Performance evaluation of mechanical blossom thinning in Y-trellis pear orchard

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Abstract: As the largest fruit producer in the world, China's comprehensive orchard mechanization rate is below 30% and faces the problem of aging orchard farmers. Thinning is an essential agronomic practice in orchard management. Therefore, to get a marketable product, artificial hand fruit thinning (AHFT) has become a major but costly management practice in modern orchard planting. The authors developed two types of new orchard blossom thinners: a tractor-mounted three-arm blossom thinner (TTBT) and a hand-held electric blossom thinner (HEBT). The arm shape, spindle rotation speed, and rope arrangement density of TTBT can be adjusted flexibly according to the canopy structure of the fruit tree. HEBT is portable and suitable for different canopy types, especially for traditional orchards with a complex-structured canopy. In this paper, a performance evaluation of the two types of blossom thinners on Y-trellis 'Sucui' No.1 pear orchard was carried out. In field tests, three treatments were designed and tested, which are TTBT combined with AHFT, HEBT combined with AHFT, and AHFT only. Four indices were used to evaluate the tests: blossom retention rate, fruit setting rate, fruit yield and quality, and work efficiency and cost. The test results showed that the blossom retention rate of TTBT and HEBT at 50% for Y-trellis 'Sucui' No.1 pear orchard was perfect; the difference in blossom retention rate and coefficient of variation of every layer of TTBT was very small, and the mean coefficient of variation was 2.97%, which is 1.98% lower than that of HEBT, meaning that the working stability of TTBT was higher than HEBT. The working efficiencies of TTBT and HEBT were much higher than that of AHFT, specifically, 130 and seven times higher, respectively. Although mechanical blossom thinning reduces the fruit setting rate to a certain extent, it has no effect on fruit yield and quality after fruit thinning for final marketable fruit. The profitable areas of TTBT and HEBT were 0.87 hm^2 and 0.08 hm^2, respectively.

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1 Introduction

China is the largest fruit producing country in the world with an orchard cultivation fruit area of more than 12 million hm^2 and a total output of nearly 300 million tons[1,2]. However, the research on orchard mechanization technology in China started relatively late, thus the foundation is unsolid, resulting in a comprehensive orchard mechanization rate below 30%[3]. Especially in some agronomic sections with high labor intensity and tight farming time, mechanization has not been realized[4,5]. Moreover, the country faces the problem of aging orchard farmers[6]. The lack of efficient and labor-saving agricultural machinery equipment has become the bottleneck that restricts the development of the Chinese fruit industry. As a necessary agronomic section in orchard management, thinning can avoid biennial bearing and improve fruit quality[7,8]. At present, there are two thinning methods in China: artificial hand fruit thinning (AHFT) and chemical pesticide spraying. Artificial hand fruit thinning consumes labor time, tree nutrients, and the risk of tree top operation is high[9]. Chemical spraying damages human health and the environment, and the application of pesticides is easily affected by spraying time, preparation concentration, and field environment[10,11]. Blossom thinning is better than fruit thinning, so mechanical blossom thinning will become a key development direction in the future.

The research on orchard mechanized blossom thinning mainly focuses on single spindle string blossom thinners, including the interaction mechanism between the thinning ropes and tree branches, the separating force of the blossom stems from different fruit trees, and the field working effect of different machinery. Hu et al. adopted a universal material testing machine to carry out tensile and shear force tests on pedicel node and receptacles corolla node on branches[12]. The research team members combined the research with ADAMS multi-body dynamics simulation, designed a performance test bench for the blossom thinning machine, and tested the striking force of the rope of three materials with different lengths, wire diameters, and spindle rotational speeds[13,14]. Yuan et al.[15,16] developed a variable angle blossom thinner for dwarf and

