JARQ 56 (3), 229-236 (2022) https://www.jircas.go.jp

REVIEW

Development of an Arm-raising Work Assistance Tool for Maintenance of Trellis-trained Fruit Trees

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Abstract
We developed an arm-raising work assistance tool and evaluated its ability to mitigate the effects of the workload during grape cultivation. The tool comprises a hip belt, arm supports, and connectors linking them. This tool supports the arms when held at any height while keeping the wearer's elbows pulled in. When performing berry thinning using the tool, the percent maximum voluntary contraction (%MVC) of the deltoid muscle was found to reduce by approximately 30%-80% without reducing the efficiency. Seven out of eight workers reported that using the tool made their work easier.

Discipline: Agricultural Engineering
Additional key words: assist suit, grape, wearable device, labor burden

Introduction

Fruit tree cultivation requires long working hours because the main tasks, such as pruning, maintenance, and harvesting, are not mechanized. For grape cultivation, approximately 450 working hours are required for every 1,000 m^2, which is approximately twice as much as for fruit trees, such as mandarins and apples (Ministry of Agriculture, Forestry and Fisheries of Japan 2010). Pollination, fruit thinning, maintenance, and bagging account for approximately 40% of the total work time for the cultivation of grapes in Japan. The maintenance work associated with fruit on the tree, such as flower spike shaping, gibberellin treatment, berry thinning, and bagging work, is carried out for a limited period from late May to early July. Additionally, as the cultivation of grapes in Japan is generally on flat-shelf trellis-trained, the fruit is located at the height of the worker's head. Thus, fruit maintenance work must be performed in a position wherein the arm is kept raised for a long time. This work is difficult because it puts a heavy load on the neck and shoulders of the worker (Ojima & Tokuda 2008, Tsujimura et al. 2011).

In recent years, to reduce the labor burden of work that is difficult to mechanize, the development of a wearable device called assist suits has been actively carried out. Some of these have been put into practical use in agricultural work. Assist suits can be broadly divided into power-assisted suits that carry out functions such as lifting heavy objects using the power of a motor, and posture-supported suits that support a long-term strenuous posture (Makino 2010). Fruit maintenance work of grapes requires keeping the arms raised for a long time, and it is considered effective to use a posture-supporting assist suit. As a tool to support the raised-arm posture, various types of devices are commercially available. These include an elastic body support type that supports the arm with an elastic force, such as a spring,

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Received 8 March 2021; accepted 11 August 2021.

an arm mount type that supports the arm with a fixed stand, and a switchable type that switches between fixing and releasing the arm mount with a switch. However, these commercially available tools have problems, such as the inability to change the height at which the arm is supported during work and the inconvenience that the support force changes depending on the height of the arm when an elastic material is used.

Therefore, we developed a prototype of an arm-raising work assistance tool with a simple mechanism that can easily change its height to stably support a worker's arms, and we verified the resulting reduction in labor burden in a grape cultivation field.

Overview of arm-raising work assistance tool

1. Structure of arm-raising work assistance tool

The prototype arm-raising work assistance tool (hereinafter called the assistance tool) has a very simple structure comprising a work belt to be attached to the waist of the worker, arm supports, a frame, and mechanisms for connecting them (Figs. 1, 2). The weight of the assistance tool is 1.8 kg. Additionally, the length from the lower end of the belt to the connecting mechanism and length of the arm support can be adjusted according to the physique of the worker (Table 1). The connecting mechanism has a hinge with two degrees of freedom so that the arm support can rotate in the up/down and left/right directions. There is a grooved segment on the work belt side and corresponding claw on the arm support side. When the worker brings his/her elbow close to their body, the grooved segment and claw mesh with each other and cannot move downward; thus, the weight of the arm is supported by the waist belt. When the worker brings their elbow away from their body, the grooved and claw parts are separated so that the worker can freely raise and lower their arm. The grooved segment contains multiple grooves radially from the center of rotation of the arm support within a range of 90°, so that the arm can be supported at any angle at which the grooved segment and claw mesh with each other.

