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EVALUATION OF THE POSSIBILITY OF SHAKING OFF RASPBERRY FRUITS WITH A PULSATING AIR STREAM

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ABSTRACT

The aim of the study was to determine the possibility of harvesting raspberries with a pulsating air stream that causes the shoots of plants to vibrate. Two tractor-driven test devices were developed under this specific objective. The first one was a high capacity compressor, and the stream of air produced by it was directed onto one side of a row of plants. The second one was a device producing two counter-flowing air streams colliding in the middle of a row of plants. The frequency of the air pulses was adjusted steplessly by varying the rotational velocity of the shutters closing and opening the outlets of the fans. In the field trials with the device based on a compressor-generated air stream, two air pulse frequencies were used: 500 and 540 pulses per minute (8.3 and 9 Hz). The mean detachment force was 0.727 N. About 50% of ripe raspberries were removed from the bushes. The results achieved during harvesting with the device operating on the principle of colliding two pulsating air streams were markedly better and put the harvesting effectiveness within the range achieved in the trials with combine harvesters with mechanical finger shakers conducted by other researchers. For two pulse frequencies (8 and 9 Hz), almost 62% of fruits were harvested. Increasing the pulse frequency of the counter-flowing air streams above 9 Hz did not improve the effectiveness of detaching raspberry fruits from shoots.

Key words: raspberry, harvester, effectiveness, pulse frequency

INTRODUCTION

Increasing manual labour costs and declining profitability of production make it impossible to grow berry fruits for processing without mechanized harvesting. As a result of breeding new cultivars and the developments in the design of combine harvesters, a high degree of over 95% harvesting effectiveness is achieved with currant, gooseberry and chokeberry bushes, whose fruits are harvested in a single stage. In the case of mechanical harvesting of raspberries, the situation is definitely worse. The fruiting period extending over several weeks necessitates a multi-stage harvest. Machines must pass along the rows of plantations several or even more than a dozen times during the season, which accumulates losses due to the mechanical damage of shoots caused by the plants coming into contact with the shaking units of the machines. Pathogens further reduce the health of the plantation by penetrating the wounds. In the case of raspberries bearing fruit on the previous year's cane, all of the above reasons can lead to a 30–40% reduction in yield the following year (Cormack & Waister 1976). In the raspberry combine harvesters used today, the separation of the fruit from the plant is achieved by making the shoots vibrate when they come into contact with the vibrating fingers of the shaking assemblies. The effectiveness of harvesting depends to a large extent on the forces that bind the fruit and the peduncle together. The fruit detachment force is significantly decreasing during fruit ripening (Dobrzański et al. 1995). Their magnitude has a decisive influence on the selection of machine operating parameters. Because the forces required to detach fruit from peduncle depend on various factors, including cultivar

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characteristics and weather conditions, there are considerable differences in their magnitude between cultivars, and fluctuations during the harvest period as well as between growing seasons. The variable forces of fruit detachment make it necessary to adjust the operating parameters of machines, mainly the vibration frequency of the shakers. When high frequency values are used, detachment of unripe fruit occurs, which results in significant yield losses. Replacing the conventional finger shakers with a different agent to induce vibrations in raspberry shoots would effectively reduce the damage to the shoots and reduce the amount of unripe fruits becoming detached together with the peduncle. One possibility is to use a pulsating stream of air with adjustable pulsation frequency. Evaluation of the possibility of harvesting raspberry fruits by means of an air stream of this nature was the subject of this study. The aim of the study was to determine the possibility of introducing into raspberry combine harvesters a system of shaking the fruit off based on a pulsating air stream in place of the mechanical shakers that damage the shoots.

MATERIALS AND METHODS

Two mobile test devices were constructed, mounted on the three-point linkage system of a tractor. The main part of the first test device was a four-cylinder high-capacity compressor driven by the tractor's power take-off (PTO) shaft. The air stream produced by it was directed only onto one side of a row of plants. Variable air pulse frequencies, in the range of 400–540 rpm (6.7–9.0 Hz), were obtained by varying the rotational speed of the PTO shaft. In order to increase the velocity of the air stream, the compressor outlets were shaped into narrow slits measuring 220 × 7 mm and 300 × 7 mm.

