Postharvest Biology and Technology 110 (2015) 103–113

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Measure of mechanical impacts in commercial blueberry packing lines and potential damage to blueberry fruit

Rui Xu[a], Fumiomi Takeda[b], Gerard Krewer[c], Changying Li[a,*]

[a] College of Engineering, The University of Georgia, 200 D.W. Brooks Drive, Athens, GA 30602, USA
[b] Appalachian Fruit Research Station, USDA-ARS, 2217 Wiltshire Road, Kearneysville, WV 25430, USA
[c] Professor Emeritus, University of Georgia, Woodbine, GA 31569, USA

ARTICLE INFO

Article history:
Received 24 March 2015
Received in revised form 10 July 2015
Accepted 15 July 2015
Available online xxx

Keywords:
Packing line
Blueberry
Instrumented sphere
Impact recording device
Bruising
Mechanical damage
Vaccinium

ABSTRACT

Blueberry fruit is susceptible to bruising from mechanical impact. Bruised fruit has shorter postharvest shelf life and softens rapidly in cold storage than non-bruised fruit. A blueberry packing line consists of a hopper for transferring fruit in field containers onto a conveyor line that moves fruit into trash removal equipment, electronic sorter, inspection line, and finally onto clamshell-filling equipment. Blueberry fruit drops as it is transferred from one equipment to the next on the packing line. The mechanical impacts that occur on blueberry packing line equipment were measured quantitatively with a miniature, instrumented sphere called the blueberry impact recording device (BIRD) at 11 packing houses in the United States in 2013 and 2014. The BIRD sensor recorded impacts at transfer points or wherever there was a vertical drop on the packing line. The potential for impact damage was determined in four cultivars ('Farthing', 'O'Neal', 'Reveille' and 'Star') by dropping fruit from different heights. The measured data revealed that the largest impacts (~230 g) were recorded when the sensor dropped into the hopper above the clamshell filler on eight empty lines. The cumulative peakG data showed strong correlation with overall drop height, indicating that reducing the overall drop height on a packing line could reduce the impact level. When the transfer points were padded with Poron foam sheet, significantly lower levels of impact were recorded by the sensor. The BIRD sensor also recorded lower impacts when it was run with fruit on the packing line. The severity of bruise damage resulting from fruit being dropped was related to the impact data recorded by the BIRD sensor. Using peakG-velocity change plot and the fruit bruising rate, several large impacts sufficient to cause bruising were identified, (e.g., >20% of cut surface area indicating bruise damage in 76% of 'Reveille' fruit). This paper quantitatively measured the mechanical impact on blueberry packing lines for the first time and the information will assist in improving the design and configuration of blueberry packing line equipment. These changes should result in reducing the magnitude and frequency of mechanical impacts and bruise damage in blueberry fruit.

1. Introduction

The United States is the largest producer of blueberries in the world. In 2013, U.S. produced around 400 million kilograms (881 million pounds) blueberries with an estimated total farm gate value of $988,435,000 (USDA, 2014). Due to the high market value of fresh blueberries (2.639 dollar per kilogram compared to 1.484 dollar per kilogram for processed blueberries in 2013), nearly 41% of the US blueberries were packed for the fresh market (USDA, 2014).

Mechanization is used in fruit harvesting and postharvest handling to increase capacity and efficiency, and to reduce labor cost. In fruit harvesting, machines are used to harvest much of the fruit designed for processing. The use of machines to harvest blueberries that will be packed for the fresh market is limited because machine harvesting produces an unacceptable amount of fruit that cannot be packed for the fresh market. The short shelf-life of machine harvested fruit is the result of excessive bruising which contributes to rapid decline in fruit firmness, loss of intact cuticular wax on the skin, and oxidative browning of fruit tissues. Excessive mechanical impacts during harvesting have been attributed to bruising damage in blueberries (Brown et al., 1996). Fruits can also become bruised during transporting fruit-filled containers from the field to the packing house and during packing when the fruits

* Corresponding author. Fax: +1 706 542 2475.
E-mail address: cyli@uga.edu (C. Li).

http://dx.doi.org/10.1016/j.postharvbio.2015.07.013
0925-5214/

collide with hard surfaces. In the transporting process, for instance, both vertical and horizontal movements occur as stacked containers are carried over uneven surfaces or with sudden acceleration or deceleration of the carrier vehicle.

Impact damage results in loss of fruit firmness leading to reduced fruit quality and shelf life. In the process of handling blueberries from the field to the market, machine harvesters and packing lines are the two main sources that produce large mechanical impacts to blueberries. Brown et al. (1996) estimated that 78% of the blueberries were bruised during the harvesting process when fruit was harvested with commercial machine harvesters. In addition, blueberries had a bruise rate of 0 to 50% when the fruit were dropped from 150 mm to 300 mm heights onto hard surfaces such as fruit catcher plates made of polycarbonate and steel on commercial berry harvesters and stainless steel surfaces on many of blueberry packing lines. The probability that a blueberry can be damaged by the packing line surfaces is high. However, these potential damages have not been systematically evaluated by quantitatively measuring the impact created by the hard surfaces on the packing lines using the instrumented sphere technology, which was widely used for other fruits and vegetables (Bajema and Hyde, 1995; Brown et al., 1990b; Desmet et al., 2004; García-Ramos et al., 2004b; Herold et al., 1998; Hyde et al., 1992; Miller et al., 1995; Timm and Brown, 1991).

