2.86 mm	4.99 mm

Fig. 2 The buds disbudded

^xDAB : day after budding(March 30)

^y average transverse diameter of buds

Fig. 3 Water jet nozzle for disbudding

Fig. 4 The time spent for water jet disbudding with two types of nozzles

^w additional manual disbudding

^x DAB : day after budding (March 30)

^y average transverse diameter of buds

^z Different letters in each treatment day show significant differences at 5% by Tukey-Kramer HSD. WJ1, WJ2: total time for water jet disbudding and the additional manual disbudding. Control: time for manual disbudding

Vertical bars indicate SE (n=3)

25–42 L/min). The pump pressure was set at 2.9 MPa.

Two types of nozzle with different discharge volumes (WJN1: Yamaha Industry's spray plate NNZO12, water jet volume: 43.8 mL/s; WJN2: Yamaha Industry's spray plate NNZO10, water jet volume: 29.3 mL/s) were used. Manual disbudding was set as a control. For each treatment, three lateral shoots were selected per tree, and the treatment was repeated three times on each tree. The time spent on disbudding operation and the number of buds removed were investigated each day. The shoot number, the total shoot elongation, and the number of nodes on them were investigated on July 29. The treatments were aimed at disbudding completely, but some buds left behind were removed by manual disbudding on April 24 and May 25.

3. Results

1) Efficiency of disbudding with the water jet nozzle

As the result shown in Figure 4, the time spent for disbudding with WJN1 was shortest at 1 DAB (March 31) and increased with time until the treatment at 16 DAB. The values of time spent for disbudding treatment at 1 DAB (March 31) was 9.2 seconds per 10 old leaves with WJN1, which was significantly less than that of the control at 18.6 seconds per 10 old leaves. The time spent for disbudding with WJN2 showed similar results to those for WJN1.

As the result shown in Figure 5, the control removal rate of buds at 1 DAB was less than 90%, which was lowest among all treatment times. The removal rate gradually increased with time and

Fig. 5 The bud removal rates of water jet disbudding with two type of nozzles

^xDAB : day after budding (March 30)

^y average transverse diameter of buds

^z Different letters in each treatment day show significant differences at 5% by Tukey-Kramer HSD

Vertical bars indicate SE (n=3)

Control represents manual disbudding

Table 1 The new shoots development after water jet disbudding with two types of nozzles

	Number of shoots / 10 old leaves				Shoot length (cm)				Number of nodes			
	1 DAB ^x	7 DAB	16 DAB	24 DAB	1 DAB	7 DAB	16 DAB	24 DAB	1 DAB	7 DAB	16 DAB	24 DAB
	1.24 mm ^y	2.30 mm	2.86 mm	4.99 mm	1.24 mm	2.30 mm	2.86 mm	4.99 mm	1.24 mm	2.30 mm	2.86 mm	4.99 mm
WJN1	1.4	1.8	2.9	3.7	1.7 b ^z	8.6	5.0	5.3	2.3 b	5.6	4.6	4.4 a
WJN2	1.5	1.4	3.7	3.4	6.5 a	4.6	3.9	3.6	5.7 a	4.6	4.1	4.1 ab
Cont.	2.1	2.0	3.3	3.2	4.8 ab	6.2	3.9	3.5	4.4 ab	5.1	4.0	3.4 b

^xDAB : day after budding (March 30)

^y average transverse diameter of buds

^z Different letters in the column show significant differences at 5% by Tukey-Kramer HSD

Control represents manual disbudding

converged to around 97% after 16 DAB. This was due to the difficulty of control disbudding for very small buds as small as peas. However, no such difficulty was observed with the water jet nozzle treatment, and the removal rate with WJN1 was over 95% regardless of the treatment time. Therefore, the removal rate with WJN1 was significantly higher than the control removal rate at 1 DAB and 7 DAB. The

efficiency with WJN2 was almost the same as that with WJN1 except for the treatment on March 31.

2) Effect of disbudding with a water jet nozzle on new shoot development

The results are shown in Table 1. There were no significant differences regarding the number of shoots among all treatments. However, for the

treatments applied at 7 DAB, the average shoot length was shorter with WJN1 (1.7 mm) than with WJN2 (6.5 mm) and almost the same as the control (4.8 mm). There were no significant differences in the shoot length among the treatments applied after April 6. Similar results were found for the number of nodes.