The unsatisfactory effectiveness of detachment of raspberry fruits by the pulsating air stream from the compressor observed in the first years of the study led to the decision to build another test device based on a different principle of operation. A tractor-driven device was designed and constructed to produce two counter-flowing air streams that collided at half the distance between their sources. The essential part of the structure of the test device was a gantry frame that allowed passage over a row of plants. On both sides of the frame there were mounted radial fans driven by hydraulic motors powered by the tractor's internal hydraulic system. The air outlets of each of the fan were equipped with two rotary shutters, whose purpose was to open and close the air ducts at a frequency adjustable steplessly by means of hydraulic valves. Such a solution makes it possible to obtain a pulsating stream of air with an output and velocity that enable penetration of the entire width of a row of plants. The design of the test device allows it to be mounted on either the front or the rear three-point tractor linkage system.

Field trials were conducted in 2012–2016 on a private raspberry plantation in Miedniewice near Skierniewice. The trials involved harvesting raspberries from bushes of the remontant cultivar 'Polka', planted at a spacing of 3.5 × 0.6 m and held in a four-wire trellis on two levels. Prior to each harvest, using at least 50 fruits (depending on the fruiting in the allocated sections of the rows), the detachment forces were measured. An electronic dynamometer with a measurement resolution of 0.01 N was used to determine them. The evaluation of harvesting effectiveness was carried out on randomly selected sections of the rows of the plantation. In the case of the test device with a compressor, for which two frequencies of air stream pulsation (450 and 520 pulses per minute), 10 plots of 5 m in length were selected. For the device with two counter-flow air streams, for which, depending on the conditions, pulse frequencies in the range of 420 to 660 pulses per minute (7 to 11 Hz) were used, the number of repetitions was limited to 5 due to the labor-intensive nature of the evaluation. A repetition was a 5-m long section selected randomly from a row of the plantation. Prior to the machine entering, a foil sleeve was spread out on the ground, from which raspberries were collected and their weight was determined. The fruits remaining on the bushes were collected manually and had their ripeness assessed visually.

Statistical analyses were conducted using analysis of variance followed by a comparison of means using Duncan's Multiple Range Test at $p = 0.05$ by means of Statistica software package, version 13.

The analyses were made for the data collected in the season 2015, and the data collected on 2 September 2016 separately.

RESULTS

Preliminary field trials with the device based on the tractor-driven compressor were conducted on 28 August 2012. Fruits of the raspberry cultivar 'Polka' were held on the bushes with a mean force of 0.730 N. Using two frequencies of air pulses: 450 and 520 per minute (7.5 and 8.7 Hz), an average of 42% of the fruits at harvest maturity were detached from the bushes (Table 1). Subsequent tests were conducted on 4 October 2012 after modernizing the test device by replacing the compressor's cylinders to increase its output capacity. Two frequencies were used: 500 and 540 pulses per minute (8.3 and 9 Hz). The mean detachment force was 0.727 N. About 50% of ripe raspberries became detached from the bushes (Table 1). Because of the unsatisfactory harvesting results obtained in 2012, before the 2013 harvest season, the compressor's exhaust manifolds had been narrowed and their shape was altered to increase the velocity of the air stream. Field trials with the modernized device were conducted on two dates: 4 and 17 September 2013. On each date, one frequency of air pulses was used: 500 or 540 pulses per minute (8.3 or 9 Hz). The mean detachment forces were 0.897 and 0.856 N on the test dates respectively, and were higher than in the season 2012. This probably contributed to poorer detachment of the fruits from the bushes, as only 42% of fruits were harvested on the first date (4 Sep), and 46% on the second date (17 Sep) (Table 1). As in the previous season, there were no unripe fruits detached with the stems from the bushes.

