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Development and Performance Evaluation of Falling-type Dried-Persimmon Weight Sorting System Utilizing Load Cell

Jongguk Lim, Giyoung Kim, Changyeun Mo*, Inchul Choi

National Institute of Agricultural Sciences, Rural Development Administration, Jeonju 54875, Republic of Korea

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Abstract

Purpose: A falling-type weight sorter equipped with a load cell was developed to sort lightweight dried persimmons. The performance of the sorter was also evaluated. **Methods:** The electronic weight sorter for dried persimmon comprises a feeder part, a weight-measurement part, an indicator part, a carrier cup, a discharging part, and a driving part. The weight setting and zero-point adjustment are performed digitally for the convenience of users. For the experimental trials, 228 rubber-clay specimens (representative of dried persimmons) in the weight range of 24.73~99.56 g were manufactured for use in experiments to evaluate the performance of the sorter. **Results:** The average error of the weight measurements from three experimental trials was 1.655%, with a bias of -0.492 g, a root-mean-square error (*RMSE*) of ±0.808 g, and a coefficient of determination (R^2) of 0.997. **Conclusions:** The load-cell-based electronic dried-persimmon weight sorter developed in this study facilitates effective, precise, and convenient sorting of dried persimmons.

Keywords: Dried persimmon, Falling type, Load cell, Performance test, Weight sorter

Introduction

The Asian or Japanese persimmon (*Diospyros kaki*), a fruit that grows widely in subtropical to temperate regions, is native to several countries in East Asia, including Korea, China, and Japan. From a horticultural perspective, there are various cultivars of persimmons. However, depending on the degree of astringency, which determines the manner in which the fruit is eaten after harvest, persimmons can be classified as astringent persimmons (*Diospyros kaki, L*) or non-astringent persimmons (*Diospyros kaki, T*). While most non-astringent persimmons are consumed fresh, astringent persimmons, which are rarely consumed raw, are processed and consumed as dried persimmons, soft persimmons, semi-dried persimmons, etc. (Cho et al., 2006; Lee et al., 2011). The main components of persimmons are fructose and glucose (approximately 15~16%). Persimmons are also abundant in vitamins A and C, soluble tannin, and mineral. Persimmons are also widely recognized as an effective treatment for high blood pressure, hangovers, diarrhea, and dieresis (Kim et al., 2004; Kim et al., 2009).

Dried persimmons are a typical dried fruit of the winter season and are produced by peeling and drying astringent persimmons. The quality characteristic of dried persimmons from each producing district depends on the astringent persimmon cultivar and the drying method used. Persimmons may vary in appearance, moisture content, color, smell, sweetness, astringency taste, sourness, and texture (Hur et al., 2014).

In Korea, because dried persimmons are classified as a forest product, their quality is assessed in accordance with the Korean Forest Product Standard (KFSN, 2014). The quality criteria for dried persimmons consider various parameters such as weight uniformity, shape, small defects, sweetness, and moisture content. In general, the purchase grade at major dried-persimmon production areas depends

***Corresponding author:** Changyeun Mo
Tel: +82-63-238-4120; **Fax:** +82-63-238-4105
E-mail: cymoh100@korea.kr

on the size or weight of -dried persimmons, and the weight difference determines the price. For example, according to the 2015 purchase-price standard in the Sangju area of Gyeongsangbuk-do, which is the area that produces the largest volume of dried persimmon, the weights of individual first-, second-, third-, and fourth-grade dried persimmons were greater than 51, 46~50, 41~45, and 36~40 g, respectively.

The dried-persimmon weight sorters used in farms to sort dried persimmons of a certain size are mostly mechanical sorters. Spring-type sorters that use the tension of a spring and leverage-type sorters that apply the theory of leverage are widely used (Jung, 1997). The spring-type sorter is appropriate for fruits with unit weights greater than 200 g, such as apples, pears, persimmons, and peaches. Although spring-type dried-persimmon weight sorters offer the advantages of a simple design and low price, these devices exhibit large weight errors in sorting farm products weighing less than 100 g apiece, and their accuracy diminishes with prolonged use because of reduced durability. The grading degree of these mechanical weight sorters for dried persimmon is approximately 80% (Lim et al., 2013). In comparison with spring-type sorters, leverage-type sorters are more precise mechanical sorters. In comparison with spring-type sorters, leverage-type sorters exhibit higher accuracy, but they require weight-setting and zero-point adjustment using a balance weight for each discharge level. There are limitations to conducting such correction work, which must be performed by experts in retail or from manufacturing companies, at individual farms. Thus, sorting is sometimes delayed during the peak season if the correction work is not performed in a timely manner.

