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ORIGINAL ARTICLE

Effect of Asafoetida Extract Solution on Red Apple Quality with a Focus on the Mechanical Properties of Peduncle, Rate Fruit Drop and Orchard Pest Control

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Abstract

This study evaluated the effect of asafoetida extract solution on the physical and mechanical properties of red apples, focusing on the apple peduncle in Dargaz County, Razavi Khorasan Province, Iran. Using a solution prepared from 50 kg of asafoetida and 250 l of water, we conducted compression, penetration, and tensile tests. The results revealed that the asafoetida treatment improved mechanical properties compared to other treatments. Specifically, it achieved the highest force in compression tests for cylindrical samples and the highest force and deformation in penetration tests with both spherical and cylindrical probes. The asafoetida treatment also resulted in the lowest fruit drop rate (4.28%) and significantly reduced apple pests, outperforming chemical pesticides in effectiveness. These findings suggest that asafoetida extract is a promising alternative to chemical pesticides for enhancing apple quality and reducing pest infestations.

Keywords Compression tests · Drop · Fruit · Plant · Pest management · Physical properties

Introduction

In recent years, the growing population and increased food demand have highlighted the need for methods to boost both the quantity and quality of agricultural production. The World Food Organization projects that the global population will exceed 8.5 billion by 2030, necessitating a 50% increase in food production to meet this demand (FAO 2021). This situation calls for a reassessment of traditional agricultural practices, focusing on enhancing efficiency and output per unit area.

In Iran, apples are a significant horticultural product with notable economic and nutritional value. With an area of 247,000 hectares dedicated to apple cultivation and an annual production of 4,224,000 tons, Iran ranks eighth globally in apple production (Ministry of Jihad Agriculture of Iran 2021; FAO 2021). Apples are rich in polyphenols, which contribute to health benefits such as reducing heart disease and atherosclerosis (Sardabi et al. 2013; Mousavi et al. 2024). Despite their excellent storage capacity, about one-third of the annual apple production is lost due to management issues during production and harvesting, resulting in increased imports (Kader 2013).

Enhancing the physical and mechanical properties of agricultural products is crucial in addressing these challenges (Brillante et al. 2015; Liu et al. 2023). Organic and environmentally friendly inputs are increasingly recognized for their role in improving these properties. Historically, the use of plant extracts as pesticides began in 1850 with nicotine from tobacco (Craeker and Simon 2002). Plant compounds, known as secondary metabolites, offer a sustainable alternative to synthetic pesticides, reducing adverse effects on humans and the environment (Enan 2001; Alaniz et al. 2014; Mousavi et al. 2024). These compounds can improve product quality and extend storage duration (Zamani 2013; Mousavi et al. 2024). Asafoetida, a medicinal plant with significant secondary metabolites, is particularly noteworthy (Delavar et al. 2014; Amalraj and Gopi 2017).

Globally, asafoetida is widely used in medicine, but its consumption in Iran is limited, with about 70 t exported annually, primarily to India (Zare Karizi et al. 2011; Delavar et al. 2014). Available as resin or extract, asafoetida has been used historically to repel pests and improve stomach health (Poushidehru 2017). The plant's leaves have anthelmintic, anti-flatulent, and diaphoretic properties, while

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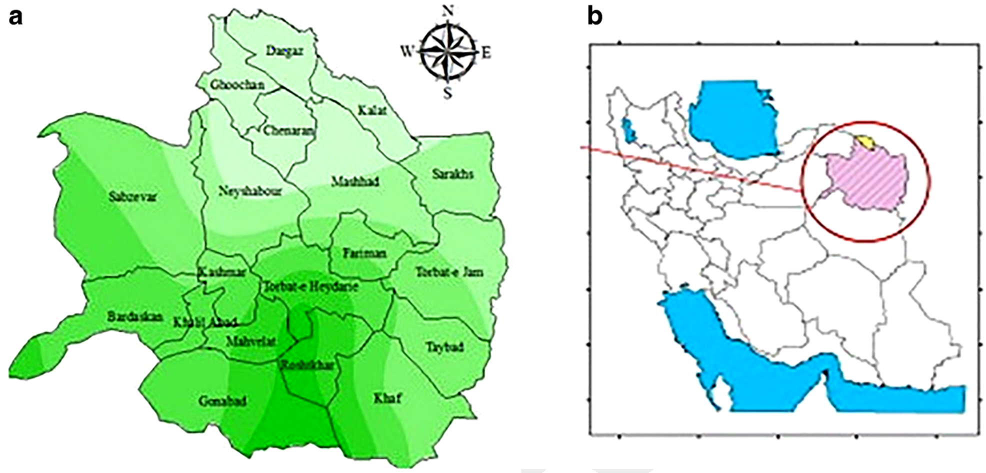