The evaluation of the effectiveness of harvesting with the test device working on the principle of counter-flowing air streams colliding within a row of raspberry bushes began in the autumn of 2014. The frequency of air pulsation was controlled by changing the rotational velocity of the air outlet shutters. The effectiveness of fruit separation from the raspberry bushes cv. 'Polka' was in these initial trials 50–65%, which markedly exceeded the values obtained in the experiments with the previous test device. In the season 2015, more detailed field tests were conducted to determine the frequency of air pulses that most effectively separated fruits from the bushes. Harvesting was carried out on 6 dates, with the detachment force determined each time (Fig. 1). On each date, two air pulse frequencies were used, which were determined arbitrarily based on the measured fruit detachment forces and harvesting effectiveness obtained in the previous trials.

Table 1. Percentage of 'Polka' raspberries harvested with a compressor-generated pulsating air stream depending on air pulse frequency in the seasons 2012 and 2013

Harvest date	Air pulse frequency (Hz)	Percentage of total weight of 'Polka' mature fruits (%)	
		collected	left on bushes
28 August 2012	7.5	42.0	58.0
	8.7	42.5	57.5
4 October 2012	8.3	48.1	51.9
	9.0	51.4	48.7
4 September 2013	8.3	42.4	57.6
17 September 2013	9.0	46.0	54.0

The effectiveness of the separation of 'Polka' raspberry fruits from the bushes was 59–73% (Table 2) and exceeded by 15–20% the values obtained in the trials with the first test device. The highest amounts of raspberries (an average of more than 67%) were detached with the frequency of 8 Hz (Fig. 2). Using pulses with a frequency of 10 Hz, the least amount of fruit (about 60%) was obtained. It should be noted, however, that the tests in the season 2015 were conducted for different values of fruit detachment forces and this could have influenced the results of variance analysis.

In order to investigate the influence of pulsation frequency on harvesting effectiveness, 'Polka' raspberries were harvested on 2 September 2016 under the same force of detachment of mature fruits. Five air pulse frequencies were used, ranging from 7 to 11 Hz (Fig. 3), with the mean detachment force of 0.861 N on the plots selected from the rows. The proportion of raspberries collected was between 56 and 62%, and the most effective frequencies were 9 and 8 Hz, at which, respectively, 61.8% and 61.5% of the total weight of mature fruits became detached from the bushes (Fig. 3). Slightly worse results were obtained using frequencies of 10 and 11 Hz. However, the high variability of the obtained results was the reason that the differences between the different frequencies of air stream pulsation were not statistically significant.

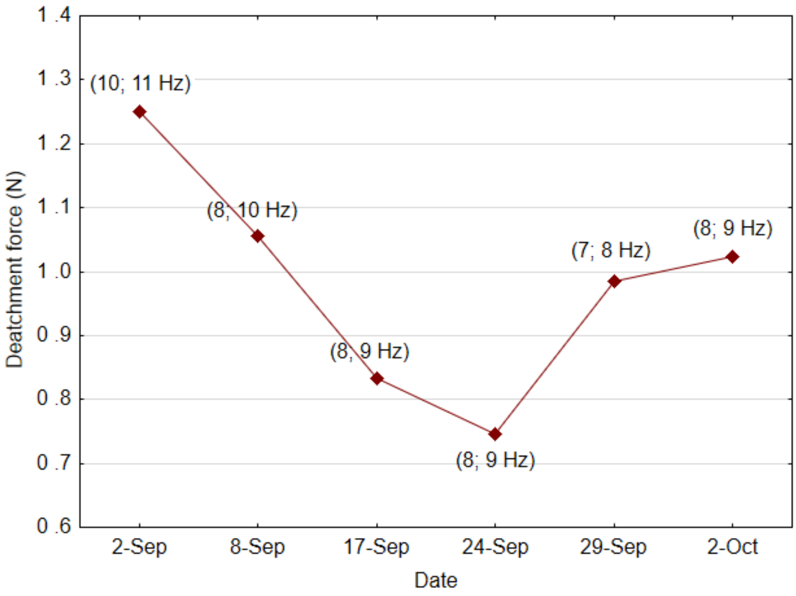

Fig. 1. Mean peduncle detachment forces determined on harvest days in the season 2015 and the air pulse frequencies applied

