INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Int. Agrophys., 2023, 37, 377-389
doi: 10.31545/intagr/169766

Effect of drop treatment on potato tuber damage and kinematic characteristics of the sieve rod**

Xiuzhi Gai, Fang Wang, Shengshi Xie, Zhanhong Gao, and Weigang Deng*

College of Mechanical and Electrical Engineering, Inner Mongolia Agricultural University, No.306 Zhaowuda Road, Hohhot 010018, Saihan District, Inner Mongolia Autonomous Region, China

Received March 14, 2023; accepted July 18, 2023

A b s t r a c t. In order to address the problem of potato damage caused by the tubers dropping onto a separating sieve, this study utilized a potato drop test rig to conduct a single-factor drop test on fresh potatoes. The kinematic characteristics of the sieve rod (acceleration peak, velocity peak, displacement peak), the variation in potato damage, and the correlation between the two were analysed under different experimental conditions. The following conclusions were drawn: As the dropping height increases, both the kinematic characteristic parameters of the sieve rod and the volume of damage increase, it was found that the two are positively correlated. As the potato mass increases, the kinematic characteristic parameters of the sieve rod decrease, and the volume of damage increases, it was found that the two are negatively correlated. When potatoes are dropped vertically along different axial positions, the kinematic characteristic parameters of the sieve rod follow the order of the x-axis direction < y-axis direction < z-axis direction, while the volume of damage follows the order of the x-axis direction > y-axis direction > z-axis direction, it was found that the two are negatively correlated. As the sieve surface inclination increases, both the kinematic characteristic parameters of the sieve rod and the volume of damage first increase and then decrease, it was found that the two are positively correlated. When the potato variety is changed, the kinematic characteristic parameter ranking of the sieve rod is Jizhangshu 12 > Holland 15 > Holland 14 > Svante > Xuechuanhong, while the damage volume ranking is Holland 15 > Svante > Jizhangshu 12 > Holland 14 > Xuechuanhong, it was found that the two rankings are unrelated. The results of this study provide a data basis and technical support for future research concerning the mechanical damage mechanism of potatoes.

K e y w o r d s: potato, drop treatment, damage volume, kinematic characteristics of sieve rod

1. INTRODUCTION

Potatoes are a highly nutritious agricultural crop which is widely used in vegetable products. Globally, the annual total potato production amounts to approximately 400 million tonnes, with China, India, Russia, the United States, and Ukraine being the most significant of the producing countries (Luo *et al*., 2021b). According to the relevant statistics, China recorded its highest potato production in 2020, reaching 18.312 million tonnes (Luo *et al*., 2021a). As the cultivation scale of potatoes continues to expand and labour costs increase, the harvesting methods used are gradually shifting towards mechanization. However, data reveals that the mechanical damage to potatoes during the harvesting process accounts for 70% of the total damage incurred throughout the entire flow-through process (Zhang, 2008). Such damage can have a significant impact on the economic value of potatoes, resulting in substantial financial losses (Hesen, 1960; Hesen and Kroesbergen, 1960). The potato processing industry, with an annual value of $2.5 billion, is estimated to incur a loss of $300 million per year due to tuber damage (Kang *et al*., 2013). In the United States, the annual economic

*Corresponding author e-mail: xieshengshi@163.com
**This work was supported by the Interdisciplinary Research Fund of Inner Mongolia Agricultural University (BR231505, 2023-2026), the National Natural Science Fund of China (31901409, 2020-2022), the Natural Science Foundation of Inner Mongolia Autonomous Region of China (2019BS05013, 2019-2021; 2022MS05027, 2022-2024)), and the Programme for Improving the Scientific Research Ability of Youth Teachers of Inner Mongolia Agricultural University (BR220127, 2022-2025) for developing the research.

losses caused by potato collision damage amounts to approximately $7.5 million (Peters, 1996). For countries like Austria and Germany, research indicates that field losses during the potato harvesting season range from 1 to 9% of the total yield (Schneider *et al*., 2019), with the estimated economic losses exceeding 40 million due to potato damage (Geyer *et al*., 2009). Therefore, reducing potato damage during the harvesting process is of crucial importance in improving the intrinsic quality and economic benefits of potatoes.

Most of the research conducted by scholars to date concerning potato damage has investigated the effects of different test conditions on the impact force and the degree of damage exerted by potato collisions. For example, Huang *et al.* (2022) constructed a physical model of potato tuber impact, selecting the impact material, potato variety, potato gravitational potential energy, and also the impact angle as test factors. The potato damage index (DI) was used as an evaluation index to assess the effect of each factor on potato tuber impact damage through an orthogonal test. Xie *et al.* (2020) used an acceleration acquisition system to determine the primary and secondary order of factors affecting the volume of potato collision damage and determined the changes in the relationship between collision acceleration and damage area under different factors. Shen *et al.* (2023) used compression tests to derive load-displacement curves to determine the critical damage point of potatoes and investigated the changes in the mechanical properties of potatoes after multiple compressions based on the plastic deformation of the potatoes after a force was applied. Zhang *et al.* (2008) proposed a potato damage classification method consisting of analysing the crush damage at different rates. Stropek and Gołacki (2022) studied the response of potatoes under impact loading conditions and determined the characterization of impact parameters such as maximum stress, maximum force, impact time, maximum deformation, permanent deformation, and the recovery coefficient. Hendricks *et al.* (2022) investigated the susceptibility of different potato varieties to black spot and crushing bruises at different impact heights. The incidence, severity, and depth of the black spot bruises, as well as the incidence of crushing bruises, were evaluated.

Studies were also conducted concerning the forms of damage to the potatoes. For example, Chiputula (2009) used drop tests to identify three types of potato damage: external shattering, internal shattering, and black spot. They demonstrated that the rate of potato damage increased with increasing drop height and shifted from black spot to external shattering as the drop height increased. Gancarz (2018) proposed a method for predicting the susceptibility of potato varieties to black spot damage after three and seven months of storage at 4°C. This method was based on the geometric parameters of the tuber parenchyma structure which was measured at harvest time.

Indeed, a portion of the research conducted also explores the application of finite element analysis in order to investigate the modifications in stress and impact forces during the descent of the potatoes. For instance, Caglayan *et al*. (2018) utilized reverse engineering methodologies, compression tests, slow-motion camera recordings, and finite element analysis (FEA) to examine the temporal changes in internal stresses and deformations during the descent of potato tuber samples. Similarly, Celik *et al*. (2019) amalgamated physical measurements, experimental test data, reverse engineering techniques, and explicit FEA-based dynamic simulation methods, thereby effectively illustrating the realistic progression of bruising and the distribution of mechanical stress within potato tubers during dynamic impact events.

Other researchers have also conducted studies on the damage characteristics of agricultural products. For instance, Yeşiloğlu (2022) investigated the occurrence of contusions in persimmon fruit wrapped in foam nets under various test conditions using a pendulum impact test apparatus. Zhang *et al.* (2022) quantified the impact damage of yellow peaches by integrating hyperspectral techniques with mechanical parameters. Furthermore, Shao *et al.* (2022) employed hyperspectral imaging for the classification of healthy, frostbitten, and diseased sweet potatoes. Additionally, Yeşiloğlu and Öztekin (2022) performed pendulum impact tests on three distinct peach varieties during different harvesting periods and developed a multiple linear regression model to predict bruising in peaches at the time of harvest.

While there has been extensive research concerning potato impact damage conducted both domestically and globally, comparatively less attention has been given to the kinematic characteristics of potato-soil separators and their correlation with potato damage. It is noteworthy that the instantaneous impact experienced by the potato upon its drop onto the potato-soil separation device serves as the primary cause of damage during the potato harvesting process (Liu *et al*., 2009). Consequently, it is imperative to thoroughly investigate the damage characteristics of potatoes during their drop onto the separator, along with conducting an in-depth analysis of the kinematic characteristics exhibited by the separator itself.