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close planting orchards. Based on the mechanical characteristics of peach and apple branches, they established a rigid-flexible coupling multi-body dynamics simulation model of the two fruit trees and optimized the operating parameters of thinning rope. Assirelli et al.[17] determined the range of peach tree fruit thinning force by studying the stem separating force of green fruit. On this basis, they replaced the traditional rope material with flexible glass fiber in the single spindle string blossom thinner[18,19]. The new thinner could save 48% and 42.4% of time compared with AHFT in apricot and peach orchards, respectively. Lordan et al.[20] established an apple blossom thinning parameter prediction model for Darwin 250 thinner through field tests, which could predict the advancing speed and the spindle rotational speed based on the number of inflorescences. Penzel et al.[21] studied the working kinetic energy of Darwin 250 thinner at the advancing speed of 8 km/h, and concluded that the spindle rotational speed of 200-380 r/min corresponded to the working kinetic energy of 0.15-0.66 J. Because of the simple structure and the difficulty for the rope to hit the inside of the tree canopy, the above single spindle string blossom thinners are mainly suitable for hedge wall type orchards, and their effect on other types of trees is not ideal, thus they are inappropriate for the planting mode of Chinese orchards. Even if they are used in the Y-trellis orchard, they are unsuitable because the length of the spindle cannot be extended and the angle cannot be adjusted freely.

Y-trellis cultivation is a modern pear orchard planting pattern originating in Korea, which has been widely adopted in recent years due to its good performance in wind and hail prevention and mechanized operation[22,23]. Mechanical blossom thinning can effectively reduce the labor intensity and greatly improve the efficiency of fruit thinning. In this paper, two types of orchard blossom thinning equipment developed by the authors were introduced: tractor-mounted three-arm blossom thinner (TTBT) and hand-held electric blossom thinner (HEBT). Three treatments for 18 Y-trellis ‘Sucui’ No.1 pear trees were performed in the test[24]: TTBT combined with AHFT, HEBT combined with AHFT, and AHFT only, respectively. Four indices were used to evaluate the test: blossom retention rate, relative fruit setting rate, fruit yield and quality, and work efficiency and cost. Studying the working effect of mechanical blossom thinning in the Y-trellis pear orchard can provide a reference for the mechanization development of orchards.

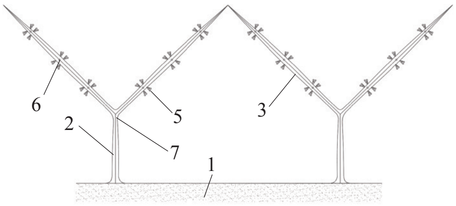
2 Material and methods

2.1 Y-trellis pear orchard

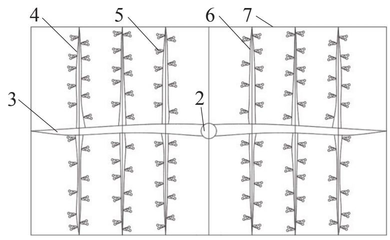
The variety of Y-trellis pear is ‘Sucui’ No.1, and the orchard is located in Yejia Development Co., Ltd., Taixing, Jiangsu province, China. Referring to the key design requirements of Y-trellis[25], the trees were planted with line spacing of 5 m and row spacing of 3 m, and the structure is shown in Figure 1. Trellis height is 3 m, and the angle between the trellis plane and ground is 45°. The plane of the trunk and main branches of the pear tree is located in the middle of the two Y-trellis single arches, and the steel pipes/wire ropes are connected with the Y-trellis single arch. The lateral branches of the pear trees are centered on the main branch, and grow along the steel pipes/wire ropes in a ‘fishbone’ shape towards both sides of the main branch. The pear trees are seven years old, and their trunk height is 0.5 m; the average diameter of the trunks, main branches, and lateral branches is 8 cm, 5 cm, and 3 cm, respectively.

2.2 Tractor-mounted three-arm blossom thinner

TTBT was independently developed by Jiangsu Academy of Agricultural Sciences. It is linked with a tractor by three-point suspension, and the structure of TTBT is shown in Figure 2. The whole machine is composed of a body frame, thinning mechanism, hydraulic control system, electronic control system, and a couple of