Fig. 1 **a** Location of the Razavi Khorasan Province, Iran; **b** Location of the Dargaz County, Razavi Khorasan Province

its stem is used as a tonic for the liver and brain (Sammbamurty 2006; Feng et al. 2010).

Studies have demonstrated the efficacy of asafoetida extracts against pests. For instance, the methanolic extract of asafoetida leaves was found to be significantly more effective against *Dacus ciliatus* larvae compared to mastic extract (Zamani 2013). Asafoetida also showed substantial antibacterial effects against *Streptococcus mutans* and *Streptococcus sanguis* (Iranshahy and Iranshahi 2011; Fani et al. 2015). Research has shown that extracts of asafoetida and *Vitex negundo* Linn. are environmentally friendly and cost-effective for insect control, though their effects may be slower compared to chemical pesticides (Lal and Verma 2005; Iranshahy and Iranshahi 2011; Amalraj and Gopi 2017).

Given the high potential of asafoetida as a secondary metabolite with beneficial properties for agricultural products, this study aims to evaluate its impact on the mechanical properties of red apples. The focus is on determining how spraying with asafoetida affects the physical characteristics of apples, which are essential for improving their quality and storage.

Materials and Methods

As part of investigating the effect of asafoetida extract on the mechanical properties of apples, this section describes the research process, including the study area, data collection, and the procedure for conducting experiments, and the comparison of results with conventional methods. The details of each stage are outlined below.

Study Area

This research was conducted in the Razavi Khorasan Province, Iran, specifically in the Dargaz County. This province, with 14,856 hectares and an annual apple production of 220,194 tons (Ministry of Jihad Agriculture of Iran 2021), is one of the most important apple-producing regions in the country. Dargaz County is located in the northeast of Iran and the north of Razavi Khorasan Province (Fig. 1). With an area of approximately 4194 km^2, it covers about 1.25% of the province's total area and has a population of over 80,000 people. The county has 530 hectares of fertile apple orchards, primarily concentrated in the mountainous Miankuh district in the northeast of Dargaz, situated 50 km away from the county center and comprising 22 rural settlements. The Dargaz plain is situated among the low and smooth slopes of the Hezar Masjed Mountains. The prominent agricultural products of this county include rice, pistachios, watermelons, melons, apples, raisins, oregano, and cacti.

Selection Criteria for Sample Orchards

The selection of sample orchards for this study was based on several key criteria to ensure the representativeness and reliability of the results. Firstly, orchards were chosen from diverse geographical locations within the region to account for variations in climate and soil conditions that could impact apple quality. Secondly, only orchards growing the specific apple variety used in the study were selected to maintain consistency in the experimental conditions. Thirdly, the orchards needed to meet minimum size requirements to ensure a sufficient number of samples for statistical analysis and to accurately reflect commercial production practices. Finally, orchards with a history of similar pest pressures and management practices were chosen to standardize the conditions under which the asafoetida extract was applied. This approach ensured that the study results are applicable to a broad range of commercial apple production scenarios.

Fig. 2 Collecting the green leaves of asafoetida plant

Steps to Prepare Asafoetida Plant Extract

First, the green leaves of the asafoetida plant were collected on the 13th of May 2022 and packed in 15-kg nylon bags. The collection was carried out in the rural areas of the study region, specifically in the village of Darbandi Sufi in the Miankuh district of Dargaz city (Fig. 2).

Due to the fact that one of the common methods for extracting gum from medicinal plants for foliar spraying on trees and agricultural products is boiling (Patil et al. 2015; Saeidy et al. 2018), this study also utilized this method to extract the gum from the asafoetida plant. For this purpose, all parts of the asafoetida plant were finely ground. To prepare the extract, a mixture of 50 kg of asafoetida and 2501 of water was used. This mixture was boiled until the volume of water reduced to about one-third of the initial volume, and the asafoetida gum was completely dissolved in the water (Fig. 3).