There are various types of potato soil separation devices available, such as the lift chain type (Lu *et al*., 2018; Wei *et al*., 2018), paddle finger wheel type (Wu *et al*., 2011), paddle roller push type (Yang *et al*., 2016), disc grate type (Shi *et al*., 2012), vibrating sieve type (Zhang *et al*., 2014; Feng, 2004), and also the rod chain-swing sieve combination type (Zhao *et al*., 2007), among others. Among them, the rod chain-swing sieve combination potato excavator is extensively used in the central and western regions of China due to its high degree of harvesting efficiency, soil adaptability, and other advantages. This type of potato soil separation device is characterized by evenly spaced rows of rods forming a separation sieve as the core component. When the potatoes drop onto the surface of the separation sieve, the forced vibration generated during the moment of impact can affect the motion of the separation sieve. Therefore, when the potatoes are dropped, it is essential to elucidate the forced vibration kinematic characteristics of the separation sieve in order to gain a thorough understanding of the factors contributing to the damage incurred when the potatoes were dropped.

Taking into account the aforementioned considerations, the present study aims to investigate the impact of various test factors, including the drop height, potato mass, potato variety, inclination of sieve surface, and the drop in different axial positions, on the potato drop test (Gancarz, 2018; Hussein *et al*., 2020; Pathare and Al-Dairi, 2021). By analysing the impact of the mandatory vibrations caused by potato drop collisions under different test conditions on the kinematic characteristic parameters of the sieve rod, the effect of the mandatory vibrations of the sieve rod on potato damage volume under different test factors, and the correlation between the kinematic characteristic parameters of the sieve rod and the potato damage volume, the fundamental causes of potato damage from the drop onto the separating sieve rod is determined. It is anticipated that the findings of this study will provide a data foundation for further investigation into the mechanical damage mechanisms of potatoes.

2. MATERIALS AND METHODS

2.1. Materials

The potatoes used in the experiment were obtained from the Dongwayao Vegetable Market in Hohhot City, China. All of the potatoes used in this experiment were freshly harvested within 5 days (the potato harvesting season in the Inner Mongolia region is from early September to mid-October). Potatoes of uniform size, regular shape, without any internal decay, and those undamaged on the surface were selected for the experiment. Among them, 10 potatoes were selected for each of the following weight categories: 150±5, 250±5, 350±5, 450±5, and 550±5 g of Holland 15 potatoes. Additionally, 100 potatoes weighing 250±5 g of Holland 15 potatoes were selected. Lastly, 10 potatoes each of Xuechuanhong, Holland 14, Jizhangshu 12, and Svante varieties, all weighing 250±5 g, were chosen. In total, 190 potatoes were used in the experiment.

2.2. Test equipment and methods

The experimental setup employed in the study consisted of a potato drop test bench (Fig. 1). This test bench comprised a stand (which included a scale), a shelf, a sieve surface, an acceleration sensor (Model 1A102E IEPE single-axis piezoelectric acceleration sensor, frequency response 1~10 000 Hz, range 500 g, Jiangsu Donghua Test Technology Co.), data acquisition and analysis equipment (AVANT series, model number M1-7016, manufactured by Hangzhou Yiheng Technology Co.), and a computer to control the entire system.

Before conducting the test, the acceleration sensor is to be securely fixed beneath the sieve rod on the side where the potato impacts during the fall (as shown in Fig. 1), and then connected to the data acquisition and analyser device for signal conversion. Subsequently, the computer software of the data acquisition and analyser device was used to measure the impact acceleration of the dropping sieve rod. At the start of the experiment, the data acquisition and analyser device, as well as the data acquisition software, were placed in the pending recording state. The potato was then dropped from the shelf according to the predetermined direction and drop height, after which the test data were recorded and saved. Following the test, the potatoes that were damaged by the drop were maintained at room temperature (22±1°C) for 48 h, and their damage volume was then measured and calculated.

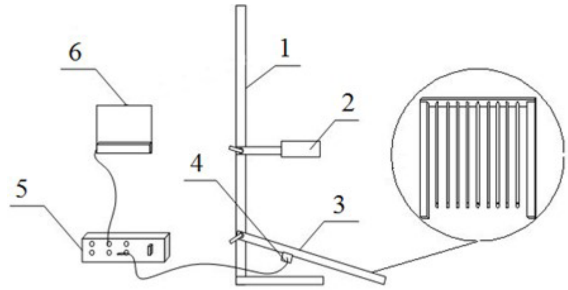

Fig. 1. Potato drop test bench: 1 – stand (with scale), 2 – shelf, 3 – sieve surface, 4 – acceleration sensor, 5 – data acquisition and analyser, 6 – computer.

2.3. Test factors and levels

The factors chosen for the study encompassed drop height, potato mass, drop direction, sieve surface inclination, and potato variety. The range of drop heights, from 300 mm to 700 mm, was determined based on the structural parameters of the integrated rod chain-swing sieve rod combination potato excavator (Feng, 2018). The mass range of the potatoes, from 150 to 550 g, was established in accordance with the grades and specifications of potatoes in China as outlined by the Ministry of Agriculture of the PRC in 2006. Due to the vertical descent of the potato, different axial positions of the drop can result in varying degrees of damage. Therefore, different axial positions in the vertical drop are chosen as test factors, namely, dropping lengthwise, dropping widthwise, and dropping according to their thickness. The drop in different axial positions was defined by the x-axis, y-axis, and z-axis in Fig. 2, which corresponded to the length, width, and thickness directions of the potato dimensions, respectively. In terms of dimensions, the length was greater than the width, which was greater than the thickness.

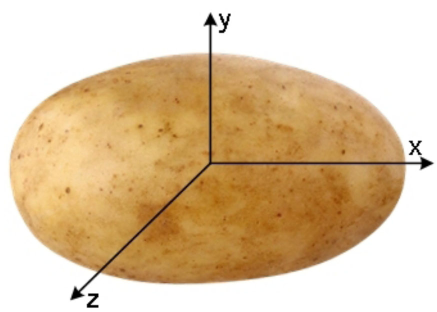

Fig. 2. The dropping direction of the potato.

Table 1. Table of test factor levels

Level	Factor				
	Drop height (mm)	Potato mass (g)	Drop direction	Inclination of sieve surface (°)	Potato varieties
1	300	150±5	x-axis	0.5	Holland 15
2	400	250±5	y-axis	7.7	Svante
3	500	350±5	z-axis	14.4	Jizhangshu 12
4	600	450±5		21.1	Holland 14
5	700	550±5			Xuechuanhong

The inclination angle of the separation sieve ranged from 0.5 to 21.1°, it was determined using the structural parameters of the integrated rod chain-swing sieve combination potato excavator (Xie *et al*., 2020). In order to account for variations in mechanical damage resistance among different potato varieties, the following varieties were selected for the trial: Holland 15, Svante, Jizhangshu 12, Holland 14, and Xuechuanhong. Table 1 displays the test factors and corresponding levels.

2.4. Test indicators

The kinematic characteristic parameters of the sieve rod are primarily defined by three indicators: impact acceleration peak, impact velocity peak, and impact displacement peak. The peak acceleration of the sieve rod at the moment when the potato drops onto it is obtained by analysing the collected acceleration data of the sieve rod using data analysis software. By utilizing the MATLAB software in order to integrate the acceleration data of the sieve rod twice, a curve depicting the change in the sieve rod's velocity over time may be obtained, from this the velocity peak of the sieve rod may be extracted. Similarly, the variation curve of the sieve rod's displacement with respect to time may be obtained, and the displacement peak of the sieve rod may be ascertained (Pfau *et al*., 2005; Alatise and Hancke, 2017).

After being maintained at room temperature for 48 h, the damaged potatoes were taken out, and several thin slices were cut parallel to the damaged surface until the undamaged areas were reached (Baritelle *et al*., 2000). The length and width of the damaged position on the largest slice of the damaged area were then measured using vernier callipers. Next, the thickness of all of the damaged slices was measured to obtain the potato damage depth. Finally, the potato damage volume was calculated using the following equation (Stropek and Gołacki, 2013; Zhang, 2008):

$$V = \frac{1}{6}\pi abh \ . \tag{1}$$

The formula for calculating the damage volume of the potatoes involves the following parameters: a – represents the damage area of the largest thin section in the x-axis direction, measured in mm; b – represents the damage area of the largest thin section in the y-axis direction, also measured in mm; and h – denotes the depth of the damage (mm).