a. Front view

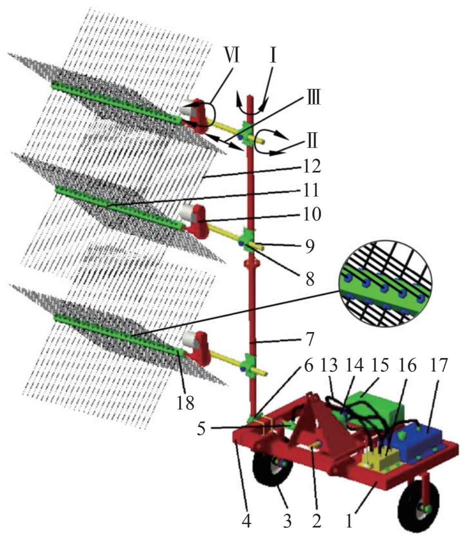


b. Top view

1. Ground 2. Trunk 3. Main branch 4. Lateral branch 5. Inflorescence 6. Steel pipe/Wire rope 7. Y-Trellis single arch

Note: Inflorescences of Y-trellis ‘Sucui’ No.1 pear tree mainly grow on lateral branches and average eight blossoms on one inflorescence. The blossom retention rate is defined as the number of blossoms after blossom thinning divided by the number of blossoms before blossom thinning. Considering the objective factors of fruit growth such as weather regurgitation, damage rate in blossom thinning, blossom pollination, pecking of insects and birds, and natural fruit drop, the blossom retention rate of ‘Sucui’ No.1 pear was set at 50%.

Figure 1 Structure of Y-trellis pear tree



1. Frame 2. Transmission shaft 3. Limit wheel 4. Movable beam 5. Hydraulic cylinder 6. Vertical rod bracket 7. Vertical rod 8. Arm bracket 9. Arm extension/contraction rod 10. Spindle power assembly 11. Spindle 12. Rope 13. Hydraulic pipeline 14. Hydraulic gear pump 15. Electric cabinet 16. Liquid distribution valve 17. Hydraulic oil tank 18. Rope fixed screw Note: Ⅰ is the rotation direction of arm bracket; relative to the vertical rod, the arm bracket can rotate within 360° at Ⅰ arrow direction; Ⅱ is the rotation direction of arm extension/contraction rod; relative to the arm bracket, the arm extension rod can rotate within 360° at Ⅱ arrow direction; Ⅲ is the movement direction of arm extension/contraction rod; relative to the arm bracket, the arm extension/contraction rod can move in the range of 0-0.5 m at Ⅲ arrow direction; Ⅳ is the rotation direction of spindle power assembly; relative to the arm bracket, the spindle power assembly can rotate within 270° at Ⅳ arrow direction.

Figure 2 Structure of TTBT

limit wheels. The hydraulic gear pump provides power for the movement of the hydraulic cylinder, which is driven by the tractor PTO (Power Take Off). The liquid distribution valve controls the extension and contraction movement of the hydraulic cylinder and makes the movable beam move horizontally relative to the frame. Three thinner arms are installed flexibly at different positions of the vertical rod as needed. The spindle rotation speed of the upper, middle, and lower thinner arms is controlled by the electronic control system. The ropes are fixed by screws and arranged around the spindle at an interval of 4 cm. The linear density of rope is determined by the spatial arrangement of rope fixed screws. The main structural and performance parameters of TTBT are listed in Table 1.

Table 1 Main structural and performance parameters of TTBT

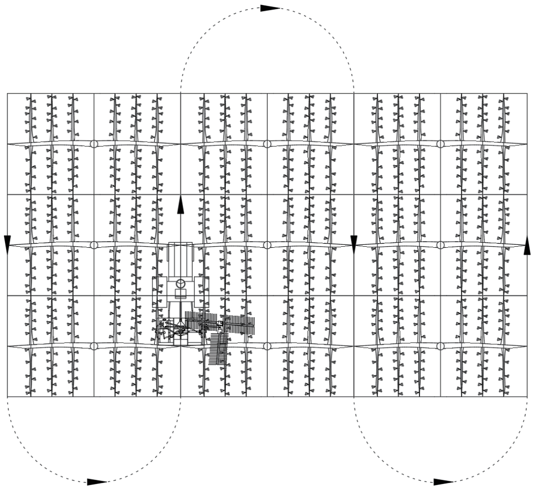
Parameters	Values
Tractor minimum power/kW	18.8
Weight/kg	200
Size (length×width×height)/m×m×m	0.9×1.2×2.7
Arm number	3
Arm extension range/m	0-0.5
Spindle length/m	1.1
Spindle rotation speed range/(r·min^{-1})	0-300
Rope rotation radius/m	0.5
Rope line diameter/mm	3
Rope axial distance/cm	4

