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Comprehensive Survey of Pre- and Post-Harvest Disease Incidence, Severity and Distribution in Selected Underground Vegetables of Warangal District, Telangana, India

N. Shobha Rani and Sujatha Edla*

Department of Microbiology, Kakatiya University, Kakatiya University, Hanamakonda, Telangana, India

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Corresponding Author: **Sujatha Edla** | E-Mail: **(sujathaedla_1973@kakatiya.ac.in)**

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ABSTRACT

Pre and post-harvest diseases have been identified as serious constraints to the quality, shelf-life and economic value of underground vegetables. The present study was carried out with the objective of assessing the incidence, severity, spatial and seasonal distribution of fungal and bacterial diseases on carrot (Daucus carota L.), beetroot (Beta vulgaris L.), sweet potato (Ipomoea batatas L.) and elephant foot yam (Amorphophallus paeoniifolius) in Warangal district, Telangana state, India. Systematic surveys using field and market approach were conducted from May 2024 to April 2025 from eight sites selected randomly out of which four were major markets and the other four were adjacent cultivation fields. Five thousand seven hundred sixty (5,760) vegetables were collected consisting of 2,808 healthy and 2,952 diseased specimens. Maximum disease incidence (55.4 ± 3.7 %), disease severity (3.32 ± 0.34) and Percent Disease Index (PDI) (66.5 ± 4.1%) was observed in sweet potato, while the elephant foot yam showed minimum disease incidence (48.1 ± 2.9%) and PDI (56.0 ± 3.3%). In the case of all the studied crops, maximum disease incidence, disease severity score and PDI was observed as 51.3 ± 3.3%, 3.03 ± 0.30 and 60.5 ± 3.7%, respectively. Among the surveyed locations, maximum disease incidence (53.4 ± 3.6%) and PDI (64.6 ± 4.0%) were recorded in Warangal district. Incidence of disease increased from 43.2 ± 2.6% in May 2024 to 57.3 ± 3.5% in October 2024 and maximum monthly PDI (69.2 ± 4.3%) and disease severity (3.46 ± 0.34) were also observed in October. The maximum prevalence of disease symptoms were soft rot (20.73% [612 samples]), dry rot (14.16%), surface discoloration (11.42%) and black lesions (9.86%). The maximum disease features observed in this study included formation of lesions (82.4 ± 4.1%), dark brown to black colour of lesion (74.8 ± 3.6%) and softening of the tissues (65.9 ± 3.4%). GIS mapping showed Warangal and Hanumakonda as major disease spots, while Narsampet showed comparatively lower disease incidence. Environmental monitoring showed that high temperature, rainfall and relative humidity during monsoon and post-monsoon seasons correlated with maximum disease incidence and severity. In storage surveys of 120 respondents, 78.3% harvested manually, 56.7% had mechanical injuries, 52.5% had vegetables stored at 25-27°C, and 49.2% kept vegetables in market for 2-3 days.

Keywords: *Underground vegetables; pre-harvest diseases; post-harvest diseases; Disease incidence; Disease severity; Percent Disease Index; Seasonal variation; Storage practices.*

Introduction

India is one of the foremost nations when it comes to vegetable production, where underground/ root and tubers such as carrots, beetroot, sweet potatoes, and elephant foot yams form a significant part of its subsistence as well as commercial horticulture. Though India produces a large volume of underground vegetables, a considerable amount of the crop is lost due to diseases and improper handling procedures. The total postharvest loss due to disease infection and mishandling of Indian vegetable crops has been estimated to be 40-60%, accounting for losses both at the field, packaging and storage, and transportation stages [26]. The fact that underground vegetables are harvested along with the attached soil, have some sort of hidden injuries after lifting, and are stored in ambient conditions without refrigeration in Indian markets makes them highly prone to pathogenic fungi and bacteria which may infect the vegetables right from the field to the marketing stage [26,27].

Modern studies reveal that the problem of postharvest disease infection in fruits and vegetables is one of the current global issues as researchers attempt to identify the causative agents, understand the physiology behind the disease, and come up with non-chemical ways to fight diseases especially those affecting small-scale farmers [8,30]. As far as underground vegetables are concerned, there are several case studies illustrating the extent and variability of the problem. Bacterial soft rot caused by *Pectobacterium carotovorum* subsp. *carotovorum* is a major constraint in carrot production with disease incidence varying greatly between different growing districts; for instance, a survey of four districts in Tamil Nadu revealed incidences ranging from 16 to 67% according to the district [13]. Beetroot has been shown to suffer from leaf spot disease, whose incidence was 85% with a severity index greater than 2.7 after only 7 weeks from planting time in Jaffna peninsula of Sri Lanka and was associated with certain deficiencies in cultivation methods such as selection of wrong season and variety [21].

The storage roots of sweet potatoes are no exception to this either as a study of market samples indicated the presence of Fusarium, Aspergillus, and Rhizopus species causing surface rot, root rot, and soft rot in storage, out of which Fusarium oxysporum was the most prevalent pathogen [23]. Similarly, elephant foot yam has its own particular disease problems, namely collar rot caused by Sclerotium rolfsii is considered the most harmful disease of the crop with a capacity to destroy the whole crop in favorable conditions, and phytoplasma associated diseases causing corm yield reduction have been characterized in Indian populations of elephant foot yam [24,29].

The present study it can be seen that the issues of pre- and post-harvest diseases in underground vegetables have been extensively studied in individual cases of different crops and regions; yet, the existing information is scattered between countries, crops, and research methodologies, and therefore is not easy to compare. There is a lack of systematic survey data about the incidence, severity (Percent Disease Index), distribution, and post-harvest handling practices which cause the development of the diseases of underground vegetables in Telangana state and Warangal district. It is necessary to find a way to conduct the survey in order to be able to capture the diseases simultaneously in different crops in Warangal district. Thus, the present study is aimed at documenting systematically the incidence, severity, and distribution of the fungal and bacterial diseases in carrots, beetroot, sweet potatoes, and elephant foot yams, Warangal district markets and their supplying cultivation fields.

Methodology

Study Area

The survey was carried out in the Warangal district of the Telangana state of India, known for the production and marketing of underground vegetables. Market places such as Warangal, Hanumakonda, Kazipet, and Narsampet were taken into consideration as they are characterized by large volumes of trading as well as availability of fresh vegetables. In order to have knowledge regarding the extent of disease incidences, fields near these market places were considered for the study. The assessment of diseases in both market place and field helped to determine the prevalence of both fungal and bacterial diseases at pre-harvest and post-harvest stages.