Fig. 1. Overview of the arm-raising work assistance tool

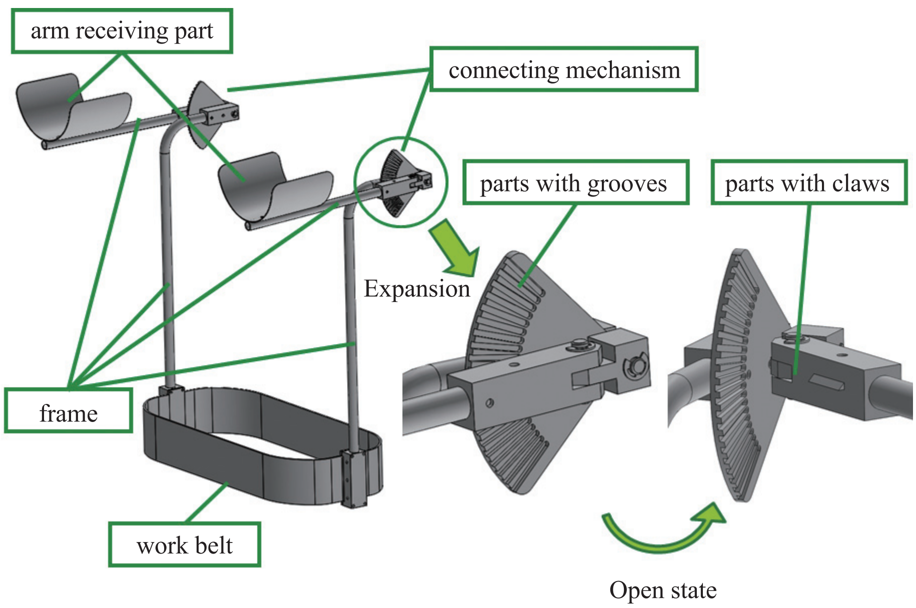

Fig. 2. Schematic of the arm-raising work assistance tool

Table 1. Specifications of the arm-raising work assistance tool

Weight (kg)	1.8
Length from the lower end of the belt to the connecting mechanism (mm)	320~400
Arm support length (mm)	220~280
Work belt waist circumference (mm)	650~950
Vertical support angle range (degrees)	–45~ 45

2. Use of the arm-raising work assistance tool

The assistance tool can be worn over work clothes. The worker can attach the assistance tool simply by tightening the work belt on the waist and fixing the arm support to the arm with a hook-and-loop fastener. With practice, a worker can attach the assistance tool alone in approximately 30 s. A worker can perform work with their arms supported by raising their arms to an arbitrary height and then moving their elbows in toward their body. When the worker wants to raise the height of their arm, they do not need to move their elbow. When the worker wants to lower their arm, they move their elbow away from their body to separate the grooved segment from the claw.

Test method

1. Labor burden evaluation method when raising arms

In this study, to evaluate the labor burden, we measured the amount of muscle activity and conducted an interview survey. Because fruit maintenance work with raised arms raised is not an aerobic activity, it is difficult to evaluate the work effort on the basis of heart rate increase and energy metabolism. As a method for evaluating the amount of muscle activity, we measured the surface electromyography (EMG) of the worker using a telemetry-type surface EMG measuring device. The sampling frequency of the surface EMG was 1 kHz, and the amount of muscle activity was evaluated by calculating the ratio of the EMG during work to the EMG in the most intense state (Ishikawa & Kikuchi 2003). Eight measurement points were used: the left and right biceps brachii, triceps brachii long head (hereinafter called triceps brachii), anterior deltoid muscle (hereinafter called deltoid muscle), and upper trapezius muscle (hereinafter called trapezius muscle), which are the muscles that bend, stretch, raise, and lower the arm (Fig. 3). The average values on the left and right sides were noted for each measurement position. In this study, the test was conducted after explaining the test methods to the test subjects and obtaining their consent in advance.