2.5. Experimental results statistical analysis

The parameters of the kinematic characteristics of the sieve rods were fitted separately using Origin 2018 software, and the significance was calculated using SPSS 26.0 software. Pearson's correlation analysis between the damage volume and the parameters of the sieve rod kinematic characteristics for potatoes under different test factors was carried out using SPSS 26.0 data analysis software. The Minitab 17.0 software was utilized in order to develop a fitted regression model for the parameters of the potato damage volume and sieve rod kinematic characteristics under the inclination of the sieve surface factor, thereby obtaining the regression equation.

3. RESULTS AND DISCUSSION

3.1. Influence of factors on the kinematic characteristics of the sieve rod

3.1.1. Effect of the potato drop height on the kinematic characteristics of the sieve rod

In order to investigate the impact of the potato drop height on the kinematic characteristics of the sieve rod, 50 potatoes of the Holland 15 variety with a weight of 250±5 g were divided into five groups. The potatoes were dropped from heights of 300, 400, 500, 600, and 700 mm, respectively, along the y-axis direction facing the sieve surface with an inclination angle of 0.5°. Each group underwent ten repetitions of the experiment, and measurements were taken to determine the impact acceleration peak, velocity peak, and displacement peak of the sieve rod. The impact acceleration peak, velocity peak, and displacement peak of the sieve rod were fitted using Origin 2018 software, and their significance was calculated using SPSS software to obtain the fitted curve (Fig. 3).

The equations fitted and presented in Fig. 3 demonstrate coefficients of determination (R^2) > 0.95, indicating the validity of both the fitted equations and curves. The fitted curve shows that the drop height of the potato is proportional to the impact acceleration peak, velocity peak and displacement peak of the sieve rod. This finding is consistent with the results by Gao *et al*. (2018), which reported a positive correlation between the maximum impact force and maximum deformation with increasing drop height using finite element analysis. This trend may be attributed to the greater gravitational potential energy of the potato at higher drop heights, which results in higher kinetic energy upon impact (Hu, 2018; Geyer *et al*., 2009; Xie *et al*., 2020). Consequently, the collision between the dropping potato and the sieve rod leads to a more substantial impact on the sieve rod, resulting in higher acceleration peaks, velocity peaks, and displacement peaks.

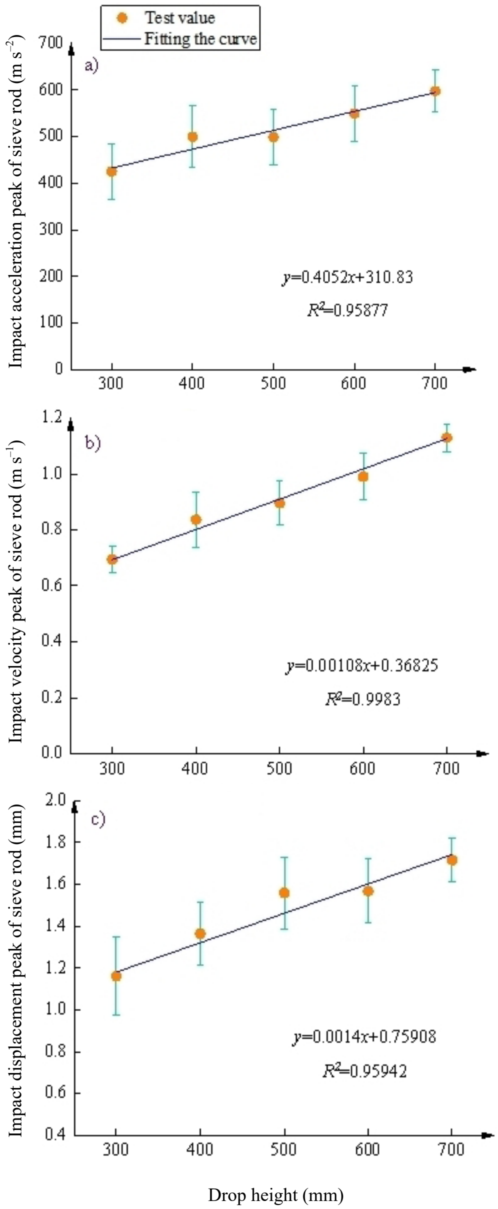

Fig. 3. Variation in the kinematic characteristics of the sieve rod with the height of the drop: a) impact racceleration peak, b) impact velocity peak, c) impact displacement peak.

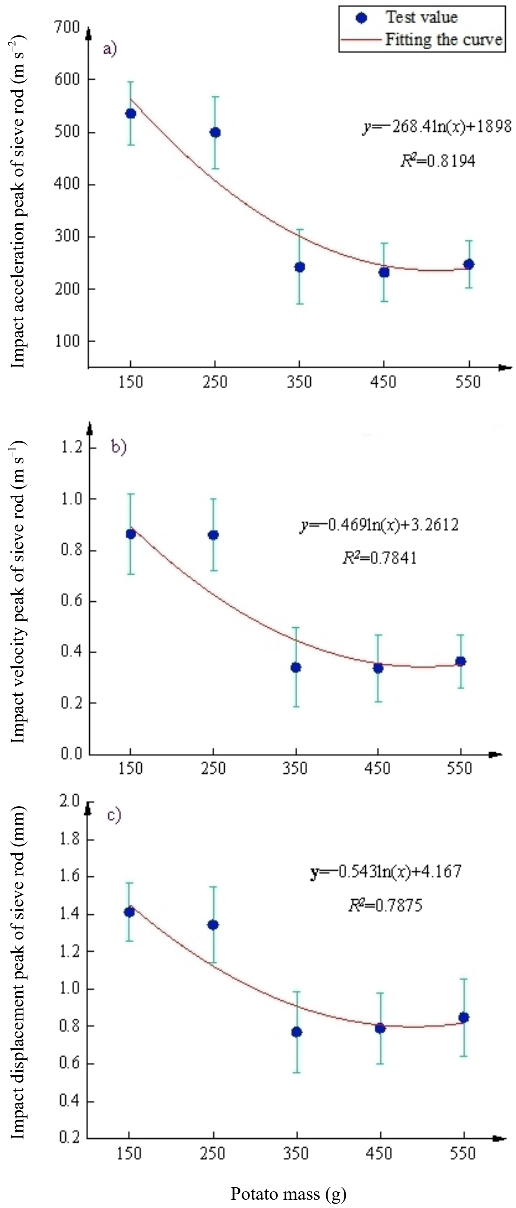

Fig. 4. Variation in the kinematic characteristics of the sieve rod with potato mass. Explanations as in Fig. 3.

3.1.2. Effect of potato mass on the kinematic characteristics of the sieve rod

In order to investigate how potato mass affects the kinematic characteristics of the sieve rod, the Holland 15 variety potato was chosen and placed at an inclination angle of 0.5° facing the sieve surface along the y-axis direction. Potatoes with masses of 150±5, 250±5, 350±5, 450±5 and 550±5 g were then dropped from a height of 400 mm, with each group of tests being repeated 10 times to measure the impact acceleration peak, velocity peak and displacement peak of the sieve rod. The impact acceleration peak, velocity peak, and displacement peak of the sieve rod were fitted using Origin 2018 software, and their significance was calculated using SPSS software. Based on the calculated results, the fitted equation with the larger and more significant coefficient of determination was selected in order to obtain the fitted curve (Fig. 4).