Experimental Design

In this context, this particular study has been conducted using an annual field survey using the approach of randomized sampling design in order to determine the prevalence of diseases among selected underground vegetables during different harvesting seasons. Regular visits during different seasons have been performed in order to observe the prevalence of the diseases depending on the changing environment. This study has focused on four economically important vegetables, which include carrot (*Daucus carota L.*), beetroot (*Beta vulgaris L.*), sweet potato (*Ipomoea batatas L.*), and elephant foot yam (*Amorphophallus paeoniifolius*).

Selection of Survey Sites

Four sample sites were selected based on the criteria of vegetable production, market transactions, storage facilities, accessibility, and the importance of the sites in terms of the regional value chain of underground vegetables.

Sampling involved wholesale markets, retail markets, and their adjacent cultivation fields that supplied them in order to assess the occurrence of the disease incidences under pre-harvest and post-harvest conditions. The sample sites were chosen with the objective of representing adequately the main underground vegetables producing regions in the Warangal district. The geographic coordinates of each of the sample sites were recorded using a handheld GPS instrument while visiting the sites. The geographic information was then transferred to GIS software in order to plot maps for disease distribution. The information about disease incidence and severity recorded at each site was related to their geographic coordinates so as to carry out the spatial analysis of disease occurrences. The thematic maps were prepared for showing the distribution pattern of fungi and bacteria.

Survey Schedule

Field surveys were conducted on a monthly basis during the harvesting period to determine the prevalence of diseases in chosen underground vegetables. The field survey was done in the morning so that the incidence of freshly harvested crops could be determined. Three visits were made to each field survey site on a monthly basis in each planting season. This allowed for consistency in data collection and minimization of temporal variance.

Sample Collection

Samples of underground vegetables that showed signs of being healthy and diseased were collected from growing fields, wholesale markets, retail markets, and storage locations using aseptic sampling procedure. Each sample was collected using sterile gloves, wrapped in sterile polyethylene bags to avoid cross-contamination. The bags with the samples were marked with a code number for each sample, names of crops, sampling location, date, where the sample was collected (field, market or storage) and visible symptoms of the disease. After collecting the samples, they were placed in the insulated ice boxes along with frozen gel packs and taken to the Plant Pathology Laboratory. Upon arriving at the laboratory, the samples were stored at 4°C until processing, which occurred not later than 24 hours after collection.

Sampling Procedure

Randomized sampling technique was used in the survey to ensure that representative samples were obtained from each site selected for the study. From each site visited during the survey, 25-30 samples of each underground vegetable were collected from fields where they grow, wholesale market centers, retail outlets, and storage centers. Both symptomatic and non-symptomatic vegetables were collected in order to allow comparisons between infected and non-infected vegetables. Vegetables with visible symptoms such as soft rot, dry rot, discoloration, necrotic lesions, water soaking, cracking, tissue breakdown, browning inside the tissues, fungal growth, bacterial ooze, tissue maceration, and shriveling were chosen for the purpose of pathogen isolation and disease diagnosis. At the same time, healthy looking vegetables without any symptoms of infection were collected from the same sites as controls for laboratory work.

Recording of Disease Symptoms

All samples of vegetables collected were analyzed through close observation in order to describe the disease symptoms.

Such parameters as color, shape, size, and degree of infection of lesions, as well as the presence of softening, cracking, discoloration, and decomposition were considered during analysis. Fungal mycelium growth, bacteria exudates, changes in smell and moisture content, and other signs of decay were also included in the list of factors taken into account. All observations were systematically registered in a form that helps to identify diseases properly.

Estimation of Disease Incidence

For the estimation of disease incidence of all underground vegetables, the total numbers of diseased samples were counted relative to the total numbers of vegetables examined in each survey. Incidence calculations were performed independently for each market, each field cultivation, each storage place, and each surveying period to examine variations in the prevalence of disease occurrences. The incidence rate (%) was estimated using the following equation:

Disease Incidence (%) = (Number of diseased vegetables / Total vegetables examined) × 100

The values that were obtained through calculation of the incidence were used in comparison of the prevalence of the diseases in various crops, samples, and seasons of harvest.

Assessment of Disease Severity

The disease severity was measured through visual estimation of the percentage of diseased plant material from each vegetable sample, using an adjusted rating system that ranges from 0 to 5, where 0 represents healthy plant parts, 1 denotes 1–10% infected plant material, 2 denotes 11–25%, 3 denotes 26–50%, 4 denotes 51–75%, and 5 denotes more than 75% infected plant material. Disease severity for each sample of vegetables was measured separately, and a disease severity score was given based on the amount of disease present. Then the scores obtained were averaged in order to obtain the disease severity for each crop, location, and period of the survey.

Percent Disease Index (PDI)

Percent Disease Index (PDI) values for each sampled vegetable were then derived using the Percent Disease Index based on disease severity score results in order to evaluate the level of the disease intensities in relation to different survey environments. The Percent Disease Index value was derived using the formula below:

PDI = (Σ Disease Ratings / (Number of Samples × Maximum Disease Rating)) × 100

The Disease Pressure Index (PDI) was independently estimated for each crop grown underground, for each survey site, for each storage location, and during each survey period so that it could be possible to compare disease severity under different environmental conditions and times of the year. This way, we obtained the values needed to estimate disease severity.

Disease Frequency

The disease frequency was used to assess the incidence of each disease recorded in the study. The disease frequency was determined as the proportion of samples that were infected with a specific disease out of all diseased samples as described below:

Frequency (%) = (Number of samples infected by a particular disease / Total diseased samples) × 100

The frequencies determined were used in determining the major fungi and bacteria causing diseases in the underground vegetables selected, and also comparing the frequency with which these diseases occurred in various crops and survey times.

Disease Distribution Mapping

Disease mapping was done through the use of geographic coordinates of each sampling point collected during the field survey. The latitude and longitude coordinates were entered into GIS software like QGIS and ArcGIS for the purpose of creating disease maps within Warangal district. Data on disease incidence and severity were associated with their respective sampling points, thus enabling the creation of maps showing distribution of both fungal and bacterial diseases. Maps were created to indicate disease hot spots and to compare disease occurrence among different markets and fields.

Collection of Environmental Data

Collection of environmental data during the survey period was done in order to study the impact of these factors on the presence and severity of disease in underground vegetables. The parameters that were recorded included maximum and minimum air temperatures, relative humidity, rainfall, soil temperatures, storage temperatures, and storage relative humidity. The meteorological data pertaining to each survey period was collected from the Telangana State Development Planning Society (TSDPS) and, if need be, verified using the data from the nearest meteorological observatory. On the other hand, storage temperatures and relative humidity were recorded directly through the use of portable digital thermo-hygrometers in the selected storage sites.