Before the TTBT is working, the operator adjusts the distribution density of the rope on the spindle according to the agronomic information such as pear variety and blossom time. Then, the tractor drives TTBT to the orchard and adjusts it to a suitable operating height by hydraulic lifting. The operator adjusts the position and shape of the three blossom thinning arms relative to the vertical rod by twisting and moving the arm bracket, the arm extension/contraction rod, and the spindle power assembly, so that the spindle working plane is parallel to the Y-trellis plane. Finally, tractor PTO drives the hydraulic gear pump, and the operator determines the position of the movable beam relative to the frame by controlling the liquid distribution valve, so as to adjust the thinning distance between the spindle working plane and the Y-trellis plane. When the TTBT is working, the electronic control system controls spindle rotation speed of the three arms, and the tractor drives the TTBT forward. The S-shaped movement path of TTBT in the field is shown in Figure 3.

2.3 Hand-held electric blossom thinner

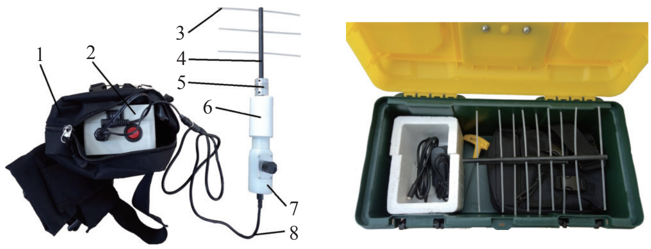
HEBT was independently developed by Jiangsu Academy of Agricultural Sciences and has been commercialized, and its price is 1000 to 1500 CNY depending on the configuration. It is portable and suitable for different canopy types, especially for traditional orchards with a complex structured canopy. The structure of HEBT is shown in Figure 4.

Before the HEBT is working, the operator ties the power bag at the waist, then puts the storage battery into the power bag, and links the storage battery, wire, governor, DC motor, shaft coupling, and spindle one by one. When the HEBT is working, the operator holds the governor in hand for thinning. The operator can adjust the spindle rotation speed according to the stalk hardness and blossom density. HEBT can have an optional extension rod in configuration for thinning the canopy areas at a long distance. The main structural and performance parameters of HEBT are listed in Table 2.



Note: The arrows signify the movement direction of TTBT, and its movement path is in an S-shape. The spindle working plane is parallel to the Y-trellis plane, and the operator can adjust the thinning distance by controlling the liquid distribution valve.

Figure 3 Movement path of TTBT



a. Assembly structure b. Packaging box

1. Power bag 2. Storage battery 3. Rope 4. Spindle 5. Shaft coupling 6. DC motor 7. Governor 8. Wire

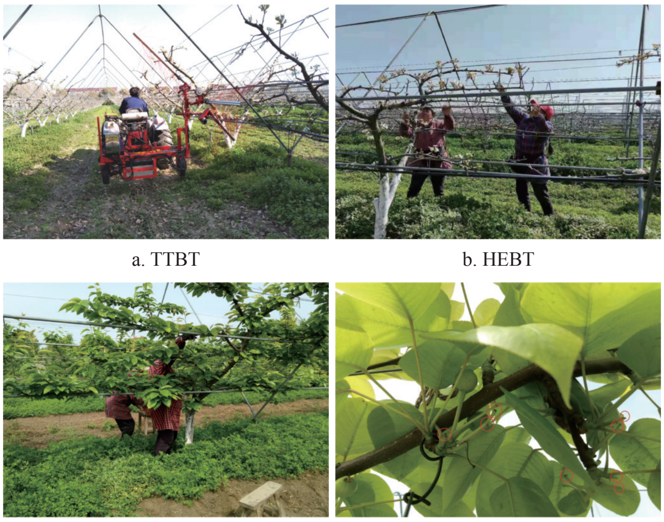
Figure 4 Structure of HEBT

Table 2 Main structural and performance parameters of HEBT

Parameters	Values
Rope rotation radius/cm	8
Rope line diameter/mm	2.4
Rope axial distance/cm	4
Spindle rotation speed range/r·min^{-1}	0-900
Battery output voltage/V	12
Battery capacity/A·h	10.4