The fitted equations presented in Fig. 4 all demonstrate coefficients of determination (R^2) above 0.79, indicating their validity. The fitted curve shows that the impact acceleration peak, velocity peak, and displacement peak of the sieve rod are inversely proportional to the mass of the potato. Feng (2017) proposed that the velocity of potatoes of different masses at the moment of collision with the sieve rod remains constant. However, the deformation of the potato at the point of impact increases with its mass, thereby resulting in greater energy loss during the collision. Consequently, the acceleration at the moment of collision between the potato and the

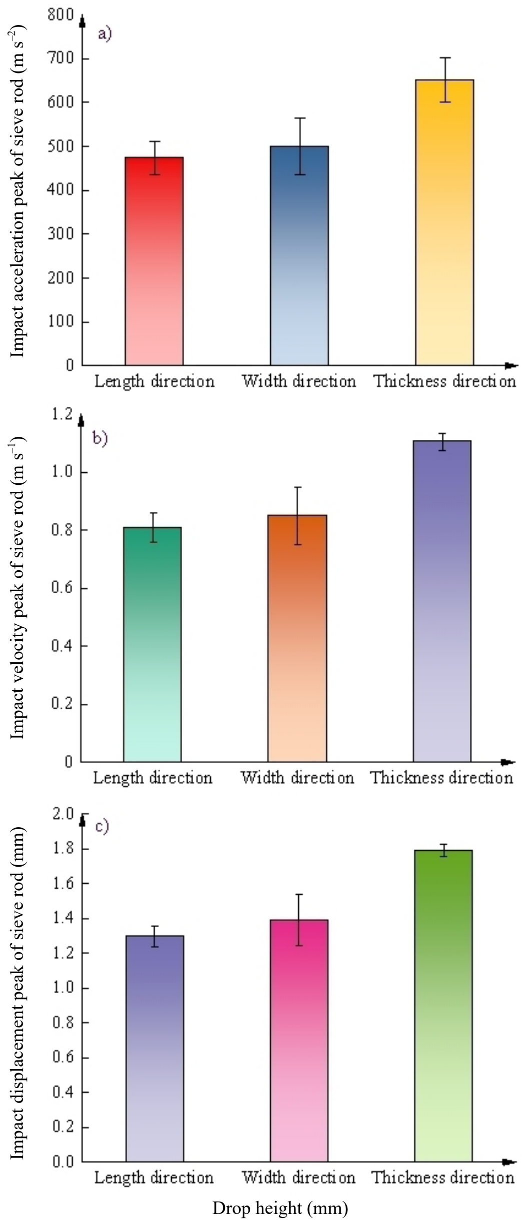

Fig. 5. Variation in the kinematic characteristics of the sieve rod with the drop direction. Explanations as in Fig. 3.

sieve rod gradually decreases with increasing mass (Geyer *et al*., 2009; Xie *et al*., 2020), leading to a smaller acceleration peak, velocity peak, and displacement peak of the sieve rod.

3.1.3. Effect of the axial positions of potato drops on the kinematic characteristics of the sieve rod

In order to explore the impact of drops in different axial positions on the kinematic characteristics of the sieve, 30 potatoes of the Holland 15 variety with a weight of 250±5 g were selected and divided into three groups. The potatoes were oriented in their x-axis directions, y-axis directions, and z-axis directions, respectively, facing a sieve surface with a tilt angle of 0.5°. They were dropped from a height of 400 mm, and each group underwent ten repetitions of the experiment in order to obtain measurements of the impact acceleration peak, velocity peak, and displacement peak of the sieve rod for each axial position.

From the results presented in Fig. 5, it is evident that the kinematic characteristics of the sieve rod are influenced by the axial positions of the potato drop. Specifically, the highest impact acceleration peak of the sieve rod occurs for vertical drops from the z-axis direction, followed by vertical drops from the y-axis direction, and finally, vertical drops from the x-axis direction. The variation in the velocity peak and displacement peak of the sieve rod also follows a similar trend to that of the impact acceleration peak of the sieve rod. This observation may be attributed to the curvature of the potato, which is greater in the x-axis direction than in the y-axis direction, which is greater than that in the z-axis direction. According to the Hertz contact stress theory, as the curvature decreases, the radius of curvature gradually increases, leading to a higher impact force on the sieve rod when the potato drops (Popov, 2011). Consequently, the amplitude of the sieve rod vibration increases, resulting in a higher impact acceleration peak, velocity peak, and displacement peak.

3.1.4. Effect of sieve surface inclination on the kinematic characteristics of the sieve rod

In order to investigate the impact of different inclinations of the sieve surface on the kinematic characteristics of the sieve rod, 40 potatoes of the Holland 15 variety with a weight of 250±5 g were selected and divided into four groups. The potatoes were positioned perpendicular to the width of the sieve with inclination angles of 0.5, 7.7, 14.4, and 21.1°, respectively. Each potato was subjected to a drop test from a height of 400 mm above the sieve surface, and the tests were repeated ten times to obtain the impact acceleration peak, velocity peak, and displacement peaks for the sieve rods at each inclination angle of the sieve surface. The impact acceleration peak, velocity peak, and displacement peak of the sieve rod were fitted using Origin 2018 software, and the significance was calculated using SPSS software. Based on the calculated results, the fitted equation with a larger and more significant coefficient of determination was selected to obtain the fitted curve (Fig. 6).

From the fitted equations presented in Fig. 6, it is clear that the coefficients of determination R^2 are all greater than 0.96, thereby indicating the reliability of the fitted equations and curves. The curve fitting analysis shows that the peak impact acceleration, velocity peak, and displacement peak of the sieve rod display a trend of initial increases followed by a subsequent decrease as the inclination of the sieve surface increases. The maximum values of the impact acceleration peak, velocity peak and displacement peak of the sieve rod are observed at an inclination of 7.7°. Conversely, the minimum values of these parameters are observed at an inclination of 21.1°.

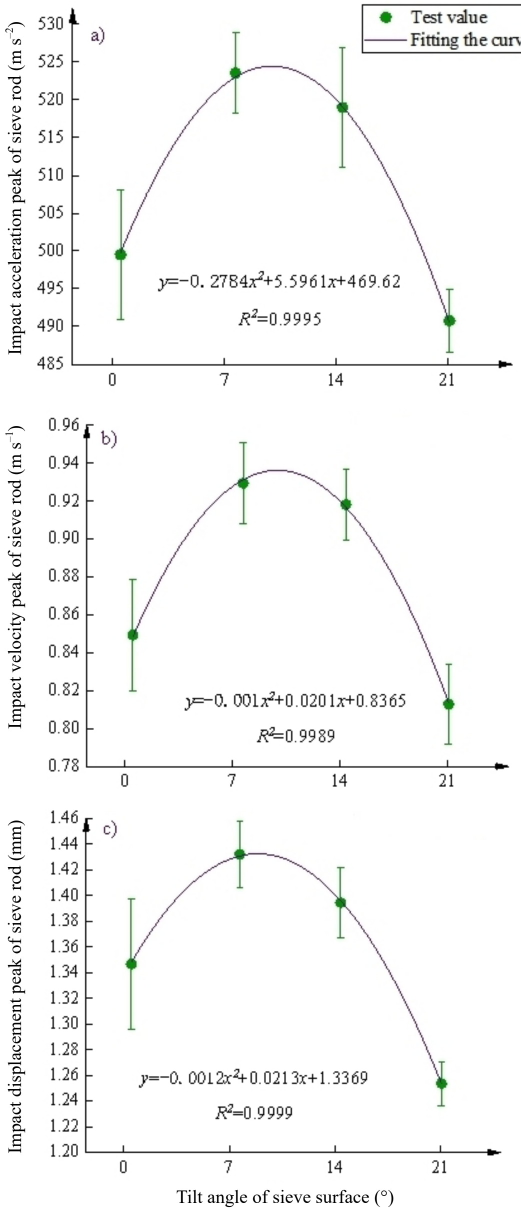

Fig. 6. Variation in the kinematic characteristics of the sieve rod with the sieve surface inclination. Explanations as in Fig. 3.