Instrumented spheres (IS) are in essence data loggers that are used to detect and quantify mechanical loads of fruits and vegetables during handling chain. The commonly used ISs in the literature include the Impact Recording Device (IRD) (Zapp et al., 1990), Pressure Measuring Sphere (PMS-60) (Herold et al., 1996) and Potato-shaped Instrumented Device (PTR-200) (Canneyt et al., 2003). Other instrumented spheres such as Mikras, Smart Spud and TuberLog are commercially available but not commonly used in the literature (Praeger et al., 2013). Several key factors were found to affect the level of mechanical impacts in previous studies. Directly dropping on machine parts with hard contact materials (e.g., singulator, size cup, clamshell filler) were found to be one key factor that could induce high level of impacts. Therefore, cushioning these hard contact surfaces can dramatically reduce the impact damage (Bajema and Hyde, 1995). High elevation change was another key factor that induces large impacts (Brown et al., 1990a). Accordingly, reducing elevation changes, such as adjusting the machine alignment and installing ramps at transfer points to reduce the drop heights, was suggested to growers to reduce impact damage (Sargent et al., 1990; Timm and Brown, 1991). Other factors such as conveyor speed, flow of fruit, deceleration elements, and even the harvesting condition can affect the impact level (Bentini et al., 2006; García-Ramos et al., 2004a). Recent studies focused on evaluating the impact damage due to different harvest machine types (e.g., electronic sorters, filling equipment) and packing line settings (e.g., line speed, elevation height, decelerators, paddings), which can be used to optimize the packing line design (García-Ramos et al., 2003a,b; García-Ramos et al., 2004b).

Although the packing line for various types of fruits and vegetables have been evaluated using instrumented spheres, no study was reported for blueberries because no IS was available to resemble small fruits like blueberries. For example, the sizes and shapes of IRD, PMS-60, and PTR 200 are 57-mm sphere, 62-mm sphere and $53 \times 53 \times 83$ mm semi-ellipse which are several times larger than a typical blueberry (7–23 mm in diameter), making it unsuitable for blueberry packing line evaluations. IrDAN datalogger (Elektronische Systemtechnik, Berlin, German) is a small acceleration measurement cube with size of $31 \times 31 \times 31$ mm^3, but the sensing range (27 $\boldsymbol{g}$) was not large enough for measuring large impacts. Our research group developed the Berry Impact Recording Device to measure the mechanical impacts for small fruits and vegetables (Yu et al., 2011a,b). The BIRD sensor is a sphere with a size of 25.4 mm in diameter, providing a close approximation to a large-size blueberry fruit. The BIRD sensor has been used in the field to assess the mechanical impact created by three commercial blueberry mechanical harvesters (Yu et al., 2012, 2014a). The sensing range of the BIRD sensor (866 $\boldsymbol{g}$) is adequate to measure the impacts generated on the packing lines, given that the drop heights of the transfer points range from 10 cm to 40 cm.

The primary goal of this study was to quantitatively measure the mechanical impacts on 11 commercial blueberry packing lines in the United States, using an in-house built miniature instrumented sphere. Specific objectives were to

1) quantitatively measure the impacts created by each packing line and each transfer point;
2) compare the impact level on packing lines with and without fruit;
3) evaluate the effect of impact reduction by padding the surface of the packing line;
4) relate the sensor data to the fruit bruising rate.

2. Materials and methods

2.1. Blueberry packing line test

Over the past two years, eleven commercial blueberry packing lines in the east coast of the United States ranging from the South to the Midwest (Florida, Georgia, North Carolina, and Michigan) were evaluated using the BIRD sensors. Almost all packing lines were tested from the beginning to the end except packing line 1 and 6 where only part of the complete line was tested. This was because the last section of the two lines (fruit filler) was separated from the rest of the line and fruit packers manually transfer the fruit using

Table 1
Summary of the 11 packing lines in the United Stated tested in this study.

Line number	Location	Time	Replicates	Transitions	Total drop height (cm)	Test condition
1[a]	GA	June, 2013	5	6	~155	Fruit
2	GA	June, 2013	5	7	107	Fruit
3	MI	August, 2013	4	4	47	Empty
4	MI	August, 2013	6	4	~56	Empty
5	MI	August, 2013	6	4	~61	Empty
6[a]	MI	August, 2013	5	5	80	Empty
7	NC	May, 2014	6	7	~79	Empty
8	NC	May, 2014	6	6	~134	Empty
9	NC	May, 2014	6	6	117	Empty
10	NC	May, 2014	6	7	92	Empty
11	FL	April, 2014	6	7	187	Empty

[a] Only part of the complete line was tested.