INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
23–0281/2024/32–2–154–162
DOI: 10.17957/IJAB/15.2188
http://www.fspublishers.org

Full Length Article

Mapping of Postharvest Structure Damage and Management of Fungal Bio-Deterioration in Pear Fruits

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Received 26 July 2023; Accepted 07 November 2023; Published 22 June 2024

Abstract

This study employed geostatistics and Geographic Information System (GIS) to analyze spatial data pertaining to pear (*Pyrus communis* L.) fruit structural damage in two districts of Gilgit-Baltistan, Pakistan, aiming to map variations in damage. The histogram results revealed that the Gilgit district exhibited a greater degree of structural damage compared to the Nagar district. Nugget/sill ratios of 0.164, 0.219 and 0.476 in the Gilgit district suggested high to moderate spatial dependence, while ratios of 0.88, 0.19, and 0.05 in the Nagar district indicated moderate to severe spatial dependence. Moreover, in a controlled experiment, pear fruits were dropped from a height of 140 cm onto different surfaces. The results demonstrated that the metal surface significantly impacted structural damage compared to wooden surfaces. Additionally, the present study evaluated the *in vitro* bio-deterioration of healthy pear fruits using four fungal species and two plant extracts. Among these, *Artemisia absinthium* showed high efficacy, and a statistically significant difference in mycelial reduction at $P \leq 0.01$ was observed. The findings of this study will be beneficial to the pear fruit packaging industry in mitigating bio-deterioration, structural deterioration, and other physiological and fungal damage.

Keywords: Bio-deterioration; Fungal contamination; Geostatistical analysis; Pear fruit

Introduction

The pear (*Pyrus communis* L.) is a common fruit found in temperate regions and has its origin and domestication in two distinct locations, China and Asia Minor, extending to the Middle East (Abdollahi 2021). It ranks as the fifth most extensively cultivated fruit worldwide, with significant production occurring in China, Europe and the United States (Civolani *et al.* 2023). Several pear cultivars are grown on over 2.4 thousand hectares in Pakistan, yielding around 30.7 thousand tonnes of fruit each year (Qadir *et al.* 2022). In Gilgit-Baltistan, the yearly pear production amounts to 396 tons, with a primary focus on cultivation in high-altitude areas like Hunza-Nagar district, Bagrote, Haramosh valleys of Gilgit and various valleys within the Baltistan region (Hussain *et al.* 2022).

The fruits are highly prone to physical damage during harvesting, classification, storage and marketing (Hussein *et al.* 2020), leading to bio-deterioration caused by pathogenic microbes especially fungi (Javed *et al.* 2017; Khan and Javaid 2022). Fresh fruits are vulnerable to mechanical damage during harvesting, packaging, and transportation, significantly impacting their quality (Li and Thomas 2014). Fruits may undergo physical damage during harvest, and the severity of the injury relies on the fruit's physical characteristics, the height at which it fell, its speed, the type of surface impact and its size (Hussein *et al.* 2020; Mahanti *et al.* 2022). Pears undergo physiological and biochemical changes between harvesting and consumption, determining their final quality characteristics. Some of these changes render the fruit desirable for consumption, while others lead to economic losses (Singh and Sharma 2018). The detrimental changes include water loss due to excessive transpiration, excessive softening, post-harvest physiological disorders, and pathological decay (Calvo *et al.* 2015; Almeida *et al.* 2016). From a safety point of view, herbs and spices are among the essential targets in the search for naturally occurring antibacterial, antifungal and antioxidant compounds (Ferdosi *et al.* 2023; Javaid *et al.* 2023). Leaf and fruit extract, seed powder, and oil exhibit antifungal and antibacterial properties (Najma *et al.* 2012; Jabeen *et al.* 2022). Plants have been a valuable source of various

To cite this paper: Hussain A, M Muhammad, W Akram (2024). Mapping of postharvest structure damage and management of fungal bio-deterioration in pear fruits. *Intl J Agric Biol* 32:154–162

medicinal compounds, particularly those with significant interest in their antimicrobial properties (Javaid *et al.* 2022; Khan and Javaid 2023). As bacterial resistance continues to rise, the discovery of new anti-microbial compounds becomes crucial (Maria *et al*. 2021). The anti-microbial activity of medicinal herbs varies, impacting different microorganisms in distinct ways. The composition of biologically active compounds in medicinal plants can differ significantly based on the plant species, soil type and their interactions with microbes (Zhao *et al.* 2011; Morsy 2014).