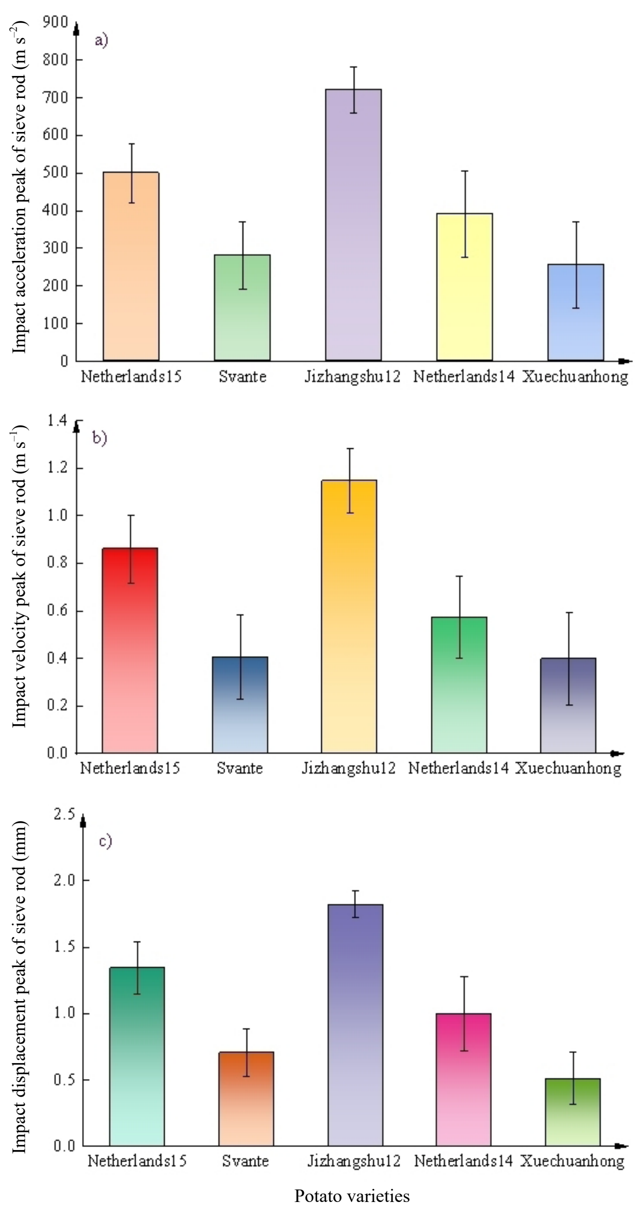

Fig. 7. Variation in the kinematic characteristics of the sieve rod with the potato varieties. Explanations as in Fig. 3.

3.1.5. Effect of potato variety on the kinematic characteristics of the sieve rod

In order to investigate the effect of the potato varieties used on the kinematic characteristics of the sieve rod, 10 potatoes of the same size were handpicked from five different varieties: Holland 15, Svante, Jizhangshu 12, Holland 14, and Xuechuanhong. The selected potatoes weighed 250±5 g. Each potato was aligned with the sieve surface at an inclination of 0.5°, and a drop test was performed from a height of 400 mm. The tests were repeated ten times for each group, and the impact acceleration peak, velocity peak, and displacement peak of the sieve rod were recorded.

Upon analysing Fig. 7, it is evident that the impact acceleration peak, velocity peak, and displacement peak of the different potato varieties on the sieve rod exhibit a distinct order of magnitude. Specifically, Jizhangshu 12 showed the highest impact acceleration peak, followed by Holland 15, Holland 14, Svante, and Xuechuanhong. In order to evaluate the hardness of the potatoes, a texture meter was employed, and the results showed that Holland 15, Svante, Jizhangshu 12, Holland 14, and Xuechuanhong had hardness values of 140.94, 142.54, 146.85, 153.55, and 155.92 N, respectively (Gao, 2021). Therefore, the ranking order of potato varieties by hardness is Xuechuanhong > Holland 14 > Jizhangshu 12 > Svante > Holland 15. Despite conducting a comparative analysis of the kinematic characteristics and hardness data of the sieve rods from different potato varieties, no correlation pattern was found between the two variables. This implies that altering the hardness of the potatoes did not have an impact on the kinematic characteristics of the sieve rods.

3.2. Effect of various factors on potato damage volume

In order to examine the effects of different test variables, including the drop height, potato weight, potato type, sieve angle, and drop orientation on the amount of damage sustained by the dropped potatoes, the test variables and their corresponding levels as specified in Table 1 were chosen. Each test variable was modified independently during testing, with 10 repetitions for each test group. The mean of the 10 repeated tests was computed as the final test outcome, as shown in Table 2, which displays the resultant potato damage volumes under various test conditions.

Table 2 presents results which indicate that the height of the drop is directly proportional to the volume of potato damage (Ito *et al*., 1994; Guo *et al*., 2016). The presented discovery is consistent with the research conducted by Feng *et al.* (2019), where it was proposed that the speed of impact between the potato and sieve rod increases with each increase in the initial height of the drop, resulting in a greater distortion to the potato when it collides with the sieve rod. Drawing on the results presented in section 3.1.1, it may be inferred that an increase in the drop height leads to a corresponding increase in the kinematic characteristic parameters of the sieve rod. This leads to an enhancement in the impact force on the sieve rod and, in turn, on the reaction force of the sieve rod on the potato. Consequently, the volume of damage to the potato also increases. This demonstrates that the volume of damage to the potato is directly proportional to the kinematic characteristic parameters of the sieve rod for different factors of drop height. In order to minimize collision damage during potato harvesting operations, it is important to effectively control the drop height of potatoes.

Table 2 shows that the volume of potato damage is directly proportional to the potato mass (Thomson and Lopresti, 2018). Xie *et al.* (2020) previously proposed that a higher potato mass leads to an increased collision pressure and a greater volume of damage. By combining these findings with the results presented in section 3.1.2, it was established that an increase in potato mass results in a reduction in the kinematic characteristic parameters of the sieve rod. As a result, the energy dissipated during the collision between the potato and the sieve rod is used for the plastic deformation of the potato, this in turn leads to greater potato deformation and an increase in the amount of damage sustained. Therefore, it may be concluded that the volume of potato damage is inversely proportional to the kinematic characteristic parameters of the sieve rod for different potato mass factors.

As presented in Table 2, the volume of potato damage varies with the different axial positions of the potato drops and follows the order of x-axis direction > y-axis direction

Table 2. Volume of potato damage under different test conditions.

Factor	Level	Potato damage (volume mm^3)
Drop height (mm)	300	735.9±470.3
	400	847.9±508.7
	500	1328.6±627.2
	600	1966.6±963.2
	700	3422.3±1985.6
Potato mass (g)	150	651.5±764.5
	250	847.9±508.7
	350	1020.2±720.7
	450	1342.6±746.1
	550	1469.3±862.0
Drop direction	x-axis direction	1203.4±645.2
	y-axis direction	847.9±508.7
	z-axis direction	727.0±562.7
Inclination of sieve surface (°)	0.5	847.9±508.7
	7.7	1247.6±716.6
	14.4	1143.8±714.0
	21.1	602.6±505.4
Potato varieties	Holland 15	847.9±508.7
	Svante	457.1±483.5
	Jizhangshu 12	438.9±355.3
	Holland 14	76.5±130.8
	Xuechuanhong	0

Initial condition: Potato mass – 250±5 g, drop direction – y-axis direction, inclination of sieve surface – 0.5°, potato varieties – Holland 15.

> z-axis direction. Based on the results in section 3.1.3, the following reasons for this were inferred: An analysis of the kinematic characteristic parameters of the sieve rod indicated that the curvature of the potato gradually reduces, and the radius of curvature gradually increases while transitioning from the x-axis, y-axis, and z-axis directions. According to the Hertz contact stress theory, when the radius of curvature increases, the deformation volume of the potato decreases, this results in a reduction in potato damage volume (Popov, 2011). This trend is consistent with the findings of Blahovec (2005) that areas with a greater curvature on the potato surface are more prone to injury. After considering the different axial positions of the potato drops, the study demonstrated that the volume of potato damage tends to decrease gradually as the kinematic characteristic parameters of the sieve rod increase. Therefore, selecting a downward-facing thickness during potato digging and transport could help to reduce the damage sustained by the potatoes.