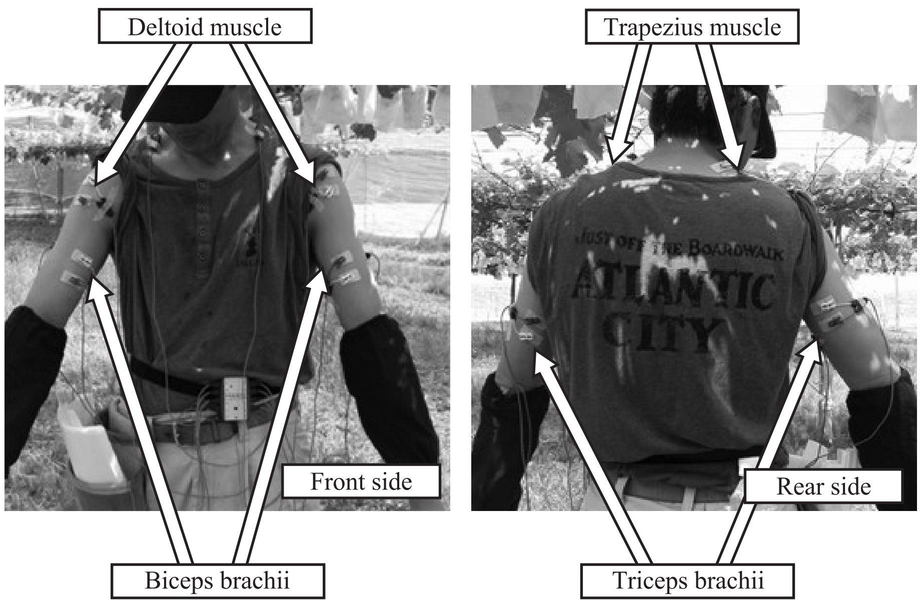

Fig. 3. Measurement of muscle activity

2. Evaluation test of the effect of using the assistance tool

(1) Indoor practice tests

To understand the change in muscle activity due to wearing the assistance tool, we measured the muscle activity when the movement of raising and lowering the arms was repeated every 10 s for 10 min in the two test groups “without assistance tool” and “with assistance tool.” The arm raising and lowering movements were as follows: keep arms down (10 s), arms raised to a relatively low position (subject’s height − 10 cm) (10 s), arms lowered (10 s), arms raised to the same position as subject’s height (10 s), arms lowered (10 s), and arms raised to a relatively high position (subject’s height + 10 cm) (10 s). The subjects repeated these movements.

(2) Demonstration test in grape cultivation field

To understand the effects of the use of the assistance tool on fatigue and work efficiency during maintenance work in a grape cultivation field, a comparative test of conventional work without the assistance tool and work with the assistance tool was conducted to measure work efficiency and muscle activity and to observe the degree of fatigue and handleability of the tool. We performed the measurement in each of the tasks of flower spike shaping, gibberellin treatment, berry thinning, and bagging (Fig. 4). The working time of each subject was 10-30 min for gibberellin treatment only and 1 h for other work. We clarified the work efficiency by measuring the number of working bunches processed within the time period. Additionally, the amount of muscle activity during work was evaluated by measuring the surface EMG during the tasks of flower spike shaping, berry thinning, and bagging. There were 6-9 subjects for each task, with their ages ranging from the 20s to 50s, both male and female, and heights ranging from 164 to 180 cm.