As the demand for fresh and processed fruits and vegetables continues to rise, there is a significant need for large-scale planting and mechanical handling, including harvesting, packaging and transportation of fruits. However, fleshy fruits are highly vulnerable to mechanical damage (Thole *et al.* 2020). Hence, the data generated from this study would be valuable for postharvest technology advancements and consumer awareness. Understanding the physicochemical properties of the fruit is essential for the development of equipment for harvesting, sorting, cleaning, and packaging processes (Ozturk *et al*. 2009). This study aimed to investigate the structural damage to pear fruits caused by fruit dropping on various surfaces and evaluate the effectiveness of a plant extract against fungal diseases.

Materials and Methods

A comprehensive survey was conducted to analyze post-harvest structural damage (occurrence (%), damage length, and depth (cm) of pear fruit (Fig. 1) in two districts of Gilgit-Baltistan, Pakistan. During harvesting, a total of 52 locations, 26 from each district of the pear fruit production farm, were considered. Within each farm, 80 fruits were chosen at random, and the percentage of structural damage was calculated using the formula:

$$\mathrm{SDI} = \frac{\mathrm{SDF}}{\mathrm{TNF}} \times 100$$

SDI = Structural damage incidence; SDF: Structural damage fruit; TNF: Total number of fruits.

A steel ruler and knife were used to determine the length and depth (cm) of structural damage to pear fruit.

Geostatistical analysis and spatial variability mapping

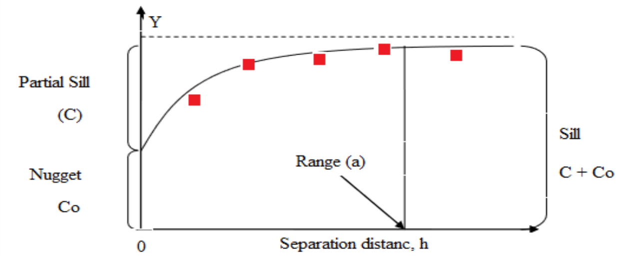
The geographic distribution mapping of structural damage to pear fruit in terms of incidence, length and depth of damage was described using geostatistical analysis. For the geostatistical analysis and mapping of structural deterioration, ArcGIS 10.4 was applied. As explained by Nikravesh *et al.* (2003) inverse distance weight (IDW) technique was employed to interpolate the values of unsampled places. For IDW the following formula was used (Hussain *et al.* 2021; Akram *et al.* 2023):

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i)$$

where $\boldsymbol{Z(s_i)}$ = the measured value at the ith location; $\boldsymbol{\lambda_i}$ = an unknown weight for the measured value at the ith location; $\boldsymbol{s_0}$ = the prediction location; $\boldsymbol{N}$ = the number of measured values.

Semivariogram can be fitted with the spherical model presented by (Webster and Oliver 2007; Olea 2012; Akram *et al.* 2023).

$$\text{Spherical} = \gamma(h) = \begin{cases} C_0 + C\left(\dfrac{3h}{2ac} - \dfrac{1}{2}\left(\dfrac{h}{a}\right)^3\right) & 0 \le h < a \\ & h \ge a, \end{cases}$$



Spatial dependence (SDP%) was calculated as described by Biondi *et al.* (1994) and Akram *et al*. (2023) are given by the expression:

$$\text{SDP Spherical\%} = \frac{\text{C1}}{\text{C0} + \text{C1}} \times 100$$

For the spherical semivariogram: SDP Spherical (%); ≤ 2 5% weak spatial dependence; 25% < SPD (%) ≤ 75% moderate spatial dependence and ≥ 75% strong spatial dependence. The spatial analyst function of ArcGIS software was used to prepare maps as described by (Hussain *et al.* 2016; Akram *et al.* 2023).