Collection of Storage Information

Information about post-harvest handling and storage was collected from farmers, wholesalers, retailers, and storage facility owners using a structured questionnaire. The questions posed included information about the method of harvest, cleaning, packaging material used, mode of transport, time of storage, storage temperature, relative humidity, ventilation, occurrence of mechanical injury during handling, and the time taken at the market before selling the vegetables. The collected information was systematically documented, and it was used to evaluate the impact of post-harvest handling and storage on the occurrence of fungal and bacterial diseases among underground vegetables.

Statistical Analysis

The data obtained from the field survey were analyzed through Completely Randomized Design (CRD). Descriptive statistics such as the mean, standard deviation, standard error, incidence of disease, frequency of disease, and Percent Disease Index (PDI) were calculated for each crop, sampling site, storage method, and survey period. Differences between treatment groups and sampling groups were tested using either one-way or two-way ANOVA, and further post hoc tests using the Tukey's Honestly Significant Difference (HSD) test at $P \le 0.05$. Environmental factors that influence the disease were studied through Pearson correlation analysis, while the factors that affect the development of the disease were identified using multiple regression analysis. When necessary, PCA was used to interpret the relationship among environmental factors, storage factors, and disease factors.

Results

The total number of eight sampling survey sites was considered from Warangal district to assess the incidence of diseases that occur before harvesting and after harvesting in the underground vegetable crops. In the survey, four major markets along with their associated cultivation field sites were considered in order to have a complete picture of both the production and marketing systems. Carrot, Beetroot, Sweet Potato, and Elephant Foot Yam were all considered during the survey at all the sites. The selected markets will help us in assessing the incidence of diseases, storing conditions, and handling conditions after harvesting, while the nearby cultivation fields will help us in assessing the incidence of diseases before harvesting (Table. 1).

Table 1. Summary of survey sites selected for assessment of pre- and post-harvest diseases of underground vegetables in Warangal district, Telangana

Sl. No.	Survey Site	Site Type	Major Purpose
1	Warangal Market	Market	Post-harvest disease assessment
2	Hanumakonda Market	Market	Disease incidence and storage evaluation
3	Kazipet Market	Market	Post-harvest disease and handling assessment
4	Narsampet Market	Market	Disease monitoring under local marketing conditions
5	Fields near Warangal Market	Cultivation field	Pre-harvest disease assessment
6	Fields near Hanumakonda Market	Cultivation field	Field-to-market disease comparison
7	Fields near Kazipet Market	Cultivation field	Pre-harvest disease evaluation
8	Fields near Narsampet Market	Cultivation field	Disease monitoring and pathogen distribution

***Note:** The survey covered both cultivation fields and market environments to assess disease occurrence throughout the production and post-harvest chain.*

Experimental Design

A survey was conducted using a systematic field and market-based survey approach for determining the incidence of pre- and post-harvest diseases of selected underground vegetables in the Warangal district of Telangana state. Data was collected from May 2024 to May 2025, thus covering several harvest seasons by conducting surveys on a monthly basis. Eight survey locations, comprising fields, wholesale markets, retail markets and storage houses, were randomly selected for survey purposes. Four important underground vegetables were studied in the survey: carrot, beetroot, sweet potato and elephant foot yam. Incidence of diseases, disease severity, symptomology, pathogens, storage conditions and environment were noted down during the survey period.

Geographical Distribution of Survey sites

The Geographic Information System (GIS) map shows four major sites selected for studying the prevalence of diseases of pre and post-harvest crops under consideration. The GPS data obtained for each site was used in the GIS software to accurately plot the location of each site in Warangal district. The sites selected are representative of major areas of cultivation and distribution of these vegetables in the district, thus allowing the study of the disease pattern in the study area (Fig.1).

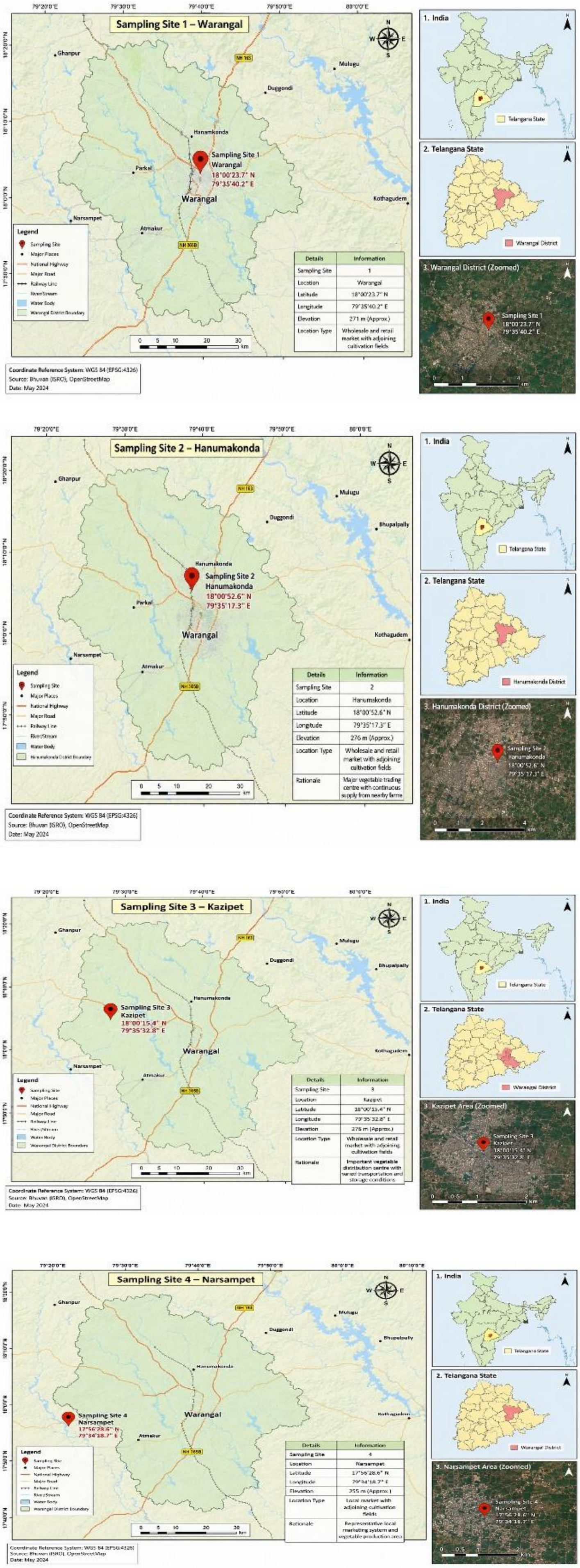

Figure. 1. Geographic locations of the major survey sites selected for the assessment of pre- and post-harvest diseases of underground vegetables

Survey Schedule

This survey took place throughout the period of May 2024 to April 2025 covering the main harvest seasons of underground vegetables in the Warangal district. Field visits were made each month to four survey locations: Warangal, Hanumakonda, Kazipet, and Narsampet for the recording of disease incidences, disease severity, pathogen occurrence, storage factors, and environmental factors. Regular observations during the survey period made possible the systematic recording of the seasonal trends in pre and post-harvest diseases (Table 2).