Results

1. Indoor practice test

Figure 5 shows the amount of muscle activity (waveform averaged for 10 cycles of the full-wave rectified waveform of each cycle) in the practice test using the assistance tool. The percent maximum voluntary contraction (%MVC) value with the arm raised differed greatly depending on whether the assistance tool was used. When the arms were lowered, both “without assistance tool” and “with assistance tool,” the %MVC value of the biceps brachii and triceps brachii muscles was approximately 0%, deltoid muscles was 2%-4%, and trapezius muscle was 4%-5%. When the arms were raised

Fig. 4. Work with the assistance tool

without an assistance tool, the %MVC value of the biceps brachii muscle was 2%-3%, triceps brachii muscle was 1%, deltoid muscle was 15%-20%, and trapezius muscle was 8%-10%. Conversely, with the assistance tool, the %MVC value of the biceps brachii muscle was 2%-4%, triceps brachii muscle was 1%, deltoid muscle was 2%-10%, and trapezius muscle was 2%-3%. The muscle activity of the deltoid and trapezius muscles was reduced by wearing the assistance tool.

Because the weight of the arm can be supported by the assistance tool, the arm-raised position can be maintained even if the deltoid and trapezius muscles do not undergo isometric muscle contraction. Although a high myoelectric potential was briefly seen during the support/release operation for raising and lowering the arms in the "wearing assistance tool" group, it is considered that this is because a potential higher than the exerted force is measured during dynamic movement (Seo 2005) and no particular effort was felt during the movement.

2. Demonstration test in a grape cultivation field

(1) Work efficiency

Figure 6 shows the work efficiency of the conventional work without assistance tools and work

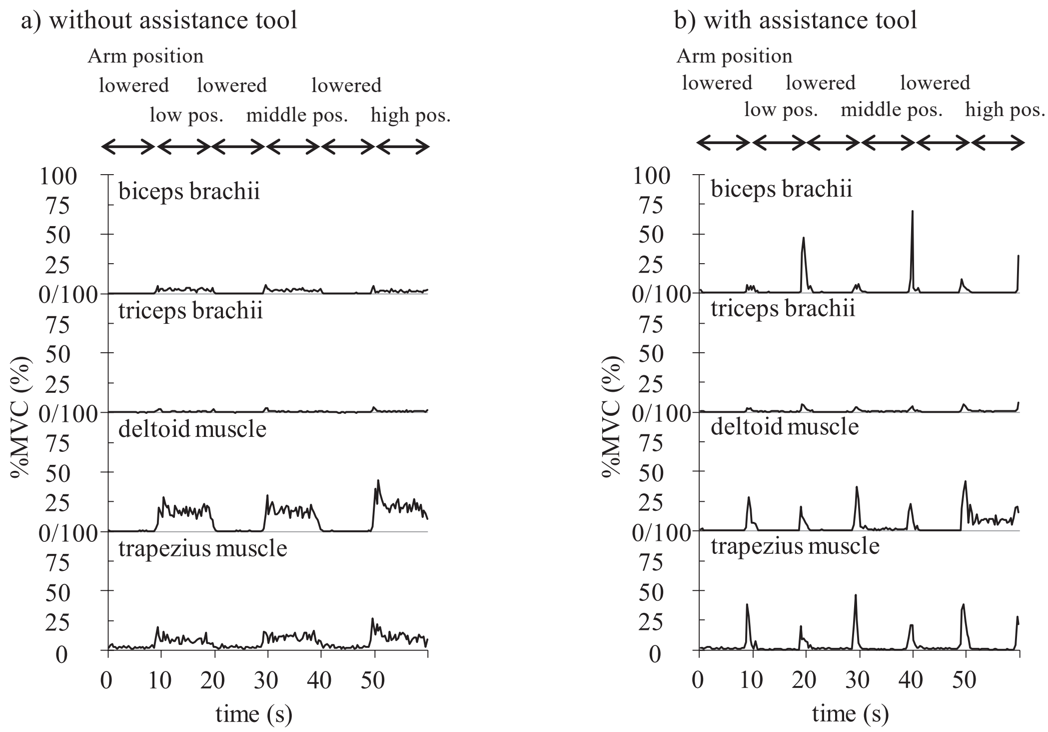

Fig. 5. Muscle activity during simulation of work using raised arms
Waveform averaged for 10 cycles of full-wave rectified waveform for each cycle