An electronic weight sorter has been developed to address the disadvantages of mechanical sorters, including the weight-setting and zero-point adjustment work required (Jung, 1997). The electronic weight sorter employs a weighing sensor such as a force coil or a load cell. A load-cell-type sorter is based on a strain-gauge method in which an electrical signal is generated in proportion to the weight of the product, and the measured value is digitized by an analog-to-digital converter (ADC). This type of sorter is mainly used as an electronic agricultural product sorter.

While most research concerning electronic load-cell agricultural-produce sorters has focused on sorting fruits such as apples, potatoes, sweet potatoes, and watermelons, which weigh more than 200 g apiece (Kim and Koh, 1993; Yang, 2002; Cho et al., 2004; Yang et al., 2005), some studies have investigated the use of load-cell-type sorters for use in weight sorting of oranges, dry oak mushrooms, and fresh oak mushrooms, which have relatively low weights (Hwang et al., 2001; Cho et al., 2005; Gaikwad et al., 2014).

The aims of this study were to develop an electronic dried-persimmon weight sorter to improve on the measurement accuracy of the conventionally used mechanical sorter for lightweight dried persimmons with unit weights less than 100 g. For the convenience of users, we sought to develop a method to easily and conveniently manipulate the weight-setting and zero-point adjustment operations, which factors form the drawbacks of mechanical sorters, and to add a function to confirm the unit weight of each sorted dried persimmon in real time.

Materials and Methods

Carrier cup

The carrier cup, which transports the dried persimmon supplied through the manual or automatic feeder and discharges a persimmon of the grade stage corresponding to the weight range, consists primarily of a sorting tray, cup frame, main shaft, and auxiliary shaft, as shown in Figure 1. The main shaft is driven while coupled by a pin to the drive motor and the conveyor chain, which is operated by a sprocket. The auxiliary shaft moves the carrier cup, transported by the conveyor chain, along a rail. The cup frame delivers the load of dried persimmons that settle on the sorting tray to the load cell of the measurement part. In our study, the sorting tray was designed as a bowl-like structure into which the dried persimmon could settle stably and not fall off while being

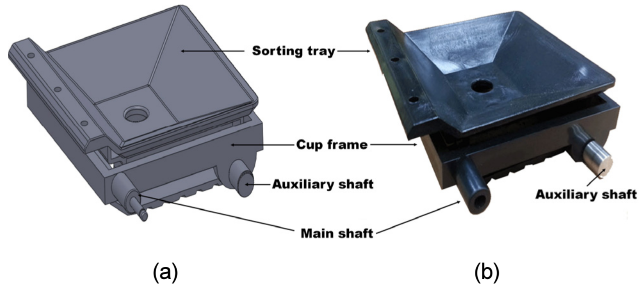


Figure 1. Schematic (a) and photograph (b) of carrier cup used for sorting dried persimmon.

Figure 2. Single-point strain-gauge-type load cell.

Table 1. Specifications of the load cell

Rated Load	49 N
Rated output	2 mV/V
Combined error	<0.02% rated output
Repeatability	<0.01% rated output
Input resistance	400 ± 20 Ω
Output resistance	350 ± 3.5 Ω
Insulation resistance	>2,000 MΩ
Safe operating range	-20°C to +70°C
Protection class	IP 65