Artificial damage assessment

For the artificial damage assessment, fresh pear fruit was used. During the field survey, thirty-five fruits of similar size and without structural damage were collected. These samples were refrigerated at a particular temperature for a day prior to use in the study. Five pear fruits were dropped from a 140 cm height in each treatment (foam, cardboard, metal, wood, stone mix mud, grass and soil). The impacted pear fruits were labeled and kept in the refrigerator for 96 h. The steel ruler was used to measure the length and depth of the damage in centimeters.

Bio-deterioration and management test

Samples of pears were taken from the study location. These fruits underwent a washing process using distilled water, followed by treatment with a 0.5% sodium hypochlorite solution and rinsing with distilled water. Subsequently, the fruits were air-dried at room temperature (25–28°C). For inoculation, a spore suspension containing 106 conidia mL^{-1} of a pathogen isolated from apple and tomato was used. The inoculated fruits were then kept at room temperature (25°C) for 120 min. The inoculation process involved dipping a 1.5

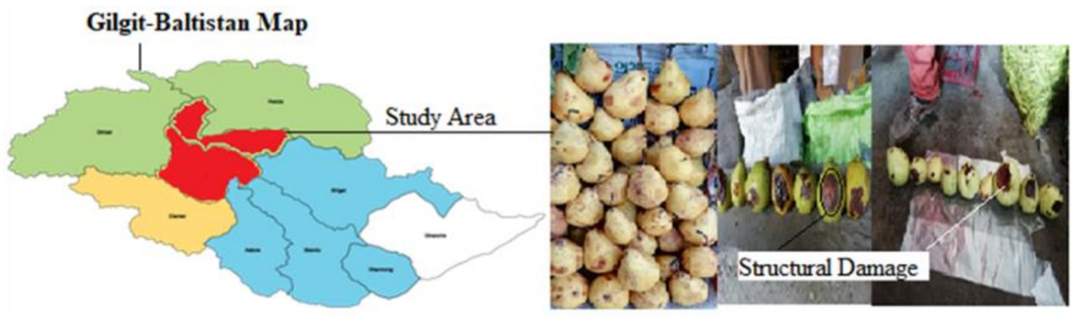


Fig. 1: Map of the study area

mm wide, 2 mm long steel rod into the spore suspension and puncturing each fruit with a rod (Tripathi and Dubey 2004).

The fruit was submerged in the solutions for a duration of 60 s at 25°C. After air-drying, the fruits were immersed in solutions of known concentrations of EOs (expressed as a percentage of volume) for 2–3 min before being air-dried again under normal conditions. Following treatment, the fruits were placed in sealed polythene bags and stored for 20 days at 51°C, with a relative humidity of 80.5 percent. The results of the effect of essential oils on several decay pathogens were outlined as follows: (Sivakumar *et al.* 2002).

Results

Damage incidence (DI), length and depth of pear fruit in district Gilgit

Damage incidence (%), damage length (DL cm) and damage depth (DD cm) revealed variations across different areas within District Gilgit. DI ranged from 3.56 to 13.75%, with DL (cm) covering from 0.58 to 5.22 cm and DD ranging from 0.44 to 2.96 cm. In District Gilgit, the mean values for these parameters were measured as follows: DL % at 8.41, DL at 2.86 cm and DD at 1.73 cm. To assess the distribution characteristics, skewness and kurtosis were calculated for fruit damage incidence (0.27, 1.89), damage length (0.07, 2.24) and damage depth (0.003, 1.60) (Fig. 2). The data are normal frequency distribution of the skewness and kurtosis values are close to 0 and 3, as described by Carvalho *et al.* (2002). Table 1 presents the semivariogram parameters derived from the spherical model when applied to selected parameters related to pear fruit damage. The nugget-to-sill variance ratio is an indicator of spatial correlation strength, with values of 25, 25–75 and 75% denoting strong, moderate, and weak spatial correlation, respectively. For the incidence percent, damage length, and depth of pear fruit structural damage, the nugget/sill ratios were determined to be 0.164, 0.219 and 0.476, respectively, indicating strong to moderate spatial dependence. It means that 83.56, 78.02 and 52.34% of the total variation in pear fruit damage incidence %, damage length and depth can be explained by spatial variation. However, the remaining 16.44, 21.98 and 47.66% were attributable to unexplained sources of variations. The interpolation maps of pear fruit damage incidence %, length and depth (cm) allowed us to understand the spatial distribution pattern in the study site visually. Map of damage incidence indicates that 34.61% area is infected at the range of 3.56–6.92, 15.38% area is affected at the range of 6.92–8.59 followed by 26.92 to 23.07% is affected as well. In the northeastern district of Gilgit, a relatively high damage incidence percent, damage length and depth were observed, indicating red color (Fig. 3). The trend study of pear fruit damage in District Gilgit is depicted in Fig. 4. This data plot and curve demonstrated how data changes over time. The damage incidence percent and length show a gradual increase from east to west and north to south, respectively. On the other hand, the damage depth exhibits a low-to-high pattern from north to south and high-to-low with a slight increase from east to west across the research region.

