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Research Paper

Effect of excitation position of a handheld shaker on fruit removal efficiency and damage in mechanical harvesting of sweet cherry

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As labour cost keeps rising and labour availability remains increasingly uncertain, growers are seeking mechanical harvesting solutions for fresh-market tree fruit production. To fulfil this need, this research aimed at assessing the effect of excitation position on fruit removal efficiency and fruit damage using a hand-held limb shaker for harvesting sweet cherry. In this study, four excitation positions were selected on each randomly selected limb of "Y" trellis cherry trees. The total number of fruit being removed from five fruiting zones of each limb and those remaining on the tree after harvesting was counted, and harvest-induced damage was assessed. Results showed that fruit removal efficiency from each zone was highly affected by the distance of the zone to the excitation position. The overall fruit removal efficiency was 84% when shaken at the lowest excitation position, and 77%, 51% and 72% respectively as the excitation position moved up the limbs. The fruit damage rates from low to high excitation positions were 20%, 28%, 20% and 23%, which was approximately 10% higher than that of handpicked fruit. No significant difference was found in the fruit damage rate when comparing different excitation positions. It was observed that the fruit removal efficiency may reach up to 97% when the limbs were excited at both the lowest and the highest excitation positions, and adopting such an excitation method could lead to a high fruit removal efficiency with not much increase in fruit damage.

1. Introduction

Fresh-market sweet cherry is one of the most valuable tree fruit crops and has been a popular fruit for consumption in USA. The per capita consumption of fresh-market cherry increased by 150% (from 0.27 to 0.68 kg) from 2000 to 2009 (USDA-ERS, 2012). The increasing market and profitability of this crop led to an increased cropping area from about 24,300 ha in 2000 to 34,400 ha in 2009 (USDA-ERS, 2012). However, the production of sweet cherry is regarded as one of the most labour intensive operations, because the fruit are small in size, scattered throughout the tree canopy, and can be damaged easily during harvesting and handling. Currently,

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Nomenclature

PFRF	Pedicel fruit retention force (N)
FM	Fruit mass (g)
R_{FP}	Fruit mass (g) to the PFRF (N) ratio
P_{zi}	Fruit removed from the i_{th} fruiting zone (%),
P_{di}	Fruit distribution in the i_{th} fruiting zone of a limb (%)
N_i	Number of fruit in the i_{th} fruiting zone
N_{rt}	Total number of fruit being mechanically removed from a limb
N_{ri}	Number of fruit being mechanically removed from the i_{th} fruiting zone
N_t	Total number of fruit on a limb
N_d	Number of damaged fruit from the sample
N_{st}	Sample number of the mechanical harvested fruit from one limb
P_O	Overall fruit removal efficiency excited at one location (%)
P_{O1}	Fruit removal efficiency excited at the first position (%)
P_{O2}	Fruit removal efficiency excited at the second position (%)
P_T	Calculated overall fruit removal Efficiency of a limb excited at two locations (%)
R_d	Fruit damage rate (%)

sweet cherry for fresh-market consumption is harvested manually to minimise fruit damage. Labour costs for harvesting accounts for about 50% of annual production expenses for growers (Caplan, Tilt, Hoheisel, & Baugher, 2014) and mechanical harvesting is seen as one of the possible solutions for reducing sweet cherry production costs.

Technologies for mechanical harvesting of sweet cherry have been studied since the early 1960s. Norton et al. (1962) developed a hydraulically powered trunk shaker to harvest sweet cherry from traditional orchard architecture with large trunk/limb diameter and tree canopy. Results showed that 80%–90% of fruit could be removed mechanically, but the machinery would result in considerable fruit damage and tree bark injury. Over the past four decades, many efforts were made to develop different mechanical harvesting technologies for tree fruit crops that are less susceptible to mechanical impact, especially for the processing market. These efforts were summarised and compared by Li, Lee, and Hsu (2011) and Zhou et al. (2013). Peterson and Wolford (2001) developed an integrated mechanical harvester to harvest fresh-market sweet cherry by knocking the limbs using an impact actuator, and achieved a fruit removal efficiency of 50–80% with 8–15% fruit damage rate which was about 2–6% more damage than commercial hand harvesting. However, this machine was found to cause some serious bark damage, due to the difficulty in accurately aiming at the target limb and by strong impacts (Chen et al., 2012). In a side-by-side comparison of the performance of this machine with a handheld shaker, Chen et al. (2012) found that the handheld shaker could achieve a fruit removal efficiency of 89.5% with a fruit damage rate of 22.7% compared to 81.8% efficiency and 25.2% damage from the mechanical harvester in that test.

Currently, mechanical harvesting is based on high-frequency, low-energy shaking and is widely used for harvesting fruit for processing as the quality of fruit is not so critical as for the fresh market (Polat et al., 2007; Torregrosa, Martín, García Brunton, & Bernad, 2008; Torregrosa, Martín, Ortiz, & Chaparro, 2006). To mechanically harvest fruit for the fresh-market, fruit removal efficiency and fruit quality are important challenges that need to be addressed. In practice, the methods used to improve fruit removal efficiency are to prolong the shaking time and excite a limb at multiple positions on selected by the operators (Blanco-Roldán, Gil-Ribes, Kouraba, & Castro-García, 2009). However, these approaches often increase the potential for breaking branches, injuring bark and thereby decreasing production in subsequent years (Blanco-Roldán et al., 2009). Other efforts to improve the fruit removal efficiency have included optimising the shaking frequency, amplitude and selecting the proper shaking duration for an intermittent harvesting method (Blanco-Roldán et al., 2009; Polat et al., 2007; Zhou et al., 2013).

To achieve high fruit removal efficiency, researchers have investigated the energy transmission from the shaker to the tree under different excitation patterns and tree structures. Adrian, Fridley, and Lorenzen (1965) found that the transmission of excitation energy along a limb was influenced by the excitation position, frequency and amplitude. It was also found that the resonant frequency increased when the excitation position approached the base of the limb, which could induce a change in acceleration when a limb was excited at different positions with a fixed frequency. Du, Chen, Zhang, Scharf, and Whiting (2012) analysed the dynamic responses of a tree to excitation forces, and found that the swing displacement at different points of a branch was different under a shaking excitation, and the displacement became larger with increasing distance between the monitoring point and the excitation position. Based on this finding, Du, Chen, Zhang, Scharf, and Whiting (2013) studied the response of cherry trees in upright fruiting offshoots (UFO) architecture to vibratory excitations, and found that the kinetic energy at the middle portion of the excited limb was much higher than that at both ends of the limb and also its neighbouring limbs when the limb was excited at the low end near the trunk. Savary, Ehsani, Salyani, Hebel, and Bora (2011) investigated the acceleration distribution along a limb of citrus trees during harvesting with a continuous canopy shaker. They found that the acceleration along a limb decreased exponentially from the base of tree trunk. He et al. (2013) also studied the energy transmission to excited limbs and neighbouring limbs using a mechanical shaker in the "Y" trellised cherry orchard. They found that the majority of energy (approximately 85% at 14 Hz shaking) was delivered to the excited limbs. The variation of the energy distribution along a limb excited at different positions brings the possibility of obtaining different fruit removal efficiencies.

Other researchers found that the limb stiffness increased with the limb diameter (Erdoğan, Güner, Dursun, & Gezer, 2003), and stiffness increased noticeably as the measured point was closer to the trunk (Lenker & Hedden, 1968). Vibration energy can be transmitted longer distances in stiffer