Fig. 3 Boiling the green leaves of the asafoetida plant

Fig. 4 Refining the boiled asafoetida solution

After cooling, the resulting solution was filtered through three stages, and the amount of pure extract obtained from this method was 1001. Subsequently, the prepared extract for use in this study was transferred to 20-liter containers and stored in the warehouse (Fig. 4).

Steps of the Experiments

To investigate the effect of the solution prepared from the asafoetida plant on the studied variables, experiments were conducted randomly in three apple orchards in the study area. For this purpose, in orchard (A), apple trees were treated with the asafoetida extract solution, in orchard (B),

Table 1 The steps of spraying apple trees with asafoetida extract and common chemical pesticide

Date	Orchard (A)	Orchard (B)	Objectives
2022-05-21	401 Asafoetida extract*	Luna fungicide	Control of apple scab
2022-06-03	301 Asafoetida extract	Biscaya insecticide	Control of codling moth
2022-03-23	151 Asafoetida extract	Domark fungicide	Control of *Panonychus ulmi* (Koch)
2022-04-06	151 Asafoetida extract	Nutrient solution	Improvement of apple fruit properties

*The amounts mentioned in the table were similar in concentration, mixed with 5001 of water, and then applied

Table 2 Details of the tests conducted to evaluate the mechanical properties of apples

Loading method	Sample conditions	Loading tool	Loading rate (mm/min)
Compression test	Cylindrical sample	Parallel plates	15
Compression test	Whole fruit	Parallel plates	15
Penetration test	Whole fruit	Spherical probe	30
Penetration test	Flat cylindrical sample	Spherical probe	15
Penetration test	Flat cylindrical sample	Cylindrical probe	10
Tensile test	Peel	–	5
Tensile test	Apple stalk	–	0.9

apple trees were treated with common chemical pesticides, and in orchard (C), apple trees were left untreated with any solution. The application of the solutions occurred in four stages in the region, and the details are provided in Table 1. Subsequently, at harvest time, the fruits harvested from these trees were transferred to the laboratory for conducting experiments related to the examination of mechanical properties.

Measuring the Mechanical Properties of Red Apples

In order to investigate the mechanical properties of apples, 30 fruit samples were collected from each orchard and transferred to the laboratory for the necessary tests. To determine the mechanical properties of apples, compression and penetration tests were performed on fruit samples. Additionally, a tensile test was conducted to determine the force required to separate the apple stalk from the fruit, and the tensile strength of the apple peel was measured. The details are presented in Table 2. For this purpose, an Instron universal testing machine (Model H5KS, Tinius Olsen Company) with a movable jaw equipped with a 5-kg load cell with an accuracy of 0.01 N was used (Fig. 5).

Determination of the Effect of Asafoetida Extract on the Studied Pests

To investigate the effect of spraying asafoetida extract solution on the pests of apple trees, 3 days before harvesting the crop (October 1, 2022), all fallen fruits under each tree

Fig. 5 The Instron universal testing machine

Fig. 6 Collection of fallen fruits for the investigation of the effect of asafoetida plant extract spraying on apple tree pests

were collected. The number of infested and healthy fruits was then counted and recorded. During the harvest, the total number of fruits on each tree was counted and documented (Fig. 6). Subsequently, using the Schneided–Orelli formula (Eqs. 1 and 2), the percentage of the pesticide's effect was calculated (Barzanti et al. 2023; Barbero et al. 2024):

$$HF = \frac{A}{B} \times 100 \tag{1}$$

$$EP = \frac{b-k}{100-k} \times 100 \tag{2}$$

where HF represents the percentage of healthy fruits, A and B indicate the counts of healthy fruits and the total number of fruits in one sample (plot), respectively. EP is the percentage of the effect of the applied pesticide, while b and k represent the percentage of healthy fruits in the pesticide-treated and control (water-treated) groups, respectively.