Damage incidence % length and depth (cm) of pear fruit in district Nagar

Fig. 5 presents the statistics for pear fruit damage incidence (DI %), damage length (DL) and damage depth (DD) in District Nagar. The mean and standard deviation (SD) values for DI%, DL and DD were 10.57 ± 5.32, 2.39 ± 0.93 and 1.75 ± 0.94, respectively. Furthermore, the skewness and kurtosis values for DI % (0.49; 2.11), DL (0.22; 1.63) and DD (0.28; 2.06) are in close proximity to 0 and 3, indicating that the data conforms to a normal frequency distribution. However, Table 2 displays the results obtained by employing a spherical model to ascertain the spatial dependencies of selected pear fruit properties. The findings reveal a nugget-to-sill ratio of 0.88, 0.19 and 0.05, indicating a moderate to highly significant spatial dependence in the Nagar district. This implies that geographical variation contributes to 11.77, 80.54 and 94.1% of the total variation in pear fruit damage incidence (DI), damage length (DL), and damage depth (DD), respectively, while the remaining 88.23, 19.46 and 5.90% can be attributed to unexplained sources of variation. Fig. 6 illustrates the regional distribution of pear fruit damage. The Geographic Information System (GIS) was employed to develop maps representing the spatial distribution of

Table 1: Geostatistical parameters for pear fruit damage incidence, length, and depth in District Gilgit

Parameters Gilgit valley	Model	Range	N (C_o)	PS (C)	S (C_o + C)	N/S ratio	SDI (%)	Spatial dependence
D. Incidence	Spherical	82.24	0.123	0.625	0.748	0.164	16.44	Strong
D. Length	Spherical	37.05	0.273	0.969	1.242	0.219	21.98	Strong
D. Depth	Spherical	42.44	0.337	0.370	0.707	0.476	47.66	Moderate

N: nugget; PS: partial sill; Sill; N/S ratio = [N/ (N+PS)]

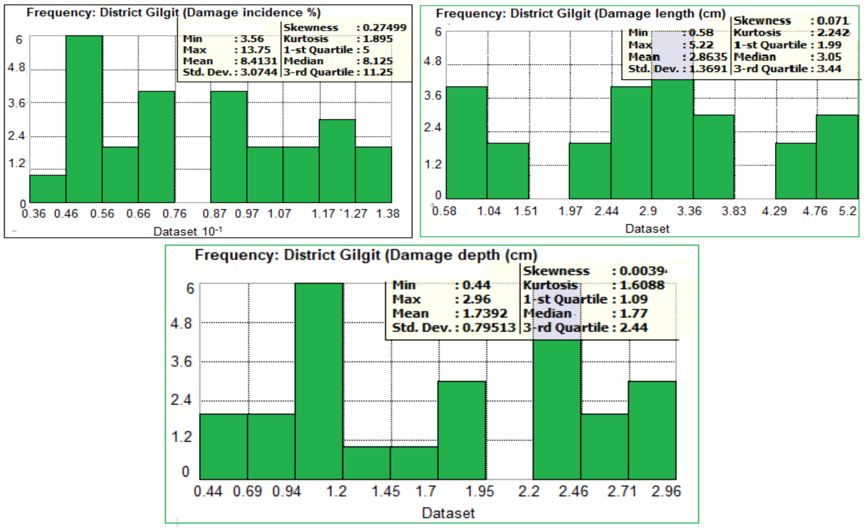


Fig. 2: Histogram of pear fruit damage incidence (%), length (cm), and depth (cm) in District Gilgit