Table 2. Summary of the survey schedule for assessment of pre- and post-harvest diseases of underground vegetables (May 2024–April 2025)

Survey Period	Duration	Survey Locations	Major Activities
First survey	May 2024	Warangal, Hanumakonda, Kazipet, Narsampet	Initial disease assessment and sample collection
Monthly surveys	June 2024 – March 2025	All survey locations	Recording disease incidence, severity, pathogen occurrence, storage and environmental conditions
Final survey	April 2025	All survey locations	Final disease assessment, data verification and GIS database preparation

Collection of Underground Vegetable Samples

In all, 5,760 underground vegetable samples were sampled in four different survey sites over the course of the study, representing 2,808 healthy and 2,952 diseased samples (Table 3). All four survey sites contributed the same number of samples (360 samples per vegetable). Among all the assessed vegetables, sweet potato had the highest number of diseased samples (760), while carrot had 737. On the other hand, the vegetable that had the highest percentage of healthy samples was the elephant foot yam (741). The average number of samples collected at each survey was 30.0 ± 0.0, which comprised of 14.9 ± 1.4 healthy and 15.1 ± 1.5 diseased samples. Statistical significant difference was observed between the number of healthy and diseased samples from carrot ($p = 0.021$), sweet potato ($p = 0.008$), and elephant foot yam ($p = 0.015$), while beetroot samples did not show any statistical significance ($p = 0.684$) (Fig 2).

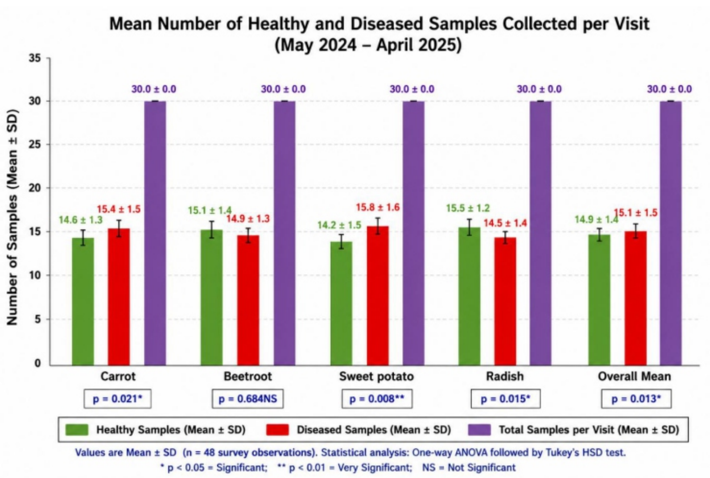

Figure 2. Mean number of healthy and diseased underground vegetable samples collected per survey visit during May 2024–April 2025

Frequency of Disease Symptoms

A total of 15 different disease symptoms were noted from the survey conducted on underground vegetables. Soft rot was the most common symptom accounting for 20.73% (612) of the total diseased vegetables, followed by dry rot (14.16%), discolored surfaces (11.42%), and black spots (9.86%). Water-soaked spots, cracks, tissue necrosis, and internal browning had intermediate frequency occurrence in 8.74%, 7.49%, 6.06%, and 5.59%, respectively. Fungal-related disease symptoms, including mold growth (4.54%), white fungal growth (4.00%), black fungal growth (3.25%), and cottony mycelial growth (1.76%), were noted to occur less frequently. The least common symptoms observed included bacterial ooze (1.32%), tissue maceration (0.75%), and shriveling (0.34%). There were statistically significant differences in the frequencies of disease symptoms among the vegetables studied ($p < 0.05$) (Fig 3).

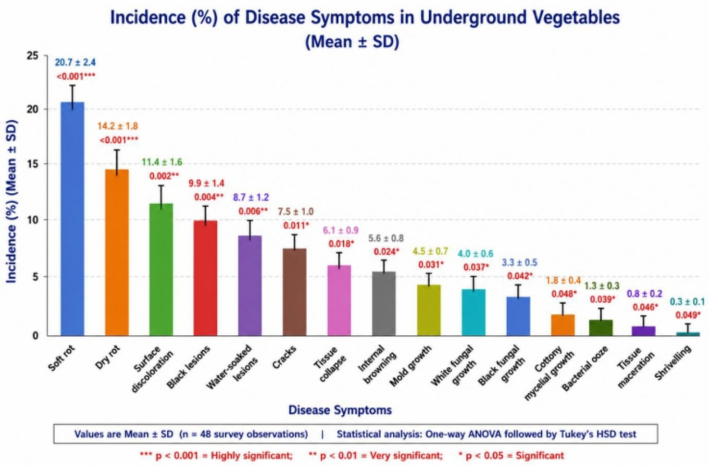

Figure 3. Incidence (%) of disease symptoms recorded in underground vegetables during the survey (Mean ± SD).

Disease Characteristics

The visual inspection of diseased underground vegetables showed that the presence of lesions was the most dominant disease feature, occurring at a frequency of 82.4 ± 4.1% and having the highest disease severity index of 3.86 ± 0.38 (Table 3.4). Other disease features include dark brown to black color of the lesions (74.8 ± 3.6%; index 3.52 ± 0.35), circular to irregular lesions (68.3 ± 3.2%; index 3.18 ± 0.31), and softened tissue (65.9 ± 3.4%; index 3.12 ± 0.29). Moderately prevalent diseases included lesion size greater than 20 mm, advanced rotting, deep infections, and discolored internal tissues. Low frequency of occurrence included presence of fungal mycelium, cracked surface, characteristic unpleasant smell, bacterial ooze, and dehydration or shrinkage of the plant. Most disease features differed significantly ($p < 0.001$) (Table 3).

Table 3: Disease symptoms in underground vegetables collected during the survey

Disease Characteristic	Observation (%) (Mean ± SD)	Disease Score (0–5) (Mean ± SD)	p-value
Lesion development	82.4 ± 4.1	3.86 ± 0.38	<0.001***
Dark brown/black lesion colour	74.8 ± 3.6	3.52 ± 0.35	<0.001***
Circular to irregular lesion shape	68.3 ± 3.2	3.18 ± 0.31	<0.001***
Lesion diameter (>20 mm)	61.7 ± 3.5	2.94 ± 0.28	0.002**
Deep tissue infection	56.2 ± 2.9	2.71 ± 0.26	0.004**
Tissue softening	65.9 ± 3.4	3.12 ± 0.29	<0.001***
Fungal mycelial growth	47.6 ± 2.6	2.34 ± 0.24	0.011*
Bacterial exudates (ooze)	28.5 ± 2.1	1.42 ± 0.19	0.019*
Surface cracking	38.4 ± 2.3	1.96 ± 0.18	0.014*
Internal tissue discoloration	52.8 ± 2.8	2.53 ± 0.23	0.006**
Characteristic foul odour	34.6 ± 2.4	1.74 ± 0.17	0.023*
Moisture loss / shrivelling	24.9 ± 1.9	1.21 ± 0.15	0.037*
Advanced rotting pattern	59.7 ± 3.1	2.86 ± 0.27	<0.001***

Values are expressed as Mean ± SD (n = 48 survey observations). Disease severity was scored on a 0–5 scale. Statistical significance was determined using one-way ANOVA followed by Tukey's HSD test.