Statistical Methods

In this study, descriptive statistics were employed to analyze the data collected from the experimental trials. The statistical analysis included the calculation of means and standard deviations to summarize the central tendencies and variability of the measured parameters. Data visualization was performed using Excel 2019 to create graphs and charts, which facilitated the interpretation of trends and comparisons across different treatments. Additionally, the analysis involved performing five replicates for each treatment to ensure the reliability and accuracy of the results. This approach allowed for a comprehensive understanding of the effects of asafoetida extract on apple quality, including mechanical properties, fruit drop rate, and pest control.

Results and Discussion

The Mechanical Properties of Apples Under Compression Testing

Compression Test with Parallel Plates for the Whole Sample

The average results and standard deviation of the force and corresponding deformation values obtained from the compression test for the whole fruit are presented in Table 3 for three treatments: spraying with asafoetida extract, conventional chemical pesticides, and the control sample. According to the results, the treatment with chemical pesticides showed a force of 867.60 ± 56.03 N under applied compressive force, which was higher than the treatment with asafoetida spray (821.15 ± 114.88 N) and the control sample (712.28 ± 78.26 N). This difference between the two sprayed treatments was not significant, but there was a significant difference between each sprayed treatment and the control. The average deformation under the influence of this force was also 17.43 mm higher in the chemical pesticide treatment compared to the other two treatments. The deformation value in the treatment with asafoetida extract was 14.66 mm, which was significantly lower than the other two treatments. As is clear from the background of the research, many studies have been conducted on measuring the mechanical properties of apples (Tscheuschner and Doan 1988; Ragni and Berardinelli 2001; Costa 2016; Golombek and Blanke 2022), but no study was found that investigated the mechanical properties of this product and the effect of foliar spraying using extracts and compounds of plants such as asafoetida.

Compression Test with Parallel Plates for the Cylindrical Samples

The results of the compression test for cylindrical samples in three treatment groups, including spraying with asafoetida solution, conventional chemical spraying, and the control sample, are presented in Table 4. The examination of the force–deformation diagram for the cylindrical sample of the fruit showed that the average force of the fruit under the treatment of spraying with asafoetida

Table 3 Mean and standard deviation of force for whole samples under compression test with parallel plates in treatments of spraying with chemical pesticides, spraying with asafoetida extract, and the control sample

Experimental treatments	Mean		Standard deviation	
	Force (N)	Deformation (mm)	Force (N)	Deformation (mm)
Spraying with chemical pesticides	867.60a	17.43a	56.03	1.44
Spraying with asafoetida extract	821.15a	14.66b	114.88	2.22
Control sample	712.28b	16.44a	78.26	1.63

(a) and (b) denote significant differences between the groups at a 5% significance level

Table 4 Mean and standard deviation of force for cylindrical samples under compression test with parallel plates in treatments of spraying with chemical pesticides, spraying with asafoetida extract, and the control sample

Experimental treatments	Mean		Standard deviation	
	Force (N)	Deformation (mm)	Force (N)	Deformation (mm)
Spraying with chemical pesticides	201.38a	7.60a	77.70	0.61
Spraying with asafoetida extract	226.95b	6.64b	51.46	0.62
Control sample	171.38c	6.73b	37.28	0.65

(a), (b) and (c) denote significant differences between the groups at a 5% significance level

was 226.95 ± 51.46 N compared to the treatment of conventional chemical spraying and the control sample with values of 201.38 ± 7.60 and 171.38 ± 37.28 N, respectively, with a significant difference. The force magnitude in the treatment with conventional chemical spraying, although significantly different from the control sample, also had a significant difference with the treatment sprayed with asafoetida at a 5% significance level. The corresponding strain for this force in the treatment with conventional chemical spraying was 7.60 mm, with a significantly greater difference than both the treatment sprayed with asafoetida and the control sample.

Mechanical Properties of Apples Under Penetration Testing

Penetration Test with a Spherical Probe for the Whole Sample

Table 5 presents the results of the penetration test with a spherical probe on the whole fruit sample in three treatments: spraying with asafoetida solution, conventional chemical pesticide application, and the control sample. The highest average force under penetration was observed in the treatment with asafoetida spray, with 40.04 ± 2.40 N. This variable for the treatment with chemical pesticides and the control sample was 39.68 ± 8.44 N and 33.71 ± 4.13 N, respectively. The results indicated that the average force in both sprayed treatments was significantly higher than that in the control, and although the average breaking force in the treatment with asafoetida spray was higher than that of chemical pesticides, the difference between them was not significant. The highest amount of deformation was also determined in the treatment with asafoetida solution, with a value of 6.37 mm.