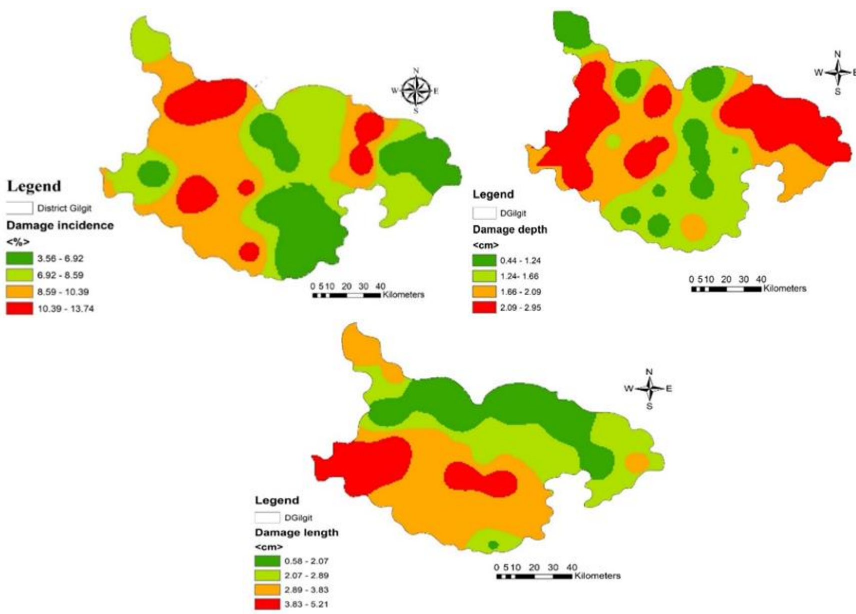


Fig. 3: Spatial distribution map of damage incidence (%), length (cm), and depth (cm) of pear fruit in Gilgit Valley

structural damage in pear fruits. Damage length and depth were represented by red shades, followed by yellow shades and areas with very high damage incidence percent displayed shades of deep green in the fields.

The damage incidence percentage showed a trend of being low to high from north to south and high to low from west to east. Similarly, the damage length exhibited a trend of being high to low from north to south and east to west. In terms of damage depth, it ranged from low to high from north to south and then low, while from east to west, it ranged from high to low and then high (Fig. 7) according to the pear fruit damage incidence trend study.

Table 2: Geostatistical parameters for pear fruit damage incidence, length, and depth in Nagar District

Parameters Nagar valley	Model	Range	N (C_o)	PS (C)	S (C_o + C)	N/S ratio	SDI (%)	Spatial dependence
D. Incidence	Spherical	58.66	0.15	0.02	0.17	0.88	88.23	Weak
D. Length	Spherical	31.28	0.20	0.93	1.13	0.19	19.46	Strong
D. Depth	Spherical	31.75	0.062	0.99	1.05	0.05	5.90	Strong

N: nugget; PS: partial sill; Sill; N/S ratio = [N/ (N+PS)]

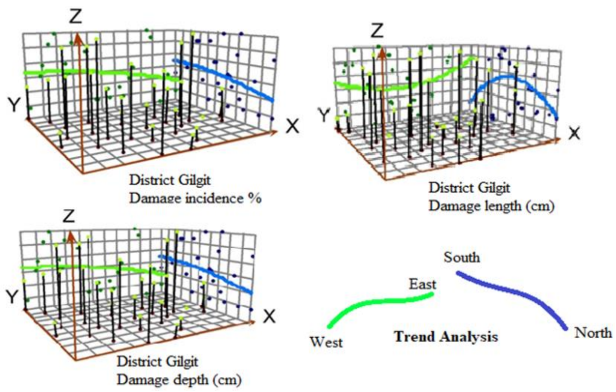


Fig. 4: Trend analysis of pear fruit damage incidence, length and depth in District Gilgit