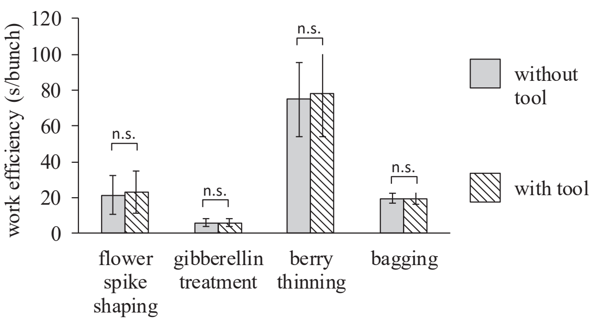

Fig. 6. Rate of work with and without the assistance tool
Average value of 6-9 people (age 20s to 50s, men and women) for each task.
Error bars indicate standard deviation.

with assistance tools. The work efficiency of flower spike shaping and bagging was approximately 20 s/bunch for both the tasks, and no significant difference was observed. Additionally, the work efficiency of gibberellin treatment was approximately 6 s/bunch in both the tasks, and the work efficiency of the berry thinning was 80 s/bunch in both the tasks. No significant difference was observed between the two tasks with and without the assistance tool. Because the developed assistance tool can easily change between the arm being supported and the state wherein the arm can be moved freely, it was thought that the worker could perform the same work as before, even if the assistance tool was worn.

(2) Muscle activity

Table 2 shows the amount of muscle activity during work and the rate of reduction of muscle activity during work with assistance tools compared with conventional work without assistance tools. The %MVC value of the biceps brachii and triceps brachii muscles was approximately 5%, and deltoid and trapezius muscles were 10%-30% for the conventional work without using an assistance tool for each task. The muscle activities of the deltoid and trapezius muscles were relatively large.

In the flower spike shaping task, there was one

Table 2. Muscle activity with and without the assistance tool

Target work	Test subjects	Assistance tool	Amount of muscle activity during work (%MVC(%))			
			Biceps brachii	Triceps brachii	Deltoid muscle	Trapezius muscle
flower spike shaping	test subject A	without	3.6	5.3	13.6	15.9
		with	1.8	2.1	7.2	4.6
		effect of tool	▲ 51.6	▲ 60.2	▲ 47.5	▲ 71.3
	test subject B	without	5.9	6.9	33.9	19.7
		with	10.4	6.9	37.4	25.3
		effect of tool	75.4	0.4	10.1	28.2
berry thinning	test subject B	without	3.3	2.9	21.3	12.7
		with	1.9	1.7	12.5	12.6
		effect of tool	▲ 43.1	▲ 41.9	▲ 41.4	▲ 0.7
	test subject C	without	4.0	3.5	15.2	16.1
		with	2.7	2.4	6.5	6.1
		effect of tool	▲ 31.7	▲ 32.3	▲ 57.1	▲ 62.2
	test subject D	without	8.2	2.1	17.6	19.2
		with	6.5	1.3	2.8	5.0
		effect of tool	▲ 20.9	▲ 34.7	▲ 84.2	▲ 73.8
	test subject E	without	5.2	4.3	20.2	27.7
		with	4.1	3.8	14.3	18.1
		effect of tool	▲ 20.7	▲ 12.5	▲ 29.3	▲ 34.8
bagging	test subject A	without	3.9	3.1	20.5	15.6
		with	1.9	2.4	15.9	4.2
		effect of tool	▲ 51.4	▲ 22.9	▲ 22.1	▲ 72.9
	test subject B	without	4.1	2.2	18.2	10.9
		with	2.7	1.6	11.8	4.8
		effect of tool	▲ 34.0	▲ 27.5	▲ 35.5	▲ 56.4
	test subject C	without	18.5	8.0	24.5	16.6
		with	12.7	5.6	26.2	9.1
		effect of tool	▲ 31.0	▲ 30.3	7.3	▲ 44.9
	test subject E	without	6.3	2.6	23.4	36.6
		with	5.5	2.7	17.1	17.8
		effect of tool	▲ 13.1	4.2	▲ 26.9	▲ 51.3