As presented in Table 2, an increase in the inclination of the sieve surface results in an initial rise and a subsequent fall in the volume of potato damage. This trend may be explained by the findings in outlined in section 3.1.4. As the inclination of the sieve surface increases, the kinematic characteristic parameters of the sieve rod initially increase and then decrease, with the highest value occurring at an inclination of 7.7° and the lowest value at 21.1°. The maximum impact force on the sieve rod is observed at an inclination of 7.7°, this results in the highest reaction force on the potato and hence the maximum volume of damage. The lowest amount of damage occurs at a sieve surface inclination of 21.1°. This pattern is in line with the outcomes obtained by Xie (2017) in his experiments concerning the optimization of separation sieve parameters (Xie *et al*., 2020). This indicates that the volume of damage sustained by the potatoes is influenced by the kinematic characteristic parameters of the sieve rod at different factors of sieve surface inclination. Therefore, adjusting the inclination of the sieve surface can be used as a reference point in the design of the inclination of the potato swing separation sieve in order to reduce damage.

Based on the results of the hardness testing of various potato varieties using a texture meter, it was found that the hardness of Holland 15, Svante, Jizhangshu 12, Holland 14, and Xuechuanhong was 140.94, 142.54, 146.85, 153.55, and 155.92 N, respectively (Gao, 2021). As indicated in Table 2, there is an inverse relationship between potato hardness and the volume of potato damage. This phenomenon may be attributed to the fact that harder potatoes are less susceptible to damage due to their increased resistance. This finding is supported by the results obtained in section 3.1.5, which indicate that potato damage volume is influenced by potato hardness and is independent of the kinematic characteristics of the sieve rod under different drop scenarios.

3.3. Correlation between the volume of potato damage and the kinematic characteristics parameters of the sieve rod

In order to investigate the influence of the kinematic characteristics of sieve rods on potato damage volume under various test conditions outlined, this study used SPSS26.0 data analysis software to establish the correlations between the impact acceleration peak, velocity peak, and displacement peak of the sieve rods, and the volume of potato damage sustained at different drop heights, potato masses, potato varieties, sieve surface inclinations, and the axial positions of the potato in a vertical drop.

In order to meet the prerequisite of conducting a Pearson correlation analysis, the normality of the sample data was assessed. A one-sample K-S test was performed using SPSS26.0 software with the aim of conducting non-parametric testing on the data, and it was duly confirmed that the five sets of data followed a normal distribution. The results of the Pearson correlation analysis are presented in Table 3.

Table 3 shows that the impact acceleration peak, velocity peak, and displacement peak of the sieve rod are highly and significantly positively correlated with the volume of potato damage at different drop heights, with significance values lower than 0.05 and correlation coefficients greater than 0.8. By contrast, at different potato masses, the volume of potato damage and the impact acceleration peak, velocity peak, and displacement peak of the sieve rod were all significant at values higher than 0.05 with correlation coefficients ranging between –0.864 and –0.837, indicating a negative but non-significant relationship. The correlation between the volume of potato damage and the impact acceleration peak, velocity peak, and displacement peak of the sieve rod for different potato varieties ranges between 0.451 and 0.526 and is not significant. Similarly, at different sieve surface inclinations, there is a highly significant positive correlation between the volume of potato damage and the impact acceleration peak, velocity peak, and displacement peak of the sieve rod, with significance values lower than 0.05 and correlation coefficients greater than 0.8. Finally, at different axial positions of the potato during vertical drops, the volume of potato damage and the impact acceleration peak, velocity peak, and displacement peak of the sieve rod were all significant at higher values than 0.05 with correlation coefficients between –0.788 and –0.766, thereby indicating a negative but non-significant relationship. Therefore, analysing the correlation patterns between the kinematic parameters of the sieve rod and the volume of potato damage could help to identify the root causes of potato damage during the separation process, with reference to the drop height, potato mass, sieve surface inclination, and axial positions of the potato used in the vertical drop.

Table 3. Pearson correlation between potato damage volume and the kinematic characteristics of sieve rods

Experimental factor	Experimental parameter	Potato damage (volume mm^{-3})	Impact peak of sieve rod		
			Acceleration	Velocity	Displacement
Drop height	Potato damage (volume mm^{-3})	1	0.907*	0.907*	0.883*
			0.034	0.034	0.047
	Impact acceleration peak of sieve rod	0.907*	1	0.994**	0.962**
		0.034		0.001	0.009
	Impact velocity peak of sieve rod	0.907*	0.994**	1	0.986**
		0.034	0.001		0.002
	Impact displacement peak of sieve rod	0.883*	0.962**	0.986**	1
		0.047	0.009	0.002	
Potato mass	Potato damage (volume mm^{-3})	1	–0.864	–0.853	–0.837
			0.059	0.066	0.077
	Impact acceleration peak of sieve rod	–0.864	1	0.998**	0.998**
		0.059		0.000	0.000
	Impact velocity peak of sieve rod	–0.853	0.998**	1	0.997**
		0.066	0.000		0.000
	Impact displacement peak of sieve rod	–0.837	0.998**	0.997**	1
		0.077	0.000	0.000	
Potato varieties	Potato damage (volume mm^{-3})	1	0.451	0.521	0.526
			0.446	0.368	0.363
	Impact acceleration peak of sieve rod	0.451	1	0.994**	0.993**
		0.446		0.001	0.001
	Impact velocity peak of sieve rod	0.521	0.994**	1	0.997**
		0.368	0.001		0.000
	Impact displacement peak of sieve rod	0.526	0.993**	0.997**	1
		0.363	0.001	0.000	
Sieve surface inclination	Potato damage (volume mm^{-3})	1	0.991**	0.994**	0.983*
			0.009	0.006	0.017
	Impact acceleration peak of sieve rod	0.991**	1	0.998**	0.951*
		0.009		0.002	0.049
	Impact velocity peak of sieve rod	0.994**	0.998**	1	0.960*
		0.006	0.002		0.040
	Impact displacement peak of sieve rod	0.983*	0.951*	0.960*	1
		0.017	0.049	0.040	
Drop direction	Potato damage (volume mm^{-3})	1	–0.788	–0.766	–0.766
			0.422	0.445	0.444
	Impact acceleration peak of sieve rod	–0.788	1	0.999*	0.999*
		0.422		0.023	0.022
	Impact velocity peak of sieve rod	–0.766	0.999*	1	1.000**
		0.445	0.023		0.001
	Impact displacement peak of sieve rod	–0.766	0.999*	1.000**	1
		0.444	0.022	0.001	

*Indicates a significant correlation at the 0.05 level (two-tailed), **indicates a highly significant correlation at the 0.01 level (two-tailed). Pearson correlation (r) > 0.8 is highly correlated; 0.5 < r < 0.8 – moderately correlated; 0.3 < r < 0.5 – weakly correlated; r < 0.3 – not correlated.

3.4. Regression analysis between the volume of potato damage and the kinematic characteristics parameters of the sieve rod

It is evident that the correlation between the volume of potato damage and the kinematic characteristics parameters of the sieve rod is greatest at various sieve surface inclination angles. Consequently, Minitab software was utilized in order to establish fitted regression models for potato damage volume and the kinematic characteristics parameters of the sieve rod under different factors of sieve surface inclination. This process yielded regression equations for the potato damage volume (*V*) in relation to the impact acceleration peak (*a*), impact velocity peak (*v*), and impact displacement peak (*s*) of the sieve rod. Additionally, a model summary and ANOVA tables were generated for the potato damage volume and the kinematic characteristics parameters of the sieve rod, respectively.

$$V = -8445 + 18.52a \quad , \qquad (2)$$

$$V = -3842 + 5072v \quad , \qquad (3)$$

$$V = -4103 + 3734s \quad . \qquad (4)$$

Based on Table 4, it is evident that R^2, R^2 (adjusted), and R^2 (prediction) all surpass 0.79. Moreover, Table 5 reveals that the P-values are below 0.05. These findings indicate that the regression equations more accurately capture the relationship between potato damage volume and the impact acceleration peak, impact velocity peak, and impact displacement peak of the sieve rod. Under the test conditions of sieve surface inclination, the kinematic characteristics parameters of the sieve rod can be employed to predict the damage volume of potatoes, as they show a positive correlation. Specifically, as the impact acceleration peak, impact velocity peak, or impact displacement peak of the sieve rod increases, the potato damage volume also increases.