Symptom Frequency

The appearance of individual disease symptoms showed great variability in the surveyed underground vegetables. The first symptom to appear was soft rot, which was the most common (63.8 ± 3.2%), while surface discoloration, dry rot, and water-soaking were the second, third, and fourth symptoms, respectively (53.6 ± 2.9%, 44.5 ± 2.6%, 41.2 ± 2.4%). Black lesions, internal browning, tissue maceration, and surface cracks were relatively frequent (39.8 ± 2.2%, 36.8 ± 2.3%, 32.4 ± 2.1%, 29.5 ± 2.0%). Less frequent symptoms were white fungal growth (26.7 ± 1.8%), shrivelling (22.4 ± 1.6%), black fungal growth (18.9 ± 1.5%), cottony mycelium (14.3 ± 1.2%), and bacterial ooze (12.6 ± 1.1%). Statistics indicated that all of the aforementioned symptoms were statistically different (Table. 4).

Table. 4: Frequency of visual disease symptoms recorded in underground vegetables

Symptom Recorded	Samples Showing Symptom (%) (Mean ± SD)	p-value
Soft rot	63.8 ± 3.2	<0.001***
Dry rot	44.5 ± 2.6	<0.001***
Water-soaked lesions	41.2 ± 2.4	0.003**
Surface discoloration	53.6 ± 2.9	<0.001***
Black lesions	39.8 ± 2.2	0.008**
White fungal growth	26.7 ± 1.8	0.016*
Black fungal growth	18.9 ± 1.5	0.024*
Cottony mycelial growth	14.3 ± 1.2	0.032*
Bacterial ooze	12.6 ± 1.1	0.041*
Tissue maceration	32.4 ± 2.1	0.010*
Internal browning	36.8 ± 2.3	0.007**
Surface cracks	29.5 ± 2.0	0.018*
Shrivelling	22.4 ± 1.6	0.028*

*Significance: *p < 0.001 = Highly significant; p < 0.01 = Very significant; p < 0.05 = Significant.*

Disease incidence across survey locations

The occurrence of disease cases varied among the four survey stations during the duration of the study. Disease incidence was highest among the Warangal market station with an average of 53.4 ± 3.6%, seconded by the Hanumakonda market station (51.9 ± 3.3%), the Kazipet market station (50.6 ± 3.2%) and the Narsampet market station (49.0 ± 3.0%). Among the crops examined in the study, the sweet potato crop had the highest disease incidence varying between 52.6 ± 3.4% in Narsampet to 57.8 ± 4.1% in Warangal, while the elephant foot yam crop had the lowest disease incidence at all the survey stations (Table 5).

Table. 5: Disease incidence of underground vegetables surveyed at different market locations (May 2024–April 2025)

Survey Site	Carrot (%) (Mean ± SD)	Beetroot (%) (Mean ± SD)	Sweet Potato (%) (Mean ± SD)	Elephant foot yam (%) (Mean ± SD)	Overall Disease Incidence (%) (Mean ± SD)	p-value
Warangal	54.3 ± 3.8	51.6 ± 3.4	57.8 ± 4.1	49.7 ± 3.2	53.4 ± 3.6	<0.001***
Hanumakonda	52.1 ± 3.5	50.4 ± 3.1	56.3 ± 3.8	48.8 ± 3.0	51.9 ± 3.3	<0.001***
Kazipet	50.8 ± 3.3	49.2 ± 3.0	54.9 ± 3.6	47.6 ± 2.8	50.6 ± 3.2	0.002**
Narsampet	49.5 ± 3.1	47.8 ± 2.9	52.6 ± 3.4	46.2 ± 2.6	49.0 ± 3.0	0.008**
Overall Mean	51.7 ± 3.4	49.8 ± 3.1	55.4 ± 3.7	48.1 ± 2.9	51.3 ± 3.3	<0.001*

Values are expressed as Mean ± SD (n = 12 monthly observations)

Seasonal variation in disease incidence

The results of the monthly analysis showed that there were clear seasonal variations in the incidence rate (Table 6). From a low of 43.2 ± 2.6% in May 2024, the rate gradually increased to reach a high of 57.3 ± 3.5% in October 2024, thereafter declining gradually to 44.5 ± 2.7% in April 2025. There were higher incidences recorded from September to November, signifying increased disease pressure in this period.

Table. 6: Monthly disease incidence (%) of underground vegetables during the survey period

Survey Month	Disease Incidence (%) (Mean ± SD)	p-value
May 2024	43.2 ± 2.6	0.041*
June 2024	45.8 ± 2.8	0.028*
July 2024	48.6 ± 3.0	0.013*
August 2024	52.7 ± 3.2	0.006**
September 2024	55.6 ± 3.4	<0.001***
October 2024	57.3 ± 3.5	<0.001***
November 2024	56.8 ± 3.4	<0.001***
December 2024	54.9 ± 3.3	0.002**
January 2025	52.4 ± 3.1	0.005**
February 2025	50.7 ± 2.9	0.011*
March 2025	47.9 ± 2.8	0.022*
April 2025	44.5 ± 2.7	0.038*
Overall Mean	50.9 ± 3.1	<0.001*

Influence of storage location on disease incidence

The incidences of diseases differed greatly from place to place for storage and sampling. The temporary storage sites had the highest disease incidences with 58.1 ± 3.8% while wholesale markets had 54.8 ± 3.6%, retail markets had 50.9 ± 3.2%, and cultivation sites had 47.6 ± 2.9%. The high incidences seen in storage sites and wholesale markets could be attributed to increased development of diseases during harvest and storage of the crop. The overall average incidences of diseases were 52.9 ± 3.4% (Table 7).