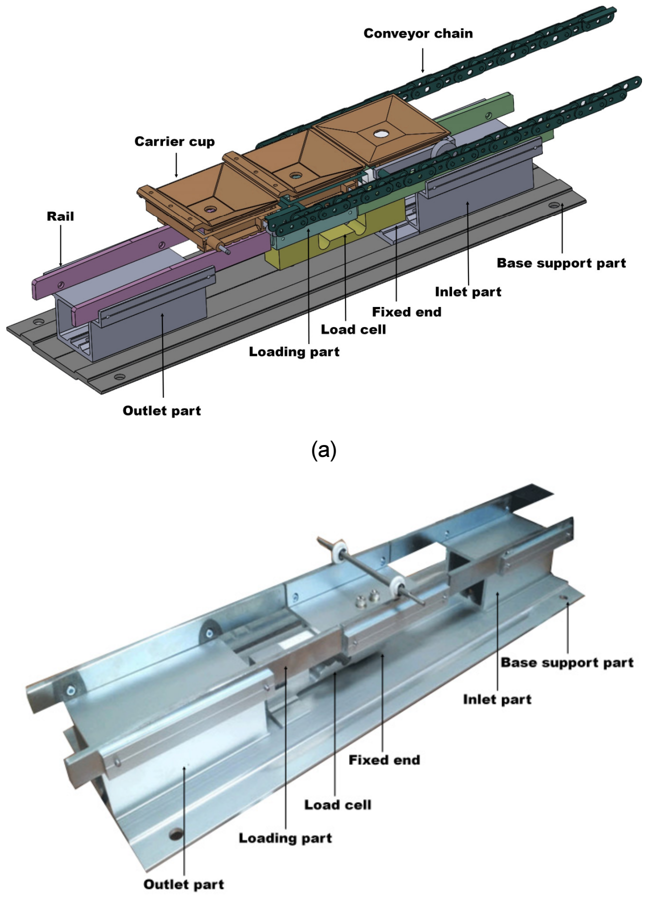
transported by the conveyer chain. There is a hole at the center of the sorting tray to allow sap and foreign substances to fall through. A total of 78 carrier cups were installed in the manufactured sorter.

Weight-measurement part

The load cell used to convert the load of the dried persimmons in the carrier cup into an electrical signal was a single-point-type (bending-beam type) strain-gauge load cell (CAS Corp. BCA-5L, Yangju, Korea),as shown in Figure 2.

The rated load of the load cell and other specifications are listed in Table 1.

Although most dried persimmons weigh less than 100 g, we used a slightly larger load cell to ensure device durability and robustness against fatigue over long operating times. The weight-measurement part of the single-point load cell is illustrated in Figure 3. It consists of an inlet part, weight-measurement part, discharging part, base-support part, and rail. The weight-measurement part is equipped with a load cell, and the fixed end is attached to the base-support part. The loading part measures the weight of the dried persimmon that enters the weight-measurement part via the rail.



(b)

Figure 3. Schematic (a) and photograph (b) of weight-measuring part equipped with a single-point load cell.

Discharging part

The discharge method used in a previously developed load-cell-type device involved the carrier cup entering a free-fall when the measured dried persimmon escaped from the corresponding grade. However, in our device, the carrier cup is forced to deviate from the rail by a solenoid valve so that the dried persimmon can escape smoothly. The carrier cup moves on the rail for a certain time. When the dried persimmon escapes at a certain stage, the auxiliary shaft forces a section of the rail that is separated to deviate via the solenoid valve. The main shaft in the weight carrier cup, which unites the transport chain and the cup frame, functions as a hinge when the measured dried persimmon drops at 90° to the corresponding outlet part. As shown in Figure 4, the auxiliary shaft is dropped to the bottom by the upper rail operated by the solenoid valve. To activate the synchronization of the operation signal of the solenoid valve, a proximity sensor (Autonics Corp., PR18-8DN, Yangsan, Korea) detects and operates a synchronous wheel linked to the drive shaft by transmitting an on/off signal.

Weight-setting and indicator part

Figure 5 shows the weight-setting and indicator part installed in the electronic dried-persimmon weight sorter. This part consists of a power switch, a mode selection switch, an automatic zero-point adjustment button, a weight-setting button, and an indicator. To set the weight class of each stage, the mode switch (weight setting, sorting, and test) is set to "weight setting," and the weight-setting switch (A, B) is shifted to A to set the weight range between stages 1 and 8. The desired weight range is determined by pressing the outlet button for each stage using the button designed only for weight setting. The range can be set freely by the user. All these processes can be checked at each step on the monitor of the indicator. The zero-point adjustment of the weight carrier cup is easily performed using the automatic calibration button. When the mode switch is shifted to the test mode, a correction is applied by running the sorter. In comparison with the use of a balance weight by existing mechanical sorters to perform corrections for each carrier cup or class, this method allows the convenient adjustment of the zero point. The indicator can check the weight of the dried persimmons in real time as the persimmons are sorted, and the number of persimmons sorted at each stage as well as the total number of sorted persimmons can be checked on the monitor.