Table 2. Effectiveness of fruit detachment from bushes in the season 2015, depending on the mean fruit detachment force and air stream pulsation frequency. Mean share of detached fruits and the corresponding values of standard deviation and standard error are given

Mean fruit detachment force (N)	Measurement date	Air stream pulsation frequency (Hz)	Mean share of detached fruits (X) (%)	Standard deviation of X (%)	Standard error of X (%)
0.746	24 September	8	67.0	2.78	1.24
		9	66.7	3.00	1.34
0.833	17 September	8	65.0	2.48	1.11
		9	62.8	2.89	1.29
0.984	29 September	7	64.9	3.74	1.67
		8	72.8	5.76	2.58
1.023	2 October	8	63.0	3.66	1.64
		9	61.4	7.44	3.33
1.056	8 September	8	68.6	2.00	0.89
		10	61.0	1.89	0.84
1.251	2 September	10	58.8	3.66	1.64
		11	64.7	5.94	2.66

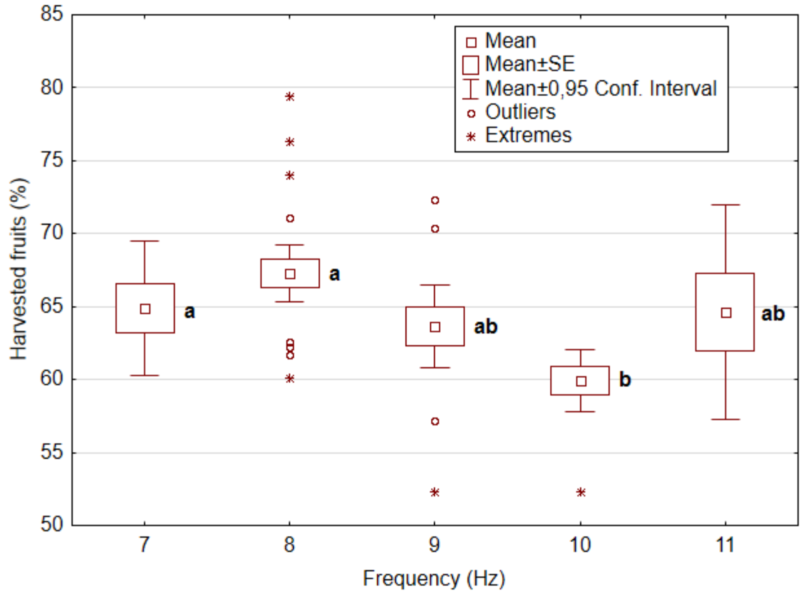

Fig. 2. Effect of air stream pulsation frequency on the effectiveness of raspberry fruit detachment in the season 2015
Mean values marked with the same letter do not differ statistically; analysis of variance, Duncan's test, p = 0.05