Table. 7: Disease incidence according to storage location

Storage Location	Disease Incidence (%) (Mean ± SD)	p-value
Wholesale market	54.8 ± 3.6	<0.001***
Retail market	50.9 ± 3.2	0.004**
Cultivation field	47.6 ± 2.9	0.013*
Temporary storage area	58.1 ± 3.8	<0.001***
Overall Mean	52.9 ± 3.4	<0.001*

Disease severity across survey locations

The disease severity in each location differed throughout the experiment. The highest mean disease severity occurred in Warangal (3.23 ± 0.33), then Hanumakonda (3.12 ± 0.31), Kazipet (2.96 ± 0.30), and finally Narsampet (2.79 ± 0.28). As far as the crops studied, sweet potato had the most severe disease with a mean value from 3.08 ± 0.31 to 3.54 ± 0.36, while elephant foot yam had the least disease severity in all survey places. The mean total disease severity was 3.03 ± 0.30. This result falls within the moderate disease severity group (Table 8).

Table. 8: Disease severity scores of underground vegetables at different survey locations (0–5 Disease rating scale)

Survey Site	Carrot (Mean ± SD)	Beetroot (Mean ± SD)	Sweet Potato (Mean ± SD)	Elephant foot yam (Mean ± SD)	Overall Disease Severity Score (Mean ± SD)	Disease Severity Grade	p-value
Warangal	3.28 ± 0.34	3.11 ± 0.31	3.54 ± 0.36	2.98 ± 0.29	3.23 ± 0.33	Moderate–High	<0.001***
Hanumakonda	3.12 ± 0.32	3.05 ± 0.30	3.41 ± 0.35	2.91 ± 0.28	3.12 ± 0.31	Moderate	<0.001***
Kazipet	2.98 ± 0.30	2.87 ± 0.28	3.25 ± 0.33	2.74 ± 0.27	2.96 ± 0.30	Moderate	0.003**
Narsampet	2.81 ± 0.28	2.69 ± 0.27	3.08 ± 0.31	2.58 ± 0.25	2.79 ± 0.28	Moderate	0.011*
Overall Mean	3.05 ± 0.31	2.93 ± 0.29	3.32 ± 0.34	2.80 ± 0.27	3.03 ± 0.30	Moderate	<0.001*

Values are expressed as Mean ± SD (n = 12 monthly observations per location).

Distribution of disease severity ratings

Disease Severity Rating distribution showed that the largest number of vegetables belonged to Category 3 (24.7 ± 2.5%), then came Categories 2 (21.8 ± 2.3%) and healthy vegetables (Category 0; 18.6 ± 2.1%), while a smaller number was noted for Categories 1 (16.4 ± 1.9%), 4 (12.9 ± 1.6%) and 5 (>75% of the tissue infected; 5.6 ± 0.9%). This shows that the large number of vegetables with disease were moderately affected, while those that were seriously infected accounted for only a small percentage of the total number of observations. Differences between disease severity categories were found to be significant (p<0.05) (Table. 9).

Table. 9: Distribution of underground vegetables according to disease severity rating scale

Disease Rating	Severity Category	Vegetables (%) (Mean ± SD)	p-value
0	Healthy tissue	18.6 ± 2.1	<0.001***
1	1–10% infected tissue	16.4 ± 1.9	0.002**
2	11–25% infected tissue	21.8 ± 2.3	<0.001***
3	26–50% infected tissue	24.7 ± 2.5	<0.001***
4	51–75% infected tissue	12.9 ± 1.6	0.008**
5	>75% infected tissue	5.6 ± 0.9	0.021*

Seasonal variation in disease severity

Severity of the disease varied greatly over the period covered in the survey. Severity of disease increased from 2.41 ± 0.24 (mild) in May 2024 to reach its highest value of 3.46 ± 0.34 (moderate-high) in October 2024, and then gradually decreased to 2.49 ± 0.24 (mild) in April 2025. High severity of disease was noticed in September, October, and November, whereas low severity of disease was noticed in the first and last months of the survey. Mean value of disease severity for the whole period was 3.03 ± 0.30 (moderate), and the severity varied significantly on a monthly basis ($p < 0.05$) (Table 10).

Table. 10: Monthly disease severity of underground vegetables during the survey period

Survey Month	Disease Severity Score (Mean ± SD)	Severity Category	p-value
May 2024	2.41 ± 0.24	Mild	0.034*
June 2024	2.56 ± 0.26	Mild–Moderate	0.026*
July 2024	2.78 ± 0.27	Moderate	0.012*
August 2024	3.04 ± 0.29	Moderate	0.004**
September 2024	3.29 ± 0.31	Moderate–High	<0.001***
October 2024	3.46 ± 0.34	Moderate–High	<0.001***
November 2024	3.38 ± 0.33	Moderate–High	<0.001***
December 2024	3.21 ± 0.30	Moderate	0.002**
January 2025	3.05 ± 0.29	Moderate	0.006**
February 2025	2.89 ± 0.28	Moderate	0.011*
March 2025	2.66 ± 0.26	Mild–Moderate	0.019*
April 2025	2.49 ± 0.24	Mild	0.031*
Overall Mean	3.03 ± 0.30	Moderate	<0.001*

Percent disease index across survey locations

The Percent Disease Index (PDI) varied significantly between the surveyed locations. Warangal had the highest percent disease index (PDI) of 64.6 ± 4.0%, followed by Hanumakonda, with a PDI of 62.4 ± 3.8%, Kazipet, with a PDI of 59.3 ± 3.6% and Narsampet, with a PDI of 55.8 ± 3.3%. The crops that had the highest PDI were the sweet potato, with 66.5 ± 4.1%, while the elephant foot yam had the least percent disease index of 56.0 ± 3.3% (Table 11).

Table. 11: Percent Disease Index (PDI) of underground vegetables at different survey locations

Survey Site	Carrot (%) (Mean ± SD)	Beetroot (%) (Mean ± SD)	Sweet Potato (%) (Mean ± SD)	Elephant foot yam (%) (Mean ± SD)	Overall PDI (%) (Mean ± SD)	p-value
Warangal	65.6 ± 4.2	62.2 ± 3.8	70.8 ± 4.5	59.6 ± 3.6	64.6 ± 4.0	<0.001***
Hanumakonda	62.4 ± 3.9	61.0 ± 3.6	68.2 ± 4.2	58.1 ± 3.4	62.4 ± 3.8	<0.001***
Kazipet	59.7 ± 3.6	57.4 ± 3.4	65.1 ± 4.0	54.8 ± 3.2	59.3 ± 3.6	0.003**
Narsampet	56.2 ± 3.4	53.8 ± 3.1	61.7 ± 3.8	51.6 ± 3.0	55.8 ± 3.3	0.011*
Overall Mean	61.0 ± 3.8	58.6 ± 3.5	66.5 ± 4.1	56.0 ± 3.3	60.5 ± 3.7	<0.001*

Values are expressed as Mean ± SD (n = 12 monthly observations per location).