The numbers in the table show the average value of muscle activity during work.
"effect of tool" indicates the rate of increase/decrease in the muscle activity with the assistance tool compared to without the assistance tool.
▲ indicates the rate at which muscle activity decreased by wearing the tool, and unmarked indicates the rate at which it increased (unit (%)).

worker whose %MVC values of the deltoid and trapezius muscles decreased by wearing auxiliary equipment and one worker whose values increased, so no clear tendency was seen. In the berry thinning task, the %MVC value of the deltoid muscle was reduced by 30%-80% in all four workers by wearing the assistance tool compared with the conventional work without the assistance tool. Additionally, the %MVC value of the trapezius muscle was reduced by 30%-70% in three out of the four workers compared with the conventional work without an assistance tool. For the bagging task, the %MVC value of the deltoid muscle was reduced by 20%-30% in three out of the four workers by wearing the assistance tool compared with the conventional work without the assistance tool. Additionally, the %MVC value of the trapezius muscle was reduced by 40%-70% compared with the conventional work without assistance tool in all four of the workers.

(3) Fatigue interview survey

Figure 7 shows the results of the survey on the differences in fatigue. Larger numbers on the graph indicate greater work fatigue. In the flower spike shaping task, there was no clear tendency in the degree of fatigue of each part between the conventional work without the assistance tool and the work with the assistance tool. In the gibberellin treatment task, the fatigue of the left arm and left shoulder holding the cup was less in the work with the assistance tool compared with that in the conventional work without the assistance tool. In the berry thinning task, the degree of fatigue of the shoulders