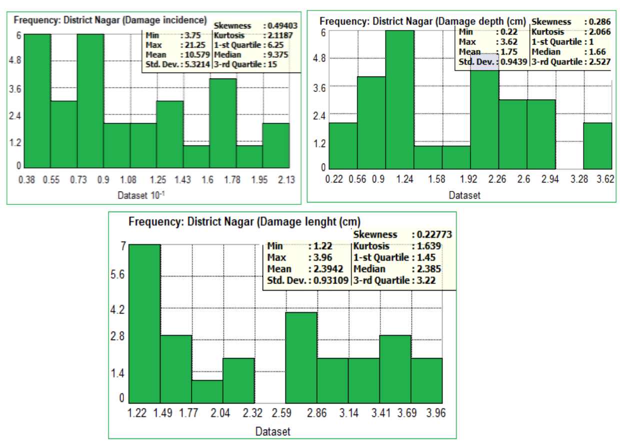


Fig. 5: Histogram of pear fruit damage incidence (%), length (cm) and depth (cm) in District Nagar

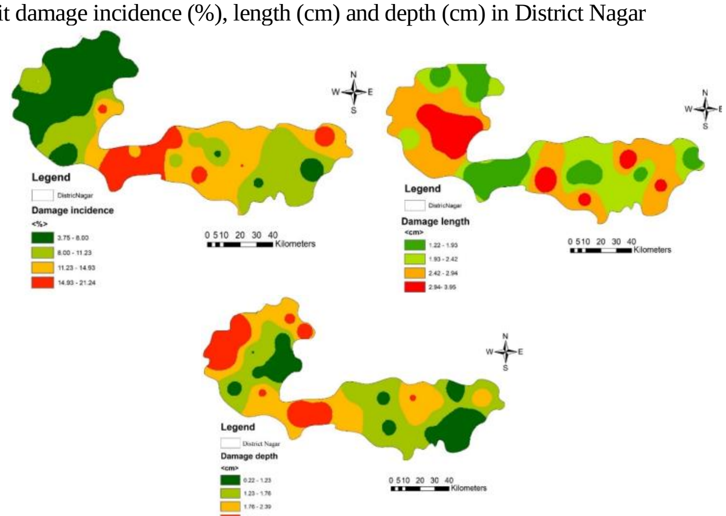


Fig. 6: Spatial distribution map of damage incidence (%), length (cm), and depth (cm) of pear fruit in District Nagar

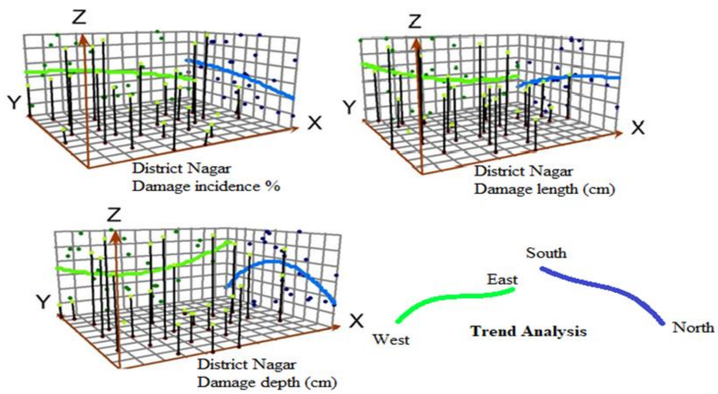


Fig. 7: Trend analysis of pear fruit damage incidence, length and depth in District Nagar

Impact assessment and bio-deterioration of pear fruits

Fresh pear fruits were subjected to an impact damage evaluation to determine the impacts of fruit samples dropped from a height of 160 cm against different sources. The average impact in terms of damage length (1.6-2.8 cm) and damage depth (0.4 to 1.4 cm) was recorded which is shown in Fig. 8. Metal, wood and stone mix soil had the most significant impact on both aspects of fruit damage, whereas foam and cardboard had the least. Four fungus species were used to evaluate *in vitro* bio-deterioration of healthy pear fruit. According to the findings, *Botrytis cinerea* deteriorates the most, followed by *Mucor* and *Rhizopus* species. Two plant extracts *Artemisia absinthium* and *A. annua* were tested on wounded pear fruits being inoculated with the mycelial disc of each fungal isolate shown in (Table 3). The result designated that both plants extract statistically significant differences in mycelia reduction at $P < 0.01$.