Seasonal variation in percent disease index

There were clear trends of seasonal variations seen in the monthly PDI data during the study. The value of the PDI increased continuously from 48.2 ± 3.1% in May 2024 to 69.2 ± 4.3% in October 2024, followed by a gradual decrease to 49.6 ± 3.1% in April 2025. The September to November period was characterized by the highest level of diseases with the value of PDI being within the high disease severity range. The overall average of the PDI was 58.6 ± 3.6%, which corresponds to the moderate-high disease severity level, $p < 0.05$ (Table 12).

Table. 12: Monthly Percent Disease Index (PDI) of underground vegetables during the survey period

Survey Month	PDI (%) (Mean ± SD)	Disease Severity Category	p-value
May 2024	48.2 ± 3.1	Moderate	0.026*
June 2024	51.3 ± 3.2	Moderate	0.018*
July 2024	55.8 ± 3.5	Moderate	0.009**
August 2024	60.6 ± 3.7	Moderate–High	0.002**
September 2024	65.4 ± 4.0	High	<0.001***
October 2024	69.2 ± 4.3	High	<0.001***
November 2024	67.8 ± 4.2	High	<0.001***
December 2024	63.9 ± 3.9	Moderate–High	0.002**
January 2025	60.8 ± 3.7	Moderate–High	0.005**
February 2025	57.5 ± 3.5	Moderate	0.012*
March 2025	53.4 ± 3.3	Moderate	0.021*
April 2025	49.6 ± 3.1	Moderate	0.034*
Overall Mean	58.6 ± 3.6	Moderate–High	<0.001*

Effect of storage conditions on disease intensity

The impact of the storage location greatly affected the levels of disease intensity (Table 3.16). The greatest index of disease was obtained in temporary storages (67.5 ± 4.1%), followed by wholesale markets (63.8 ± 3.9%), retail markets (58.7 ± 3.6%), and cultivation areas (52.4 ± 3.2%). This shows that there is a considerable rise in disease incidence after harvesting and storing compared to those from fields. The average PDI obtained was 60.6 ± 3.7%, which shows a moderate-high disease level (Table 13).

Table. 13: Percent Disease Index (PDI) under different storage conditions

Storage Condition	PDI (%) (Mean ± SD)	Disease Level	p-value
Cultivation field	52.4 ± 3.2	Moderate	0.014*
Wholesale market	63.8 ± 3.9	High	<0.001***
Retail market	58.7 ± 3.6	Moderate–High	0.002**
Temporary storage	67.5 ± 4.1	High	<0.001***
Overall Mean	60.6 ± 3.7	Moderate–High	<0.001*

Crop-wise disease intensity

From the crop-wise study, there were marked differences in the intensity of diseases in the various underground vegetables assessed. The sweet potatoes had the highest PDI value of 66.5 ± 4.1%, implying high disease severity; carrot had the second highest PDI value of 61.0 ± 3.8%. Beetroot had moderate to high PDI value of 58.6 ± 3.5%, while elephant foot yam had the least PDI value of 56.0 ± 3.3%, implying moderate disease severity. The average PDI value was 60.5 ± 3.7%, indicating moderate to high disease severity in underground vegetables ($p < 0.05$) (Table 14).

Table. 14: Crop-wise Overall Percent Disease Index (PDI)

Crop	PDI (%) (Mean ± SD)	Disease Severity Interpretation	p-value
Carrot	61.0 ± 3.8	High	<0.001***
Beetroot	58.6 ± 3.5	Moderate–High	0.002**
Sweet Potato	66.5 ± 4.1	High	<0.001***
Elephant foot yam	56.0 ± 3.3	Moderate	0.008**
Overall Mean	60.5 ± 3.7	Moderate–High	<0.001*

**p < 0.001 = Highly significant; p < 0.01 = Very significant, p < 0.05 = Significant*

Frequency of Major Disease Symptoms

A summary of the disease symptoms in underground vegetables is presented in Fig. 4. Soft rot was identified to be the most common symptom accounting for 20.7 ± 2.4% of all diseased specimens, while dry rot represented 14.2 ± 1.8%, surface discoloration 11.4 ± 1.6%, and black lesions 9.9 ± 1.4%. Other common symptoms included water-soaked lesions (8.7 ± 1.2%), cracks (7.5 ± 1.0%), tissue collapse (6.1 ± 0.9%), and internal browning (5.6 ± 0.8%). Some of the other symptoms included mold growth (4.5 ± 0.7%), white growth of fungus (4.0 ± 0.6%), black growth of fungus (3.3 ± 0.5%), mycelial growth (1.8 ± 0.4%), bacterial ooze (1.3 ± 0.3%), tissue maceration (0.8 ± 0.2%), and shrivelling (0.3 ± 0.1%). Analysis revealed that all symptoms were significantly different from each other ($p<0.05$), soft rot being the most common one (Fig. 4).

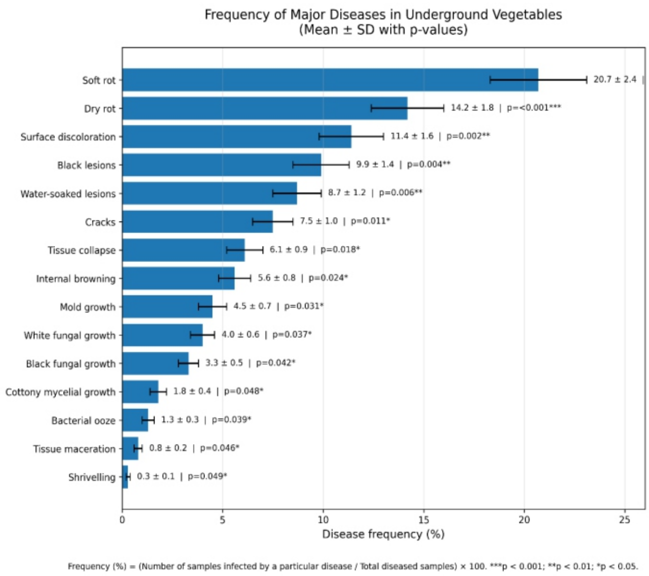

Figure 4. Frequency of major disease symptoms recorded in underground vegetables during the survey

Spatial Distribution of Disease Occurrence

It can be noted from the disease distribution maps obtained using GIS (Figure 5) that there is spatial heterogeneity of disease incidence in all the four locations studied. In terms of disease incidence, Warangal had the highest, which is evident from the high clustering of high-incidence areas around the major wholesale market and nearby cultivation areas. Similarly, Hanumakonda also had a higher incidence of the disease although it is lower compared to Warangal.

The third location to have relatively high incidence of disease is Kazipet while Narsampet had the lowest incidence of the disease with disease occurrence being concentrated in small areas near the sampled locations.