Penetration Test with a Spherical Probe for the Whole Sample

The results of the maximum force under penetration and the corresponding deformation are presented in Table 6. Accordingly, the treatment of spraying with asafoetida solution exhibited the highest force among the three studied treatments. In other words, the average breaking force in the three treatments of spraying with asafoetida, spraying with chemical pesticides, and the control sample was determined as 41.12 ± 7.29 N, 32.64 ± 5.32 N, and 27.47 ± 3.81 N, respectively. According to Table 6, the force under penetration in the treatment of spraying with asafoetida solution was significantly higher than that in the other two treatments. The corresponding deformation to the force in the treatment of spraying with asafoetida was 7.44 mm greater than that in the other two treatments, and this difference was statistically significant at a 5% level.

In line with the results of this study regarding the comparison of various theories for measuring the mechanical properties of apples, Shirvani et al. (2014) determined the elastomechanical properties of three varieties of apples on a macroscopic scale with the help of existing elasticity theories such as Hertz's theory, Boussinesq's theory, and Hooke's law. The findings indicated the practical usability of Hertz's theory, which demonstrated better prediction accuracy. In contrast, Boussinesq's theory exhibited a significant difference in the predicted modulus of elasticity compared to other theories and values reported in some publications. While Hooke's theory enables the identification

Table 5 Mean and standard deviation of force under penetration test with spherical probe on whole fruit samples in the treatments of spraying with chemical pesticides, spraying with asafoetida solution, and control Sample

Experimental treatments	Mean		Standard deviation	
	Force (N)	Deformation (mm)	Force (N)	Deformation (mm)
Spraying with chemical pesticides	39.68a	4.79b	8.44	1.27
Spraying with asafoetida extract	40.04a	6.37a	2.40	1.22
Control sample	33.71b	6.30a	4.13	1.74

(a) and (b) denote significant differences between the groups at a 5% significance level

Table 6 Mean and standard deviation of force under penetration test with spherical probe on cylindrical fruit samples in the treatments of spraying with chemical pesticides, spraying with asafoetida solution, and control Sample

Experimental treatments	Mean		Standard deviation	
	Force (N)	Deformation (mm)	Force (N)	Deformation (mm)
Spraying with chemical pesticides	32.64b	5.87b	5.32	0.67
Spraying with asafoetida extract	41.12a	7.44a	7.29	1.73
Control sample	27.47c	5.39b	3.81	0.77

(a), (b) and (c) denote significant differences between the groups at a 5% significance level

of a bio-yield point on its force-deformation curve, Hertz's theory was recommended as the most suitable method due to its ease of application on a cylindrical sample of apples and its closer agreement with reality.

Mechanical Properties of Apples Under Tensile Testing

Tensile Testing of Fruit Peel

Table 7 presents the average values and standard deviations of the force and deformation under the tensile test of the apple peel. Accordingly, the treatment of spraying with asafoetida solution with a value of 23.51 ± 4.59 N showed a higher average breaking force compared to the treatments of spraying with chemical pesticides and the control sample, with 18.89 ± 1.76 and 16.15 ± 2.23 N, respectively. The difference between all three treatments was statistically significant at a 5% significance level. Moreover, the evaluation of the average length change corresponding to the breaking force in the examined treatments indicated that the treatment of spraying with asafoetida solution, with a value of 2.80 ± 0.58, had the highest elongation compared to the other evaluated treatments.

Peduncle Tensile Test (Separation of the Apple from the Peduncle)

The results of the examination of the average values and standard deviations of the force under the tensile test of the peduncle are presented in Table 8. Based on this, although the treatment of spraying with chemical pesticides had the highest average force at 154.46 ± 18.91 N, there was no significant difference compared to the treatment of spraying with asafoetida solution, which had a force of 152.42 ± 16.72 N. Additionally, the results indicated a significant difference in force between the treatments of spraying with chemical pesticides and asafoetida compared to the control treatment.