Table 4. Model summary table

Model summary	S	R^2 (%)	R^2 (%)	
			Adjust	Prediction
Impact acceleration peak of sieve rod (*a*)	46.8921	98.29	97.43	92.58
Impact velocity peak of sieve rod (*v*)	38.2489	98.86	98.29	95.34
Impact displacement peak of sieve rod (*s*)	65.7791	96.63	94.94	79.21

4. CONCLUSIONS

This study utilized a potato drop test platform to conduct single-factor drop tests on potatoes. It investigated the influence of the mandatory vibrations caused by potato drop collisions under different test factors on the kinematic characteristics parameters of the sieve rod. It also examined the effect of the mandatory vibrations of the sieve rod on potato damage volume under different test factors. Furthermore, the correlation between the kinematic characteristics parameters of the sieve rod and potato damage volume was analysed. The primary research conclusions are outlined as follows:

1. The kinematic characteristic parameters of the sieve rod exhibit a notable regularity in response to the impact of the dropped potatoes. Increasing the drop height leads to an increase in the peak acceleration, peak velocity, and peak displacement of the sieve rod, while increasing the potato mass results in a decrease in these peaks. Additionally, an initial increase followed by a subsequent decrease is observed in these peaks as the inclination of the sieve surface increases. Furthermore, the impact acceleration peak, velocity peak, and displacement peak of the sieve rod caused by the potato drop vary depending on the axial positions of the drop, with the sequence of the three parameters being x-axis direction < y-axis direction < z-axis direction.

Table 5. Variance analysis of potato damage volume and the kinematic characteristics parameters of the sieve rod

Variance analysis	Source	Freedom	Adjusted sum of squared		F value	P value
			Deviations	Deviations after averaging		
Impact acceleration peak of sieve rod (*a*)	Regression	1	252378	252378	114.78	0.009
	a	1	252378	252378	114.78	0.009
	Errors	2	4398	2199		
	Total	3	256776			
Impact velocity peak of sieve rod (*v*)	Regression	1	253850	253850	173.52	0.006
	v	1	253850	253850	173.52	0.006
	Errors	2	2926	1463		
	Total	3	256776			
Impact displacement peak of sieve rod (*s*)	Regression	1	248122	248122	57.34	0.017
	s	1	248122	248122	57.34	0.017
	Errors	2	8654	4327		
	Total	3	256776			

With regard to the different potato varieties, the impact acceleration peak, velocity peak, and displacement peak of the sieve rod show the following order: Jizhangshu 12 > Holland 15 > Holland 14 > Svante > Xuechuanhong.

2. The regularity of variation in potato damage volume under different test conditions exhibits a notable pattern, as follows: increasing the drop height and potato weight leads to an increase in the volume of potato damage. Concerning the inclination of the sieve surface, the volume of potato damage initially increases and subsequently decreases, with the maximum damage volume occurring at an inclination of 7.7° and the minimum damage volume occurring at an inclination of 21.1°. Furthermore, the volume of potato damage is greatest when it is dropped vertically along the x-axis direction, followed by the y-axis direction, and the z-axis direction yields the least damage volume. In terms of different potato varieties, the damage volume follows the order of Holland 15 > Svante > Jizangshu 12 > Holland 14 > Xuechuanhong.

3. The correlation between potato damage volume and the kinematic characteristics parameters of the sieve rod under different test conditions was investigated. The results reveal that, with varying drop heights and sieve surface inclinations, the potato damage volume is positively correlated with the impact acceleration peak, velocity peak, and displacement peak of the sieve rod. Conversely, under different potato masses and axial positions of the potato in the vertical drop, there is a negative correlation between the volume of potato damage and the impact acceleration peak, velocity peak, and displacement peak of the sieve rod, although it is not statistically significant. In terms of the different potato varieties tested, there is no correlation observed between the potato damage volume and the impact acceleration peak, velocity peak, and displacement peak of the sieve rod.

4. The regression equation provides an accurate reflection of the relationship between the volume of potato damage and the impact acceleration peak, impact velocity peak, and impact displacement peak of the sieve rod. The kinematic characteristics of the sieve rod can be used to predict the volume of potato damage under the test conditions of the sieve surface inclination, and there is a positive correlation between the two.

In summary, the research findings above confirm the importance of investigating the kinematic characteristics of the separation sieve rod and the pattern of changes in potato damage volume after the potato drops onto it during the mechanical harvesting process. These results could potentially provide a data basis for analysing the underlying causes of potato damage.

Conflict of interest: The authors declare no conflict of interest.

5. REFERENCES

Alatise M.B. and Hancke G.P., 2017. Pose estimation of a mobile robot based on fusion of IMU data and vision data using an extended Kalman filter. Sensors, 17(10), 2164, https://doi.org/10.3390/s17102164

Baritelle A., Hyde G., Thornton R., and Bajema R., 2000. A classification system for impact-related defects in potato tubers. Am. J. Potato Res., 77, 143-148, https://doi.org/10.1007/BF02853938

Blahovec J., 2005. Impact induced mechanical damage of Agria potato tubers. Res. Agric. Engin., 51(2), 39-43, https://doi.org/10.17221/4900-RAE

Caglayan N., Oral O., Celik H.K., Cinar R., Rodrigues L.C. D.A., Rennie A.E.W., and Akinci I., 2018. Determination of time dependent stress distribution on a potato tuber during drop case. J. Food Process Eng., 41(7), e12869, https://doi.org/10.1111/jfpe.12869

Celik H.K., Cinar R., Yilmaz D., Ulmeanu M.E., Rennie A.E., and Akinci I., 2019. Mechanical collision simulation of potato tubers. J. Food Process Eng., 42(5), e13078, https://doi.org/10.1111/jfpe.13078

Chiputula J., 2009. Evaluating mechanical damage of fresh potato during harvesting and postharvest handling. University of Florida.

Feng B., 2018. Study on physical characteristics and damage of potato tubers at harvesting stage. Gansu Agricultural University.

Feng L., 2004. The performance study of the potato digger sieving system. Hebei Agricultural University.

Feng B., Cheng X.B., Sun W., Shi L.R., Sun B.G., Zhang T., and Wu J.M., 2017. Determination of restitution coefficient of potato tubers collision in harvest and analysis of its influence factors TCSAE, 33(13), 50-57.