2.4 Methods of field tests

In field tests, three kinds of treatments were adopted to evaluate the efficiency of blossom thinning: TTBT combined with AHFT, HEBT combined with AHFT, and AHFT only. Test indices were blossom retention rate, relative fruit setting rate, fruit yield and quality, and work efficiency and cost[26-27,27]. Eighteen trees were selected randomly as the test objects and the tree canopy was divided into three layers in the direction of height, then five inflorescences were randomly selected from each layer as observation samples. The eighteen trees were divided equally into three groups: TTBT combined with AHFT as group 1 for test, HEBT combined with AHFT as group 2 for test, and AHFT (two times) as group 3 for control. Experience of the AHFT worker is more than five years. The rotation speeds of TTBT and HEBT used in test are 300 and 800 r/min, respectively. The thinning working sites are shown in Figure 5. Blossom thinning tests were carried out from March 25 to 30, 2024. The blossom number of the inflorescence samples before and after thinning, and the thinning time of each tree was recorded. Fruit thinning tests were carried out from April 15 to 23, 2024. The green fruit number of the inflorescence samples before and after thinning, and the thinning time of each tree were recorded. Harvesting tests were carried out on July 3, 2024. Referring to national standard NY/T440[28] and GB/T10650[29], fruits of each test pear tree were graded for high-quality fruits and ordinary fruits. The high-quality fruits are those with correct shape and dark green peel, intact fruit stem, and fruit surface free from stab, scratch, crush, grind, or worm, and the mass of a single fruit should not be less than 350 g.



a. TTBT b. HEBT

c. AHFT d. Green fruit are removed

Figure 5 Test sites for thinning

Blossom retention rate of the pear tree is defined as the number of sample blossoms after blossom thinning divided by the number of sample blossoms before blossom thinning. Barreto et al.[9] performed mechanical blossom thinning on peach trees, and the average blossom retention rate was 55%. McClure et al. performed mechanical blossom thinning on apple trees, and the average blossom retention rate was 54.5%[30]. Each inflorescence of 'Sucui' No.1 pear has an average of eight blossoms. Considering the objective factors in fruit growth, such as weather regurgitation, blossom thinning damage, blossom pollination, pecking of insects and birds, and natural fruit fall, the blossom retention rate of 'Sucui' No.1 pear was set at 50%. To reflect the individual stability of blossom thinning on pear trees, the coefficient of variation of the blossom retention rate in different layers was calculated. The calculation formulas of blossom retention rate, standard deviation, and coefficient of variation are shown in Equations (1)-(4).

$$a_i = \frac{n_{ba}}{n_{bb}} \times 100\% \tag{1}$$

where, a_i is the blossom retention rate of tree i, %; n_{ba} is the number of sample blossoms after blossom thinning; n_{bb} is the number of sample blossoms before blossom thinning.

$$a = \frac{\sum_{i=1}^{6} a_i}{6} \tag{2}$$

where, a is the blossom reserve rate of six sample pear trees, %.

$$s_a = \sqrt{\frac{\sum_{i=1}^{6} (a_i - a)^2}{6}} \tag{3}$$

where, s_a is the standard deviation of the blossom retention rate, %.

$$\mathrm{CV} = \frac{s_a}{a} \times 100\% \tag{4}$$

where, CV is the coefficient of variation of blossom retention rate, %.

Relative fruit setting rate is defined as the number of sample green fruits before fruit thinning divided by the number of sample blossoms after blossom thinning. The purpose of thinning is to improve fruit yield and quality, and blossom thinning can relieve the heavy labor pressure of AHFT. Some blossoms hit by the ropes will slowly wither after thinning, and relative fruit setting rate is a better index to evaluate the damage. The calculation formulas of relative fruit setting rate are shown in Equations (5) and (6), and its coefficient of variation is the same as that of blossom retention rate.

$$b_i = \frac{n_{fb}}{n_{ba}} \times 100\% \tag{5}$$

where, b_i is the relative fruit setting rate of tree i, %; n_{fb} is the number of sample green fruits before fruit thinning.

$$b = \frac{\sum_{i=1}^{6} b_i}{6} \tag{6}$$

where, b is the relative fruit setting rate of six sample pear trees, %.