Measuring the Effect of Asafoetida Solution on the Rate of Apple Drop

In order to evaluate the effect of asafoetida extract spraying on the rate of apple drop, the number of apples dropped on the ground in three treatments—asafoetida spraying, the use of chemical pesticides, and the control sample—was investigated, and the results are presented in Table 9 and Fig. 7. Based on the results shown in Fig. 7, the asafoetida extract spraying treatment, with 4.28%, had the lowest percentage of drop compared to the chemical pesticide spraying treatment and the control sample, with significant differences at the 5% level. In the two treatments of chemical pesticide spraying and the control sample, the amount of drop was 6.76% and 11.37%, respectively, with the difference between them also significant at the 5% level. In general, the results showed that in controlling the apple drop pest, although both methods of asafoetida spraying and the use of chemical pesticides had a significant effect, the effect of asafoetida spraying was significantly greater than that of chemical pesticide spraying.

In this study, the percentage of the effects of chemical pesticides and asafoetida solution on apple drop was investigated, according to Fig. 8. To this end, the amount of apple drop from the spraying treatments was compared with the amount of apple drop from the control treatment, and the re-

Table 7 Mean and standard deviation of force in the peel tensile test for the treatment of spraying with chemical pesticides, spraying with asafoetida solution, and control sample

Experimental treatments	Mean		Standard deviation	
	Force (N)	Deformation (mm)	Force (N)	Deformation (mm)
Spraying with chemical pesticides	18.89b	3.67b	1.76	0.27
Spraying with asafoetida extract	23.51a	2.80a	4.59	0.58
Control sample	16.15c	3.28b	2.23	0.78

(a), (b) and (c) denote significant differences between the groups at a 5% significance level

Table 8 Mean and standard deviation of force in the tensile test of the peduncle under the treatments of spraying with chemical pesticides, spraying with asafoetida solution, and the control sample

Experimental treatments	Force (N)	
	Mean	Standard deviation
Spraying with chemical pesticides	154.46a	18.91
Spraying with asafoetida extract	152.42a	16.72
Control sample	116.63b	10.84

(a) and (b) denote significant differences between the groups at a 5% significance level

Table 9 Investigation of the effects of chemical pesticides and asafoetida solution on apple drop

Treatment	Total number of apples on the tree	Number of dropped apples
Spraying with asafoetida extract	1033	47
Spraying with common chemical pesticide	1172	77
Untreated (control sample)	825	112

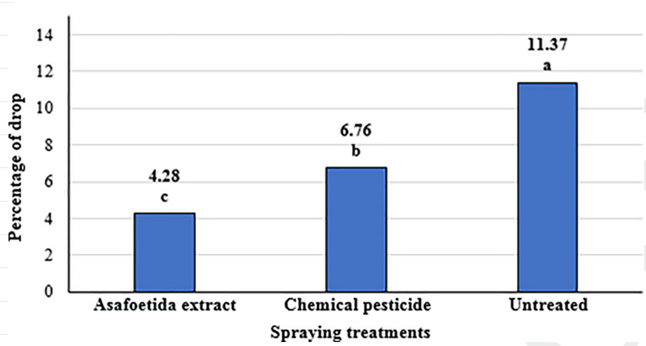

Fig. 7 Investigation of the effects of chemical pesticides and asafoetida solution on red apple drop

sults were presented as a percentage of the amount of drop reduction in comparison with the control treatment. According to the results of Fig. 8, foliar spraying with asafoetida solution and chemical pesticides were effective in reducing apple drop by 59.71% and 41.03%, respectively, with the effect of asafoetida solution being significantly greater than that of chemical pesticides.

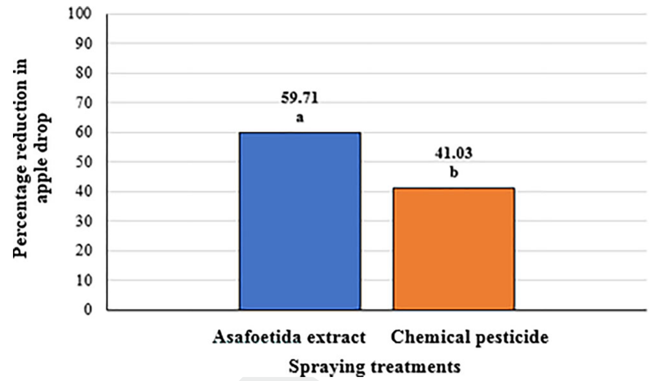

Fig. 8 Percentage of the effects of chemical pesticides and asafoetida solution on apple drop

In line with the results of this study regarding the comparison of various theories for measuring the mechanical properties of apples, Arseneault and Cline (2016) reviewed apple preharvest fruit drop and practices for horticultural management.