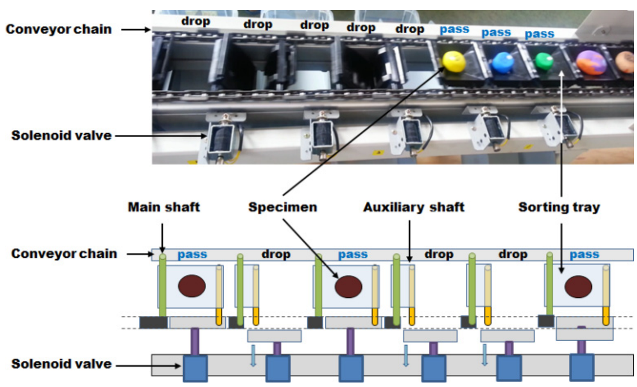


Figure 4. Role of solenoid valve in dried persimmon discharging mechanism.

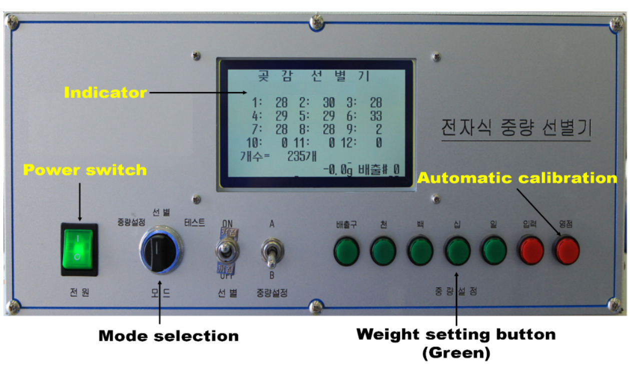


Figure 5. Indicator developed to set weight and display grading results.

Integration of components

The manufactured electronic dried-persimmon weight sorter, shown in Figure 6, consists primarily of an inlet part, weight-measurement part, weight-setting and indicator part, driving part, discharging part, and carrier cup. There are eight escape stages per weight, four on each of the right and left sides, when viewed from the processing direction of the dried persimmon. The 78 carrier cups connected to the conveyor chain are operated by the driving motor, and the dried persimmons are fed in automatically or manually at the inlet part. The dried persimmon that settles in the carrier cup applies a load to the load cell while passing through the weight-measurement part, and the measured weight is displayed on the indicator in real time. When the measured weight reaches the class stage of the corresponding weight range, the solenoid valve is operated via the synchronous wheel linked to the drive shaft, and the carrier cup falls. The dried persimmon that falls from the carrier cup is placed into the outlet bin through the outlet slide.

Specimens

Dried persimmons stored in the frozen state deformed from their original form or leaked sap during the experiment, which was conducted at room temperature. These frozen dried persimmons left behind a residual sticky substance in the carrier cup, making it difficult to conduct consecutive

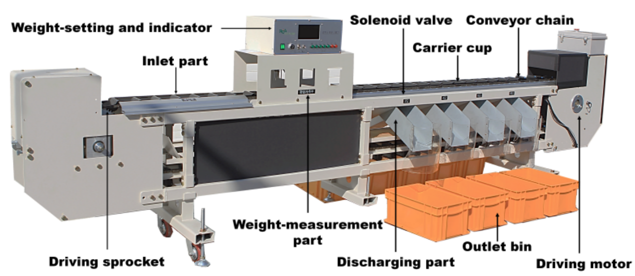


Figure 6. Prototype of weight grading of dried persimmon with use of load cell.

Figure 7. Rubber-clay specimens representative of dry persimmons used in the study.

experimental trials. More importantly, as the experiment was repeated, the weights of the persimmons decreased; thus, they lost their usefulness as standard weight specimens. Thus, in this study, rubber clay, which has a density similar to dried persimmon, was used in place of actual dried persimmons for each weight. Figure 7 shows the manufactured rubber-clay specimens. Three specimens were manufactured at each weight increment of approximately 1 g within the range from 24.73 to 99.56 g. A total of 228 "rubber-clay-persimmon" specimens were manufactured.