The fruit retention rate is defined as the number of sample ripe fruits divided by the number of sample blossoms before blossom thinning. Fruit yield and quality can be used to evaluate orchard production, which is directly related to the income of the orchard manager. The test measured fruit retention rate, total yield per tree, high quality fruit yield per tree, and brix of sugar solids. The calculation formulas are shown in Equations (7)-(9). In each treatment, three fruits were selected from the high-quality fruits and the ordinary fruits, respectively, and the brix of sugar solid of each fruit was measured. Then, the average value of these six fruits was calculated to obtain the brix of sugar solid for each treatment.

$$d = \frac{n_f}{n_{bb}} \times 100\% \tag{7}$$

where, d is the fruit retention rate, %; n_f is the number of sample ripe fruits.

$$m = \frac{m_i}{6} \tag{8}$$

where, m is the total yield per tree, kg; m_i is the yield of tree i, kg.

$$m_h = \frac{m_{hi}}{6} \tag{9}$$

where, m_h is the high-quality fruit yield per tree, kg; m_{hi} is the high-quality fruit yield of tree i, kg.

The thinning time of each treatment is recorded and the data is converted to work efficiency. The profitable areas of TTBT and HEBT were calculated based on the work efficiency, so as to guide the orchard manager to make a decision. The profitable area of the machine is the minimum planting area required by the machine to replace labor in management costs. According to Equations (10)-(12), the profitable area can be calculated. When the planting area of crops is larger than the profitable area, the machine can bring about profits.

$$q = \frac{p}{n_y} \tag{10}$$

where, q is the annual depreciation of one thinner, Yuan; p is the price of one thinner, Yuan; n_y is the depreciable life, year.

$$c = \frac{c_0 t}{t_0} \times \eta \tag{11}$$

where, c is the cost that can be saved by the thinner by replacing with AHFT, Yuan/hm²; c_0 is the labor cost in an 8-h working day, Yuan; t is the AHFT time per unit area, h/hm²; t_0 is the working hours (8 h) in one day, h; η is the proportion of time saved in mechanical thinner to that of AHFT.

$$z = \frac{q + c_{um}}{c} \tag{12}$$

where, z is the profitable area of one thinner, hm²; c_{um} is the use and maintenance costs of one thinner per year, Yuan.

3 Results and discussion

3.1 Blossom retention rate

Blossom retention rate is applied to evaluate the thinning quality of two mechanical thinners, and the results are listed in Table 3. AHFT was the control group and its blossom retention rate was 100%. The blossom retention rates of upper, middle, and lower layers of two mechanical thinners could better meet the requirements of 50%. The difference in blossom retention rate and coefficient of variation in every layer of TTBT was very small, and the mean coefficient of variation was 2.97%, which is 1.98% lower than that of HEBT and related to that of Y-trellis planting mode suitable for mechanized working. The tractor of TTBT followed a fixed moving route at a fixed speed, and the ropes hit the Y-trellis at a fixed distance and speed, so that the striking force on each branch of the pear trees was the same. Compared with HEBT, which requires the operator to repeatedly move around the tree canopy, it has higher stability. Although the values of blossom retention rate in the upper, middle, and lower layers were close to 50%, the coefficients of variation of HEBT were larger with larger differences. HEBT can work with accurate quantification, but the thinning distance between the rope and inflorescence is subject to the control of the operator. Coupled with the artificial fatigue factor, the operation fluctuation is larger than that of TTBT. In addition, it can be seen from Table 3 that the operation fluctuation of HEBT in the middle and lower layers of sample pear trees is smaller than that in the upper layers. This is because the operation in the upper layers requires tools such as bench and ladder, and the operation comfort is lower than that in the other two layers.

Table 3 Blossom retention rate *a* and coefficient of variation CV

Position	Index	TTBT	HEBT	AHFT
Upper layer	*a*/%	51.43	49.02	100.00
	CV/%	2.63	6.77	-
Middle layer	*a*/%	49.75	47.12	100.00
	CV/%	2.69	3.13	-
Lower layer	*a*/%	50.59	48.61	100.00
	CV/%	3.59	4.97	-
Average *a*/%		50.59	48.25	100.00
Average CV/%		2.97	4.95	-

Note: TTBT represents TTBT+AHFT; HEBT represents HEBT+AHFT.