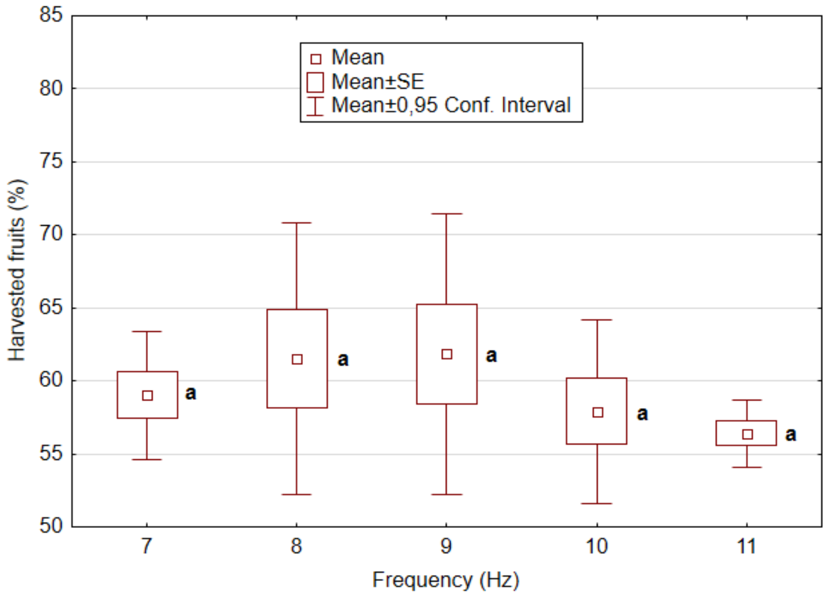

Fig. 3. Effectiveness of raspberry fruit detachment obtained with five frequencies of air stream pulsation. Experiment was conducted on 2 September 2016
Mean values marked with the same letter do not differ statistically; analysis of variance, Duncan's test, p = 0.05

DISCUSSION

The effectiveness of harvesting 'Polka' raspberry fruits achieved with the test device based on compressor-generated air pulses exceeded 50% only at one frequency. In the other combinations, more than half of ripe fruits remained on the bushes. The harvesting effectiveness was worse than that achieved during trials with combine harvesters equipped with assemblies of shaking fingers. It was even surpassed by the relatively low harvesting effectiveness of 52% achieved by Kowalczuk et al. (2008). The results obtained during harvesting with the device operating on the principle of colliding two pulsating air streams were considerably better and put the harvesting effectiveness within the range achieved in the trials with harvesters fitted with mechanical shaking fingers conducted by other researchers. For two pulse frequencies (8 and 9 Hz) almost 62% of fruits were harvested. According to Ramsay (1983), harvesters equipped with finger assemblies are able to satisfactorily harvest 50–70% of ripe fruits of red raspberry. In the studies conducted at the Research Institute of Pomology and Ornamentals (currently the Research Institute of Horticulture) with a New Zealand 'Peco' harvester equipped with shaking fingers, 74–91% of fruits were harvested (Rabcewicz et al. 1995); however, the trials were conducted with the cultivar 'Canby', which is particularly suited to mechanical harvesting. In the studies of the quality of harvesting raspberries of the cultivar 'Polka' with a 'Natalia' harvester (manufactured by Weremczuk FMR), the maximum amounts of satisfactorily harvested fruits were as high as 80% (Rabcewicz & Danek 2010). More than 70% of the fruits were harvested using a shaker vibration frequency of 8.3 Hz, i.e. a value at which there were no excessive losses due to detachment of unripe fruits from the bushes. The optimum vibration frequencies for the cultivar 'Polka' were 8.3–9.2 Hz. The amounts of fruit harvested at these values were statistically comparable with those obtained at higher frequencies (10.0–11.7 Hz), but the proportion of unripe fruits harvested was significantly lower. In the trials conducted with the device that generated two air streams, the best results were obtained at frequencies of 8–9 Hz. Increasing the frequency did not have a positive effect on the effectiveness of harvesting. On the contrary, the amount of fruits detached from the bushes with pulses of 10 and 11 Hz was slightly smaller (the differences were not statistically proven). The differences in the influence of vibration frequencies of finger shakers and air pulses can be explained by the different nature of the transfer of vibrations to raspberry shoots. Two counter-flowing air streams can, at higher pulse frequencies, cancel each other out, reducing the effect of causing the shoots of plants to vibrate.

CONCLUSIONS

1. The effectiveness of detaching raspberry fruit cv. 'Polka' with a pulsating air stream acting on one side of a row of bushes was 42–51% and was lower than the effectiveness reported in the literature for conventional finger shakers.
2. The effectiveness of harvesting raspberry cv. 'Polka' with two, directed from both sides of a row of bushes, pulsating air streams at frequencies 8 and 9 Hz was 62% and was comparable with the effectiveness reported in the literature for conventional finger shakers.
3. Increasing the frequency of pulses of counter-flowing air streams above 9 Hz did not improve the effectiveness of detaching raspberry fruits from shoots.

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