Measuring the Effect of Asafoetida Solution on Apple Codling Moth and *Panonychus ulmi* (Koch)

To evaluate the effect of asafoetida extract spraying on reducing the apple codling moth and *Panonychus ulmi* (Koch) pests of red apple, the number of infested apples in three treatments of asafoetida spraying, chemical pesticides use, and the control sample were investigated, and the results are presented in Table 10 and Figs. 9 and 10. In the evaluation of the reduction of apple codling moth, according to Fig. 9, the percentage of damage of this pest in three treatments of asafoetida spraying, chemical pesticides use, and the control sample was obtained as 1.02, 3.38, and 4.69%, respectively, with the effect of asafoetida foliar spraying being significantly greater than the other two treatments.

In a study to reduce the *Panonychus ulmi* (Koch) pest, according to Fig. 10, the percentage of damage caused by this pest was 2.49%, 2.15%, and 4.83% for the asafoetida solution, chemical pesticide, and control treatment, respectively. The effect of asafoetida solution and chemical pesticide was significantly greater than the control treatment. According to the results of this figure, although the percentage of infestation of this pest was lower in the chemical pesticide

Table 10 Investigating the effect of chemical pesticides and asafoetida solution on apple pests

Treatment	All apples on the tree	Number of apples damaged by codling moth	Number of apples damaged by *Panonychus ulmi* (Koch)
Spraying with asafoetida extract	1033	12	26
Spraying with common chemical pesticide	1172	40	25
Untreated (control sample)	825	51	44

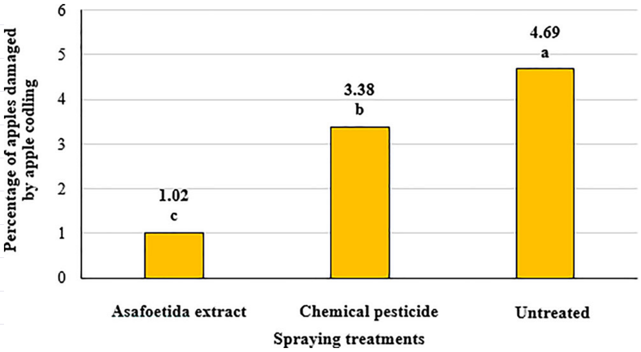

Fig. 9 Investigating the effect of chemical pesticides and asafoetida solution on reducing the red apple codling pest

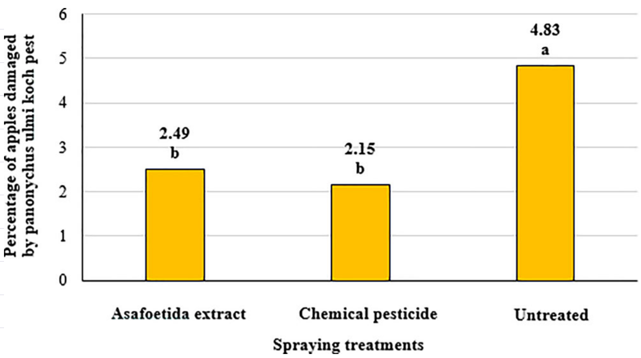

Fig. 10 Investigating the effect of chemical pesticides and asafoetida solution on reducing the *Panonychus ulmi* (Koch) pest (The means with common letters based on the Duncan test at a significance level of 5% do not have statistically significant differences)

treatment than in the asafoetida solution treatment, the difference between them was not significant.

Furthermore, in this study, according to Fig. 11, the percentage of the effect of chemical pesticides and asafoetida extract on the reduction of infestation by apple codling moth and *Panonychus ulmi* (Koch) was examined. For this purpose, the level of infestation in the apple treatments sprayed with asafoetida extract and chemical pesticides was compared to the infestation level in the control treatment, and the results were presented as a percentage of pest reduction compared to the control treatment. In the examination of the percentage reduction of apple codling moth infestation, spraying with asafoetida extract and chemical pesticides achieved significant reductions of 77.72% and 28.65% in pest infestation, respectively, with the asafoetida extract showing a significantly greater effect compared to chemical pesticides. In the examination of the percentage reduction of *Panonychus ulmi* (Koch) infestation, spraying with asafoetida extract and chemical pesticides resulted in reductions of 47.65% and 54.70%, respectively.