3.2 Relative fruit setting rate

The relative fruit setting rate can reflect the damage in blossom thinning, and its results are listed in Table 4. The relative fruit setting rate of three groups ranked from small to large in the order of TTBT, HEBT, and AHFT. The relative fruit setting rate of AHFT was 86.11%, which is 20.82% and 6.86% higher than that of TTBT and HEBT, respectively, showing that mechanical blossom thinning leads to some damage on the reserved blossoms. The hit of rope on inflorescence is random. Although some blossoms are not shot down in thinning, they gradually wither and fall in the later growth due to a certain degree of damage, which significantly reduces the relative fruit setting rate. Mechanical blossom thinning reduces the fruit setting rate to a certain extent, and it has no effect on fruit yield and quality through harvest tests. The coefficients of variation of the three groups were less than 10%, indicating that the fruit bearing stability was acceptable. The coefficients of variation of the three groups ranked from small to large in the order of AHFT, HEBT, and TTBT. The coefficient of variation of AHFT was 2.49%, which is 5.03% and 2.23% lower than that of TTBT and HEBT, respectively. The AHFT was a natural fruit set, and the coefficients of variation in the upper, middle, and lower layers of sample pear trees were small; the differences between them were also small. TTBT and HEBT are artificial interventions, and the blossoms suffered different damages in the process of mechanized blossom thinning; some blossoms grow into fruit, while others do not, leading to the increase of the coefficient of variation. The collision force of the flexible thinning rope ranges from 2 to 4 N, and it will not cause damage to the tree during the operation. In addition, the main purpose of blossom thinning is to save the nutrients wasted by excess fruit set, which has a positive effect on the future growth of the fruit trees.

Table 4 Relative fruit setting rate *b* and coefficient of variation CV

Position	Index	TTBT	HEBT	AHFT
Upper layer	*b*/%	66.11	77.57	84.98
	CV/%	8.16	4.68	2.72
Middle layer	*b*/%	62.02	79.84	87.33
	CV/%	6.94	5.14	2.45
Lower layer	*b*/%	67.73	80.34	86.02
	CV/%	7.45	4.33	2.30
Average *b*/%		65.29	79.25	86.11
Average CV/%		7.52	4.72	2.49

Note: TTBT represents TTBT+AHFT; HEBT represents HEBT+AHFT.

3.3 Fruit yield and quality

Fruit yield and quality are the final indices to evaluate fruit production management, and the results are listed in Table 5. After blossom thinning, it was necessary to thin a small amount of green fruit for final marketization. The control group underwent fruit thinning twice. The fruit retention rate is positively related to the total yield per tree and high-quality fruit yield per tree, and negatively related to the brix of sugar solids. After averaging the data of TTBT and HEBT, the fruit retention rate was 12.98%, the total yield per tree was 33.19 kg, the high-quality fruit yield per tree was 27.87 kg, and the brix of sugar solids was 11.2%. Compared with the AHFT, the fruit retention rate decreased by 0.16%, the total yield per tree decreased by 0.18 kg, the high-quality fruit yield per tree decreased by 0.27 kg, and the brix of sugar solids increased by 0.1%. The fruit retention rate, the total yield per tree, and the high-quality fruit yield per tree of AHFT were higher than those of TTBT and HEBT. The reason is that the leaves of the tree formed in the period of fruit thinning and the thick leaves blocked the operator’s sight. The number of green fruit for thinning in TTBT and HEBT was only about 50%, which was less affected than that in AHFT. The brix of sugar solids in AHFT were lower than those of TTBT and HEBT, which is related to the nutrient waste of fruit trees. There is no blossom thinning in AHFT, and most of the blossoms developed into green fruits, while about 50% of the blossoms of TTBT and HEBT were eliminated in the blossom stage, and the number of blossoms developing into green fruits in the later stage was less than that of AHFT. During the fruit setting period, nutrients were saved and brix of sugar solids increased.