Performance evaluation

Two tests were performed using the electronic dried-persimmon weight sorter: a test of the accuracy of the weight measurements and a sorting performance test of the eight sorting stages. The rubber-clay specimens used in the tests ranged in weight from 24.73 g to 99.56 g, with three specimens at each 1-g increment of weight within that range. A total of 228 specimens were used in the tests. The specimens were fed individually into the sorter at the inlet part so that there was no gap in the carrier cup. The sorting processing rate was 1.8 specimens per second, which yielded a sorting capacity of 6,480 specimens per hour. The weight-measurement test was performed three times to assess the weight-measurement error and sorting degree.

To evaluate the weight-measurement accuracy in a statistical manner, certain additional evaluation factors were considered.

The percentage error between the measured and predicted values was calculated by means of equation (1):

$$E_W = \sqrt{\frac{\Sigma_{i=1}^{n}\left(\frac{W_{R_i} - W_{M_i}}{W_{R_i}}\right)}{n}} \times 100 \quad (1)$$

Here, E_W represents the weight-measurement error (%), W_M the weight of the specimens measured by the dried-persimmon weight sorter (g), W_R the weight measured by a precise scale, i.e., a standard weighing machine (g), and n = 228 samples. The overall degree of bias of the 228 total weight-measurement values was expressed by equation (2):

$$Bias = \frac{\Sigma_{i=1}^{n}\left(W_{M_i} - W_{R_i}\right)}{n} \quad (2)$$

Here, $Bias$ represents the systematic difference between measured and predicted values (g). The root-mean-square error (*RMSE*) was calculated to measure the accuracy of the developed weight sorter (g). In addition, the coefficient of determination (R^2) was calculated to express the degree to which a linear regression equation fits the predicted values. The grading degree per stage, expressed as a percentage, was determined by counting the number of rubber-clay specimens that exceeded or fell short of the grading range of the corresponding class among the measurement specimens for each outlet stage, and this degree was calculated as per equation (3):

$$E = \left(1 - \frac{P}{S}\right) \times 100 \quad (3)$$

Here, E represents the grading degree (%), P the number of specimens exceeding or falling short of the sorting range per stage (piece), and S the number of measurement specimens per stage (piece).

Results and Discussion

Performance evaluation

The results of the performance evaluation of the electronic dried-persimmon weight sorter are listed in Table 2. With respect to the weight-measurement error, the error of the first trial was 1.638%, that of the second was 1.685%, and that of the third was 1.642%. The average

Table 2. Weight measurement error (E_W) of dried-persimmon sorter

	E_W (%)	*Bias* (g)	*RMSE* (g)	R^2
1st test	1.638	-0.441	0.790	0.999
2nd test	1.685	-0.507	0.832	0.999
3rd test	1.642	-0.529	0.802	0.999
Average	1.655	-0.492	0.808	0.999

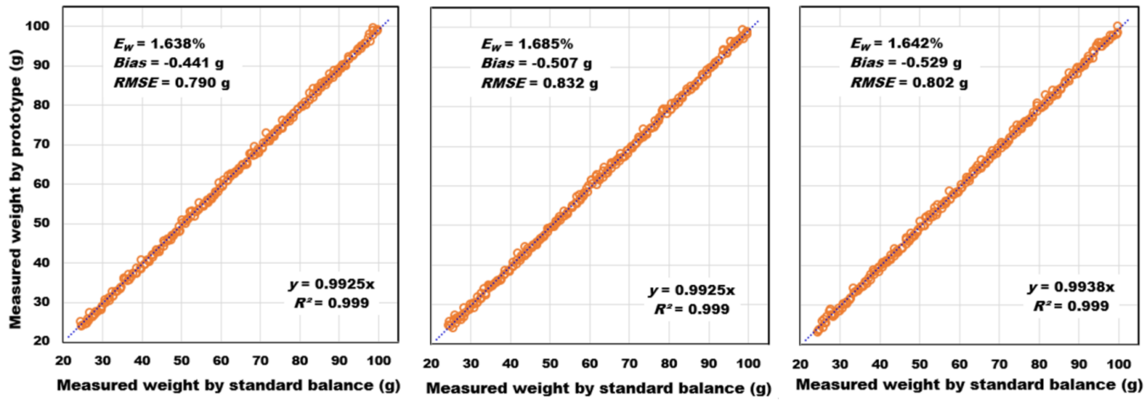


Figure 8. Scatter plot of dried-persimmon weights determined by standard balance and prototype sorter.