Discussion

One of the primary global challenges we are facing today is the dilemma of providing adequate food and ensuring sustainable food production for a steadily increasing population. According to the Food and Agriculture Organization (FAO), it is projected that agricultural production must grow by 70% by the year 2050 in order to provide nourishment for the world's population, which is expected to surpass nine billion people. On the flip side, substantial quantities of food are lost each year due to spoilage and infestations as it moves from the farm to the table across the globe, as highlighted by the FAO in 2011. In certain developing nations, where adverse weather conditions, a shortage of skilled labor, and inadequate infrastructure all play a part in this wastage, it can regularly amount to 40–50%, as reported by Spore in 2011. Similarly, Pakistan is grappling with a comparable predicament and has incurred substantial food losses. Gilgit-Baltistan, Pakistan, is endowed with an abundance of delicious, top-quality fruits and vegetables, which serve as the mainstays for revenue and long-term food security in the mountainous region. Nevertheless, in Gilgit-Baltistan, the wastage of fruits and vegetables, from pre-harvest to post-harvest, stands at a staggering 50–70%, resulting in an average overall wastage of 50%, as reported by the Agricultural Statistics of Gilgit-Baltistan in 2017. Physiological, pathological, mechanical, and environmental factors contribute to fruit and vegetable post-harvest losses. Careless handling during harvesting, packing, transit and storage are among the causes of structural/ mechanical damage. The focus of this research was to map postharvest structural damage, trend analysis, and assess the bio-deterioration of pear fruit. The findings spatially distributed pear fruits' structural damage (incidence %, damage length and depth) in both regions. The outcomes of the trend analysis of the study also showed that different locations are affected. Pear fruit is harvested in both regions by catching or shaking it, inflicting structural damage. Fruit structural damage, caused by inappropriate harvesting, handling, and transportation techniques, is a widespread and serious issue that has significant economic consequences. This damage primarily results in unfavorable changes in organoleptic qualities, such as skin and flesh browning and off-flavors, and internal breakdown reactions (Castillo 1992).

Structural or mechanical damage is a form of stress that occurs during fruit harvesting and leads to physiological and morphological alterations, affecting the quality of the fruit product. Apart from mechanical stress, other types of stress induced by biological and environmental factors can also contribute to a decline in fruit quality (Aliasgarian *et al.* 2015). The effect of structural damage was studied by dropping pear fruits on various surfaces. The largest damage was caused by dropped fruits on metal surfaces, followed by wood. Researchers came up with comparable findings (Ruiz-Altisent 1991; Idah *et al.* 2007). Along with structural damage, pear fungal contamination also appears during field, harvesting, storage, and transportation. Fruits also contain high nutrients and sugar, and low pH makes them exceptionally desirable to fungal decay (Abdullah *et al.*

Table 3: *In-vitro* pear fruit infection length (mm) and reduction (mm) by using plant extracts

		Reduction of infection (mm)	
Fungal Species	Bio-deterioration (mm)	*Artemisia absinthium*	*Artemisia annua*
Rhizopus sp.	6.80 ± 0.13^{C}	5.03 ± 0.08^{D}	4.91 ± 0.092^{C}
Penicillium sp.	5.92 ± 0.09^{D}	5.54 ± 0.12^{C}	5.03 ± 0.075^{C}
Botrytis cinerea	8.24 ± 0.05^{A}	7.01 ± 0.13^{A}	6.26 ± 0.070^{A}
Mucor sp.	7.44 ± 0.06^{B}	6.46 ± 0.19^{B}	6.003 ± 0.092^{B}

The values represent the means of three replications and ±SD; the means with different letters/letter is statistically significant at $P < 0.05$