Table 5 Fruit yield and quality

Index	TTBT	HEBT	AHFT
Fruit retention rate/%	12.95	13.01	13.14
Total yield per tree/kg	33.16	33.21	33.37
High-quality fruit yield per tree/kg	27.82	27.91	28.14
Brix of sugar solids/%	11.20	11.20	11.10

Note: TTBT represents TTBT+AHFT; HEBT represents HEBT+AHFT. The high-quality fruit are those with correct shape, dark green peel, intact fruit stem, and fruit surface free from stab, scratch, crush, grind, or worm, and the mass of the single fruit is not less than 350 g.

3.4 Work efficiency and cost

The planting space of one pear tree is 15 m^2, and 667 trees can be planted in 1 hm^2. The work efficiency of mechanical blossom thinning is calculated based on mechanical blossom thinning time of one tree, and the results are listed in Table 6. The work efficiency of TTBT and HEBT are much higher than that of AHFT, which are 130 and seven times that of AHFT. The prices of TTBT and HEBT are 15 000 Yuan and 1000 Yuan, respectively, with five years of depreciable life. The use and maintenance costs of TTBT and HEBT are 300 and 50 Yuan, respectively. The labor cost is 100 Yuan in an 8-h working day, and the total proportions of time saved by TTBT and HEBT to the AHFT are 84.2% and 71.91%, respectively. According to Equations (10)-(12), the profitable areas of TTBT and HEBT are 0.87 hm^2 and 0.08 hm^2, respectively. The test pear orchard is situated on flat terrain, so the calculation above is based on the flat field conditions. Since population aging in China nowadays has become more and more serious, with a large number of farmers now working in cities, the small-scale orchard farms have been replaced by large-scale modern fruit companies. Labor working is suitable for family farms and has been eliminated in industry. In such circumstances, mechanical blossom thinning is especially suitable for the large-scale mechanized orchard management. Orchard managers can use a certain amount of TTBT and HEBT according to their orchard planting area and the cost that they can afford.

Table 6 Work efficiency of mechanical blossom thinning and profitable area

Treatment	TTBT	HEBT	AHFT
Mechanical blossom thinning time or AHFT time per tree/min	0.23	4.50	32.30
Fruit thinning time per tree for final marketable fruit/min	5.90	6.40	6.50
Work efficiency of mechanical blossom thinning/(hm^2·h^{-1})	0.39	0.02	-
Profitable area/hm^2	0.87	0.08	-

Note: TTBT represents TTBT+AHFT; HEBT represents HEBT+AHFT.

4 Conclusions

1) This paper introduced two types of new orchard blossom thinners: tractor-mounted three-arm blossom thinner (TTBT) and hand-held electric blossom thinner (HEBT). TTBT is linked with a tractor by three-point suspension, and it is composed of a body frame, thinning mechanism, hydraulic control system, electronic control system, and a couple of limit wheels. The arm shape, spindle rotation speed, and rope arrangement density of TTBT can be adjusted flexibly according to the canopy structure of the fruit tree. The spindle length of TTBT is 1.1 m and the rotation speed is adjustable from 0 to 300 r/min. HEBT is easy to carry and suitable for different canopy types, especially for traditional orchards with a complex structured canopy. The spindle rotation speed of HEBT is adjustable from 0 to 900 r/min, the battery capacity is 10.4 A·h, and it can work continually for more than 8 h.

2) This study carried out performance evaluation of the two types of blossom thinners on Y-trellis 'Sucui' No.1 pear orchard. In field tests, three treatments were designed and tested: TTBT combined with AHFT, HEBT combined with AHFT, and AHFT only. Four indices were used to evaluate the tests: blossom retention rate, fruit setting rate, fruit yield and quality, and work efficiency and cost. The test results showed that the blossom retention rate of TTBT and HEBT at 50% for Y-trellis 'Sucui' No.1 pear orchard was perfect. The difference of blossom retention rate and coefficient of variation of every layer of TTBT was very small, and the mean coefficient of variation was 2.97%, which is 1.98% lower than that of HEBT, meaning that the working stability of TTBT was higher than HEBT. The working efficiencies of TTBT and HEBT was much higher than that of AHFT, at 130 and seven times higher. Although mechanical blossom thinning reduces the fruit setting rate to a certain extent, it has no effect on fruit yield and quality after fruit thinning for final marketable fruit. The profitable areas of TTBT and HEBT were 0.87 hm^2 and 0.08 hm^2, respectively.

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