Table 3. Grading results of dried persimmon using prototype sorter

Sorting grade	1	2	3	4	5	6	7	8	Average (%)
Weight range (g)	90 over	80-89	70-79	60-69	50-59	40-49	30-39	20-29	-
1st test (%)	83.33	91.67	91.67	91.67	95.83	100.00	100.00	100.00	94.27
2nd test (%)	87.50	91.67	91.67	91.67	95.83	100.00	100.00	100.00	94.79
3rd test (%)	91.67	95.83	91.67	91.67	91.67	100.00	100.00	100.00	95.31
Average (%)	87.50	93.06	91.67	91.67	94.44	100.00	100.00	100.00	94.79

error was 1.655%. The biases were -0.441, -0.507, and -0.529 g (it is to be noted that these are all negative) for the first, second, and third trials, respectively, with an average of -0.492 g. The RMSE values for the first, second, and third trials were 0.790, 0.832, and 0.802 g, respectively, with an average of 0.808 g. The R^2 values for the three trials were 0,998, 0.995, and 0.998, in that order with an average of 0.997.

Figure 8 shows the results of the three weight-performance experiments. The horizontal (x) axis represents the weight measured by the standard balance (W_R), and the vertical (y) axis represents the weight measured by the electronic dried-persimmon weight sorter (W_M). The scatter plot indicates that the weights measured by the sorter (W_M) were concentrated around the trend line y = 0.9925x with a slope of 0.9925 and intercept of 0, which represents the predictive model equation. No weight-measurement values deviated significantly from the trend line within the entire weight range, and the dried-persimmon weight sorter exhibited stable weight-measurement performance.

To calculate the degree of grading by weight per class, weight ranges were set for weight classes 1 to 8 in increments of 10 g. The results of three experimental trials are listed in Table 3. The average grading performance for stages 1 to 8 was 94.79%, thereby indicating an excellent degree of grading. The grading performance of the weight range below 50 g was 100% in all of the experiments, and the average in the class over 90 g, i.e., the heaviest weight, was 87.50%, which was the poorest grading performance.

The measurement accuracy of the commercial mechanical weight sorter for dried persimmons was specified as ±2 to 5 g in the product brochure. The results of our study showed that the developed electric weight sorter exhibited a 250% higher performance with an accuracy of ±0.808 g.

Conclusions

We developed a load-cell-based electronic dried-persimmon weight sorter to overcome the limitations of the existing types of mechanical dried-persimmon sorters and evaluated the new sorter's performance in precisely measuring lightweight dried persimmons. The sorter developed in this study consists primarily of an inlet part, a weight-measuring part, an indicator part, a 49-N load cell, 78 carrier cups, an escape part with 8 stages, and a driving part. The sorter was designed to enable easy digital weight setting and zero-point adjustment for the convenience of users. The measured weights of dried persimmons are displayed by the indicator in real time, along with the number of dried persimmons sorted by class and the total number of dried persimmons. For a weight-measurement performance experiment of the prototype, 228 rubber-clay specimens (representative of dried persimmons) with weights ranging from 24.73 to 99.56 g in increments of approximately 1 g (three specimens at each weight) were used in three experimental trials. The transport rate of the carrier cup was set to 1.8 pieces per second. The average weight-measurement error for the three experimental trials was 1.655%, and the bias was -0.492 g. The RMSE for the linear model for the weight measured using a standard balance (W_R) versus the weight measured using the electronic dried-persimmon weight sorter (W_M) was 0.808 g, and the R^2 value was 0.997, thus indicating stable weight-measurement performance. In the sorting-performance test conducted for eight classes, the grading degrees and measurement accuracy of the developed weight sorter were 94.79% and ±0.808 g, respectively. The electronic dried-persimmon weight sorter measures the weights of dried persimmons precisely and permits convenient weight setting and zero-point adjustment for the convenience of users. In comparison with the existing types of mechanical sorters, the load-cell-based electronic weight sorter developed in this study offers practical advantages in dried-persimmon sorting.

Conflict of Interest

The authors have no conflicting financial or other interests.

Acknowledgement

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