4. Discussion

The newly developed disbudding technique using a water jet nozzle (WJN1) proved effective at removing newly developed small buds when applied just after budding. The total amount of time spent on the initial and corrective disbudding operations was 49.5% of the time spent for manual disbudding.

The efficient disbudding with a water jet may be because the buds were soft enough to be removed by water pressure. The manual disbudding was less effective because the location and size of the new buds made them difficult to reach with fingers. As the buds grew bigger, however, the water jet became less successful for removing buds. These findings suggest that water jet disbudding should be performed before early April, when the bud size reaches approximately 2.3 mm. Once the buds grew beyond this size, their peduncles grew thicker, and removing buds with the water jet nozzle took just as much time as the manual disbudding.

Regarding the new shoot characteristics (i.e., number of shoots, number of nodes, average shoot length, total elongation) the average shoot length when WJN1 was applied at 7 DAB was shorter than that with WJN2, which suggests that the shoot development was damaged by water spray volume. Further information is needed to determine suitable water spray volume conditions regarding the tree vigor, cultivar, and tree age.

A balanced development of shoots and flowers is necessary to prevent alternate bearing and to ensure the stable production of high-quality fruit every year. All young fruit thinning from partial or all branches is fundamental method to prevent alternate bearing (Kihara *et al.* 1995). Disbudding can early remove the flowers prior to the fruit thinning. Therefore, disbudding seems to be advantageous in preventing

the loss of reserve nutrients and promoting newly shoots sprouting more than the fruit thinning (Ishida and Yakushiji 1960).

Nakagawa *et al.* (2003) claimed that disbudding is a more painstaking process than fruit thinning, which makes it less suitable for large-scale applications. Using the water jet nozzle described in this paper for disbudding is ideal for young trees with a lower canopy volume or for cultivars with relatively low tree vigor. In addition, the disbudding method by water injection showed high fruit thinning effect with lower cost than machinery spraying of fruit thinning agent (Suzuki *et al.* 1990).

This experiment showed that using the newly developed water jet nozzle to remove small buds is an effective way of extending the disbudding period and reducing labor. No difference was observed between the two types of spray plates (i. e., WJN1 and WJN2) used to produce different water jet volumes in terms of the time spent for disbudding operation. However, WJN1 was more successful for removing buds. Therefore, although it requires 43.8 mL/s of water (approximately 155 L/h), it is the preferred spray plate for the nozzle used for water jet disbudding.

Further investigation is needed on the effects of the pump pressure, jet nozzle, and water jet volume on labor reduction and disbudding efficiency. Suitable conditions for this method regarding the cultivar, tree vigor, and bearing intensity also need to be defined.

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要旨

水噴射ノズルを使った新たな摘蕾方法を開発した。着果過多が予想される樹齢32年生の「興津早生」を用い、発芽期から1日後の3月31日（蕾横径1.24 mm）、7日後の4月6日（蕾横径2.30 mm）、16日後の4月15日（蕾横径2.86 mm）、24日後の4月23日（蕾横径4.99 mm）に側枝別の摘蕾を水噴射ノズルで行った。水噴射時の噴出水量が異なる2種類のノズル（WJN1：ジェット・ボリュウム：43.8 mL/秒；WJN2：29.3 mL/秒）を使って摘蕾に必要な時間と除去率を比較検討した。その結果、WJN1は芽の除去率がWJN2より優れた。蕾の除去作業時間は、発芽期から1日後の蕾横径1.24 mm処理では水噴射ノズル1で手作業の49.5%と少なく、除去率は96%であった。発芽後の日数が経過するほど蕾の花梗が硬くなるため、除去には時間がかかった。これらのことから水噴射ノズルを使った摘蕾は発芽後7日（蕾横径2.3 mm）までの処理が有効と考えられた。発芽後7日以降は処理時間に差は認められなかった。このことから水噴射ノズルを使った摘蕾は、発芽直後の小さな芽を除去するためには有効であると考えられた。

キーワード

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