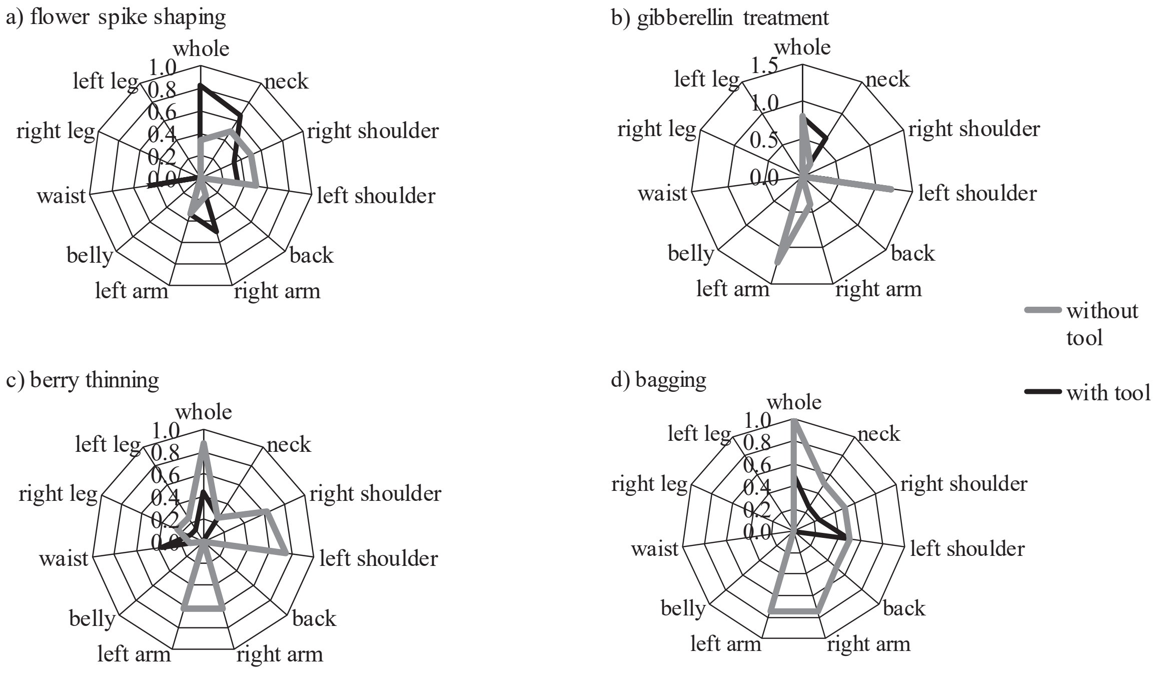

Fig. 7. Fatigue experienced with and without the assistance tool
Value obtained by subtracting the evaluation value before work from the evaluation value after work.
(Subjective evaluation: 0 did not feel tired at all, 1 felt a little, 2 felt, 3 felt very much).
Average value of 6-8 people for each task.

Table 3. Interview survey results of the effect of reducing the labor burden with the assistance tool

	Became much easier	Became easy	No change	Became hard	Became much harder
flower spike shaping	1	1	2	1	0
gibberellin treatment	0	3	1	2	0
berry thinning	1	6	0	1	0
bagging	0	5	1	2	0

Evaluation results of 5 to 8 people (age twenties to fifties, men and women) for each task and arms was less in the work with the assistance tool compared with that in the conventional work without the assistance tool, and the degree of fatigue of the whole body was also less. In the bagging task, the degree of fatigue of the shoulders, arms, neck, and back was less in the work with the assistance tool compared with that in the conventional work without the assistance tool, and the degree of fatigue of the whole body was also less. In the interview survey on the effect of reducing the labor burden when using the assistance tool, multiple workers answered that it was "easier" in each task. Particularly, in the berry thinning task, seven out of eight workers answered that it was "easier" or "much easier." In the bagging task, five out of eight workers answered that it was "easier." However, some workers answered that it was "not easier" in each task (Table 3).

Discussion

In the demonstration test in the viticulture field, the flower spike shaping task was performed at a relatively early stage, and many of the fruit bunches did not hang downward because of their own weight, requiring relatively frequent arm raising and lowering. Thus, there was no clear tendency toward an increase or decrease in muscle activity due to the assistance tool. The working time per bunch of gibberellin treatment is shorter than for other tasks, but it is necessary to lift the cup containing the liquid. By using the assistance tool, the arm could be rested even when the arm was raised, so that the distance between the arm-raising and -lowering movements while holding the cup could be shortened. Consequently, it is considered that the degree of fatigue of the arms and shoulders was lower when using the assistance tool than in the conventional work without the assistance tool. Berry thinning has the lowest work efficiency among grape cultivation maintenance tasks. It is a task wherein reduction of the work effort is highly requested. Because it is time consuming to keep raising the arms to the same height during the berry thinning task, it is considered that the effect of reducing the muscle activity of the deltoid and trapezius muscles by supporting the arm with the assistance tool was particularly large. In a conventional bagging task that does not use the assistance tool, a bundle of bags is attached to the waist position, a bag is removed from the bundle, and the bag is hung on the fruit at an overhead height. However, with the assistance tool, it was possible to attach a bag bundle to the end of the arm, remove a bag with the arm raised, and place the bag on the fruit. Consequently, it was not necessary to raise and lower the arms frequently, and the amount of muscle activity of the deltoid and trapezius muscles and the degree of fatigue of the neck, shoulders, and arms could be reduced.

From these observations, it was concluded that the prototype arm-raising work assistance tool reduces the work effort required in the maintenance work of grape cultivation by assisting the arm-raising posture. This tool has been on the market since 2015 and is used by farmers.

Acknowledgements

We would like to thank the people involved in the National Institute of Fruit Tree Science NARO; Gunma Agricultural Technology Center; Saitama Prefectural Agriculture and Forestry Research Center; Nagano Fruit Tree Experiment Station; and Tokushima Agriculture, Forestry, and Fisheries Technology Support Center for their cooperation in conducting the test of this research. We would like to thank Nikkari Co., Ltd., for their cooperation with the production of the prototype.

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