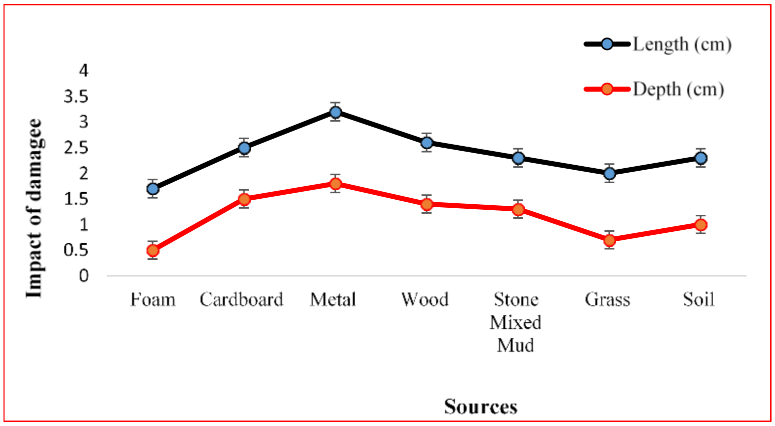


Fig. 8: Artificial damage assessment of pear fruit

2016). Four fungus species were employed to assess the magnitude of bio-deterioration of healthy pear fruits in this study. *Botrytis cinerea* was the most prevalent isolate, followed by *Mucor* sp. and *Penicillium* sp., with *Penicillium* sp. being the least common. The growth of filamentous fungi in perishable fruits, like pears, poses a significant quality issue, leading to substantial financial losses. *Penicillium expansum*, *Botrytis cinerea* and *Mucor piriformis* are the three most common fungi responsible for pear fruit losses during the post-harvest period (Sutton *et al.* 2014). These species typically infect wounds and senescent fruits and are commonly present in the air and surrounding environments, such as soil and water (Mari *et al.* 2003). *Rhizopus*-induced soft rot occurs during various stages, including the sale, transportation, shelf display in markets, and storage (Pitt and Hocking 2009).

During pear fruit harvesting, fall wounds are vulnerable to infection by *Botrytis cinerea*, a fungus that thrives in temperatures ranging from 0 to 10°C. Infections seldom occur at temperatures above 25°C, but when they do, the fungus can grow in a temperature range of 0 to 35°C. *Penicillium* species cause blue mold, mainly entering the fruit through spores, resulting in fluid lesions that rapidly spread to healthy tissues at room temperature. *Rhizopus* soft rot is another potentially hazardous infection that occurs due to pear tissue injury, typically during transportation, storage, and sale (Pitt and Hocking 2009). *Mucor* rot manifests around the stem or calyx end of the fruit and puncture wounds in the skin and stem-end *mucor* rot is also observable on pears (Sardella *et al.* 2016). The rotting area appears light brown to brown, with a distinct edge. Controlling these pathogens remains challenging, necessitating multiple fungicide applications. While chemical control is effective and efficient, it may also contribute to disease resistance, leave chemical residues in the fruit, lead to phytotoxicity in other organisms, or result in other environmental and public health concerns (Leroux *et al.* 2002; Adebayo *et al.* 2013).

There is a growing interest in bio-ecology studies of this pathogen and a global trend is emerging to explore innovative alternatives to synthetic fungicides in order to address these concerns and adhere to food safety regulations. Plant extracts offer one such alternative approach, characterized by their non-toxicity to humans and the environment, selectivity, biodegradable nature, and diverse chemical composition containing a wide range of secondary metabolites. Plant extracts derived from *Artemisia* species, including *A. absinthium*, *A. annua* and *A. vulgaris*, have demonstrated antimicrobial activity (Ivanescu *et al.* 2010).

Conclusion

This study has been conducted for the first time to explore the spatial distribution of structural damage to pears, the effects of drops on various surfaces, and the effects of *in-vitro* bio-deterioration in two Gilgit-Baltistan regions of Pakistan. According to this research, structural damage to pear fruit is widespread in the field. This study's findings will be helpful to pear fruit growers in terms of structural damage management during picking, storage, and transportation, resulting in increased profitability and food security. This study's findings clearly show that plant extracts can prevent fungal diseases from bio-deterioration. In the future, these plant extracts could be helpful in the development of plant-based biopesticides and pear fruit coatings for a distant market.

Acknowledgment

The authors express their gratitude and extend a vote of thanks to the Faculty of Life Sciences, Department of Agriculture & Food Technology, Karakoram International University, for granting permission to utilize their facilities during the research.

Author Contributions

AH designed and investigated the research and supervised the finding of this work. MM and WA analyzed field data, isolated and maintained cultures of fungal isolates. WA assesses bio-deterioration management, plant extract preparation, and impact assessment. Finally, GIS was applied by AH and supervised manuscript preparation.

Conflict of Interest

The authors state that there are no conflicts of interest.

Data Availability

The data presented in this study will be made available upon a reasonable request to the corresponding author.

Ethics Approval

Not applicable to this paper.

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