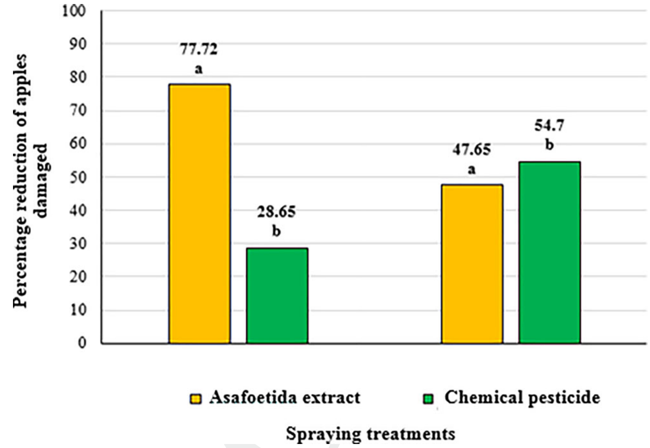

Fig. 11 Investigating the effect of chemical pesticides and asafoetida solution on reducing the infestation of *Panonychus ulmi* (Koch) in red apple trees. (The means with common letters based on the Duncan test at a significance level of 5% do not have statistically significant differences)

Conclusion

In this study conducted in Dargaz County, Razavi Khorasan Province, the impact of asafoetida solution on the mechanical properties of red apples and its effectiveness against apple pests was evaluated. The results showed that apples treated with asafoetida had superior mechanical properties, including higher breaking force and deformation resistance, compared to those treated with chemical pesticides. Asafoetida treatment also significantly reduced apple drop rates, with a drop percentage of 4.28% compared to 6.76% for pesticides and 11.37% for the control. Furthermore, asafoetida solution proved more effective in controlling apple codling moth and *Panonychus ulmi* (Koch), showing a lower pest damage percentage than both chemical pesticides and the control. Overall, asafoetida demonstrated greater efficacy in enhancing apple quality and controlling pests than traditional chemical treatments.

Discussion of Limitations

While our study provides valuable insights into the effect of asafoetida extract solution on the mechanical properties of red apple peduncles, fruit drop rates, and pest control, there are several limitations that should be considered. Firstly, the study was conducted under controlled conditions in a specific orchard, which may not fully represent the variability found in different environmental conditions or apple varieties. Additionally, the duration of the study was limited to a single growing season, and long-term effects of asafoetida extract on apple quality and pest management remain unexplored. The concentration of the asafoetida extract solution used in our experiments was based on preliminary trials, and further research is needed to determine the optimal concentration for different apple varieties and environmental conditions. Moreover, while we assessed mechanical properties, fruit drop rates, and pest control, other factors such as the impact on fruit flavor, nutritional content, and postharvest storage quality were not investigated. Addressing these limitations in future research could provide a more comprehensive understanding of the benefits and potential applications of asafoetida extract in apple cultivation.

Future Research

Building on the findings of this study, several avenues for future research could be explored to further understand the impact of asafoetida extract solutions on apple quality. Firstly, conducting longitudinal studies across multiple growing seasons and diverse environmental conditions would help assess the long-term effects and broader applicability of asafoetida extract. Investigating different concentrations and formulations of asafoetida extract could also optimize its efficacy for various apple varieties and growing conditions. Additionally, research into the effects of asafoetida extract on other quality attributes, such as flavor, nutritional content, and postharvest storage life, would provide a more comprehensive understanding of its benefits. Exploring the mechanism of action of asafoetida extract in pest control and its potential interactions with other pest management strategies could enhance integrated pest management approaches. Finally, studies on the economic feasibility and practical implementation of asafoetida extract solutions in commercial apple orchards would be valuable for assessing their viability as a sustainable agricultural practice.

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Conflict of interest M.R. Esmaeili, R. Khodabakhshian and M. Khojastehpour declare that they have no competing interests.

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