Feng B., Sun W., Sun B.G., Zhang T., Wu J.M., and Shi L.R., 2019. A study on dropping impact characteristics and damage regularity of potato tubers during harvest. J. Vib. Shock, 38(24), 267-273, https://doi.org/10.13465/j.cnki.jvs.2019.24.037

Gancarz M., 2018. At harvest prediction of the susceptibility of potato varieties to blackspot after impact over long-term storage. Postharvest Biol.Technol., 142, 93-98, https://doi.org/10.1016/j.postharvbio.2018.01.009

Gao Z.H., 2021. Investigation of the dropping damage and the kinematics characteristics of potatoes. Inner Mongolia Agricultural University, https://doi.org/10.27229/d.cnki.gnmnu.2021.001056

Gao Y., Song C., Rao X., and Ying Y., 2018. Image processing-aided FEA for monitoring dynamic response of potato tubers to impact loading. Comput. Electron. Agric., 151, 21-30, https://doi.org/10.1016/j.compag. 2018.05.027

Geyer M.O., Praeger U., König C., Graf A., Truppel I., Schlüter O., and Herold B., 2009. Measuring behavior of an acceleration measuring unit implanted in potatoes. Trans. ASABE, 52(4), 1267-1274, https://doi.org/10.13031/2013.27770

Guo S.L., Wang W.B., Li M., Chen S.J., and Li J.H., 2016. Research on the test of potato mechanism and finite element analysis for crash (in Chinese). Mach. Des. Manuf. Eng., (01), 56-59, https://doi.org/10.3969/j.issn.2095-509X.2016.01.012

Hendricks R.L., Olsen N., Thornton M.K., and Hatzenbuehler P., 2022. Susceptibility of potato cultivars to blackspot and shatter bruise at three impact heights. Am. J. Potato Res., 99(5-6), 358-368, https://doi.org/10.1007/s12230-022-09887-y

Hesen J.C., 1960. Mechanical damage to potatoes II. Europ. Potato J., 3, 209-228, https://doi.org/10.1007/BF02365802

Hesen J.C. and Kroesbergen E., 1960. Mechanical damage to potatoes I. Europ. Potato J., 3, 30-46, https://doi.org/10.1007/BF02366080

Huang T., Wu B., Li L., Zuo T.L., and Xie F.P., 2022. Construction of impact mechanics model and experimental study on impact damage of potato tuber. INMATEH - Agric. Eng., 139-149, https://doi.org/10.35633/inmateh-66-14

Hu B., 2018. Study on potato dropping damage mechanism and damage-proof device. Xihua University.

Hussein Z., Fawole O.A., and Opara U.O., 2020. Bruise damage of pomegranate during long-term cold storage: Susceptibility to bruising and changes in textural properties of fruit. Int. J. Fruit Sci., 20(2), S211-S230, https://doi.org/10.1080/15538362.2019.1709602

Ito M., Sakai K., Hata S., and Takai M., 1994. Technical notes: Damage to the surface of potatoes from collision. Trans. ASAE, 37(5), 1431-1433, https://doi.org/10.13031/2013.28224

Kang J., Li T., Wang D., Zhang J.L., Sun W., Zhang F.W., and Wu J.M., 2013. Analysis and reflection on mechanical damage in potato harvesting (in Chinese). Agric. Machinery, 10, 137-139, https://doi.org/10.16167/j.cnki.1000-9868.2013.10.019

Liu B., Zhang D.X., and Li J., 2009. Mechanism analyses and countermeasures on the main problems of potato harvester. J. Agr. Mech. Res., (01), 14-16+28

Lu J.Q., Tian Z.E., Yang Y., Shang Q.Q., and Wu J., 2015. Design and experiment of 4U2A double-row potato digger. TCSAE, 31(6), 17-24.

Luo Q.Y., Gao M.J., Liu Z.X., Lu H.W., and Zhang Y., 2021a. Analysis of the development situation of China's potato industry in 2020 (in Chinese). Heilongjiang Sci. Technol. Press, 15-18, https://doi.org/10.26914/c.cnkihy.2021.013153

Luo Q.Y., Gao M.J., Zhang Y., and Lun Y.Q., 2021b. Comparative analysis on potato industry between China and other countries. Chin. J. Agric. Res. Regional Plann., 7, 1-8.

Pathare P.B. and Al-Dairi M., 2021. Bruise damage and quality changes in impact-bruised, stored tomatoes. Horticulturae, 7(5), 113, https://doi.org/10.3390/horticulturae7050113

Peters R., 1996. Damage of potato tubers, a review. Potato Res., 39(4), 479-484, https://doi.org/10.1007/BF02358463

Pfau T., Witte T.H., and Wilson A.M., 2005. A method for deriving displacement data during cyclical movement using an inertial sensor. J. Exp. Biol., 208(13), 2503-2514, https://doi.org/10.1242/jeb.01658

Popov V.L., 2011. Principles and applications of contact mechanics and tribology. Tsinghua University Press, Beijing, China

Schneider F., Part F., Göbel C., Langen N., Gerhards C., Kraus G.F., and Ritter G., 2019. A methodological approach for the on-site quantification of food losses in primary production: Austrian and German case studies using the example of potato harvest. Waste Manag., 86, 106-113, https://doi.org/10.1016/j.wasman.2019.01.020

Shao Y., Liu Y., Xuan G., Shi Y., Li Q., and Hu Z., 2022. Detection and analysis of sweet potato defects based on hyperspectral imaging technology. Infrared Phys. Technol., 127, 104403, https://doi.org/10.1016/j.infrared.2022.104403

Shen Y., Hu H.B., Xu G.T., Chen Q., Zhou M.G., and Zhang C., 2023. Accumulative damage characteristics of potato. Sci. Technol. Eng., 23(2), 536-541.

Shi L.R., Wu J.M., Zhao W.Y., Sun W., Wang D., Li H., and Liu Q.W., 2012. Design and experiment on potato digger of disc ce-grate type. TCSAE, 28(24), 15-21.

Stropek Z. and Gołacki K., 2013. The effect of drop height on bruising of selected apple varieties. Postharvest Biol.Technol., 85, 167-172, https://doi.org/10.1016/j.postharvbio.2013.06.002

Stropek Z. and Gołacki K., 2022. Studies concerning the response of potatoes to impact. Int. Agrophys., 36(2), 115-122, https://doi.org/10.31545/intagr/148097

Thomson G.E. and Lopresti J.P., 2018. Size and temperature characteristics of potatoes help predict injury following impact collisions. N. Z. J. Crop Hortic. Sci., 46(1), 1-17, https://doi.org/10.1080/01140671.2017.1334669

Wei Z.C., Li H.W., Sun C.Z., Li X.Q., Liu W.Z., Su G.L., and Wang F.M., 2018. Improvement of potato harvester with two segment of vibration and wave separation. TCSAE, 34(12), 42-52.

Wu J.M., Li H., Sun W., Huang X.P., and Zhang W., 2011. Experiment on poke finger wheel type potato digger (in Chinese). Trans. CSAE, 27(7), 173-177, https://doi.org/10.3969/j.issn.1002-6819.2011.07.030

Xie S.S., Wang C.G., and Deng W.G., 2020. Collision damage test and acceleration characteristic analysis of potato (in Chinese). J. China Agric. Univ., 25(1), 163-169, https://doi.org/10.11841/j.issn.1007-4333.2020.01.18

Xie S.S., 2017. Theoretical and experimental investigations of potato soil separation on swing separation sieve. Inner Mongolia Agricultural University.

Yang R.B., Yang H.G., Shang S.Q., Xu P.X., Cui G.P., and Liu L.H., 2016. Design and test of poking roller shoving type potato harvester (in Chinese). Trans. Chin. Soc. Agric. Mach., 47(7), 119-126, https://doi.org/10.6041/j.issn.1000-1298.2016.07.017

Yeşiloğlu C.E., 2022a. Determination of bruise preventing capacity of the cushioning material in persimmon fruit under pendulum impact test. J. Food Process Eng., 45(12), https://doi.org/10.1111/jfpe.14162

Yeşiloğlu C.E., and Öztekin Y.B., 2022b. Prediction of bruise in peach with impact energy. J. Food Process Eng., 45(3), https://doi.org/10.1111/jfpe.13969

Zhang H., Wu J.M., Sun W., Luo T.E., Wang D., and Zhang J.L., 2014. The design and experiment of 4UM-640 vibration potato digger. Agric. Res. Arid Areas, 32(2), 264-268.

Zhang J.H., 2008. Assessment technology and genetic analysis for tuber browning in potato (*Solanum tuberosum*). Chinese Academy of Agricultural Sciences.

Zhang S., Fu J., Zhang R., Zhang Y., and Yuan H., 2022. Experimental study on the mechanical properties of friction, collision and compression of tiger nut tubers. Agriculture, 12(1), 65, https://doi.org/10.3390/agriculture12010065

Zhao M.Q., Zhao S.J., She D.Q., Liu H.T., Liu W.Z., and Wang Z., 2007. Combined separation type potato digger. J. Agric. Mech. Res., 29(4), 69-72.