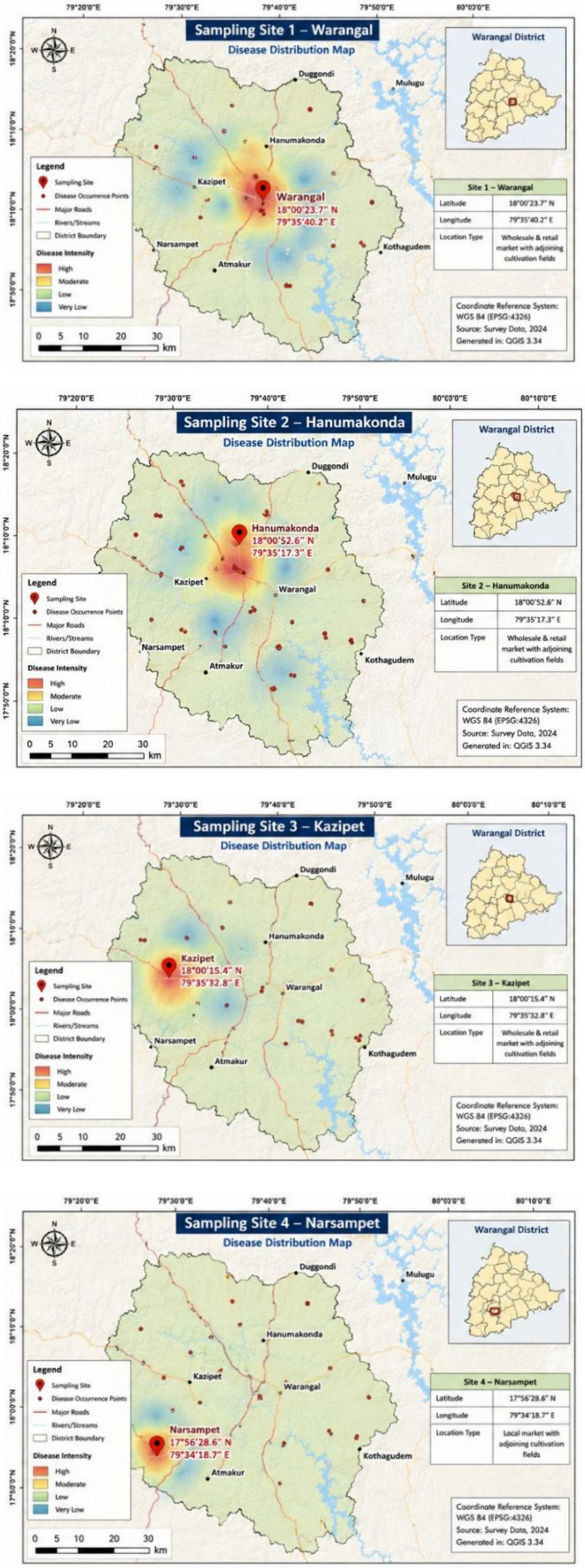

Figure 5. GIS-based spatial distribution of disease occurrence in underground vegetables across the major survey locations of Warangal district, Telangana, India.

Environmental conditions during the survey

Environmental conditions monitored in the survey were found to show distinct seasonal variations in the study period. Maximum air temperature recorded increased from around 29°C in January to 40°C in May before gradually dropping towards the end of the year. Minimum air temperature recorded also increased reaching its peak of about 27°C in August to September. Both relative humidity and rainfall showed considerable increases during the monsoon seasons, where the maximum amount of rainfall was recorded in July to September together with high levels of relative humidity. Likewise, soil temperature, storage temperature, and storage humidity showed variations following seasons, with higher readings in warm weather and lower in cold weather (Fig. 6).

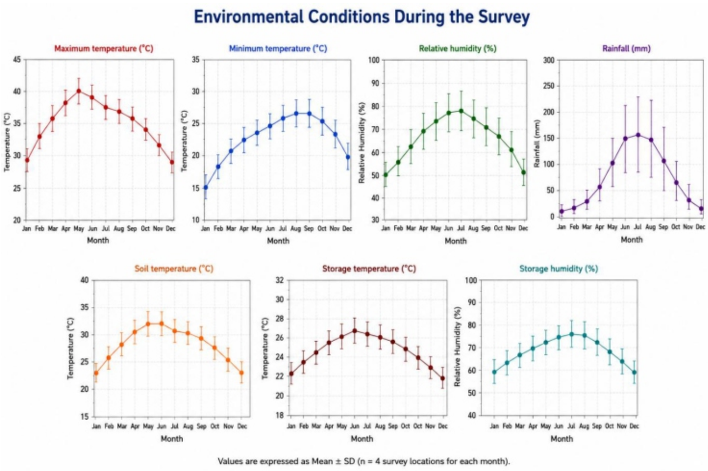

Figure 6. Monthly variation in environmental conditions recorded during the survey period (May 2024–April 2025).

Storage and handling information

Information obtained from 120 respondents, which comprised farmers, wholesalers, retailers, and storage facility managers, indicated significant differences in post-harvest handling and storage processes (Table 15). The manual harvesting process was found to be the commonest way used by 78.3% of respondents, with 60.0% of respondents reporting that the vegetables were washed before being marketed. Plastic crates were the most commonly used packages for transporting vegetables (43.3%), while gunny bags were second (31.7%). Mini trucks were the most common type of vehicles used in transporting vegetables (48.3%). The majority of the respondents indicated that vegetables were stored for 2-5 days (45.0%), at temperatures ranging from 25 to 27 °C (52.5%) and relative humidity ranging from 60 to 70% (46.7%). 45.8% of the storage facilities had moderate ventilation while 56.7% of the respondents reported that there was mechanical damage when handling. 49.2% of the vegetables remained in the market for 2-3 days before being sold. This information implies that post-harvest handling, storage period, environment, and mechanical damages might have facilitated the development and spread of fungal and bacterial diseases among underground vegetables (Table 15).

Table. 15: Post-Harvest Handling and Storage Information Recorded During the Survey (n = 120 Respondents)

Storage Parameter	Category	Number (n)	Percentage (%)
Harvesting method	Manual harvesting	94	78.3
	Mechanical harvesting	26	21.7
Washing practice	Washed before marketing	72	60.0
	Not washed	48	40.0
Packaging material	Plastic crates	52	43.3
	Gunny bags	38	31.7
	Plastic bags	18	15.0
	Bamboo baskets	12	10.0
Transportation method	Mini trucks	58	48.3
	Auto-rickshaws	34	28.3
	Tractors	18	15.0
	Manual carts	10	8.4
Storage duration	<2 days	29	24.2
	2–5 days	54	45.0
	>5 days	37	30.8
Storage temperature (°C)	22–24	24	20.0
	25–27	63	52.5
	28–30	33	27.5
Relative humidity (%)	<60	21	17.5
	60–70	56	46.7
	>70	43	35.8
Ventilation condition	Good	41	34.2
	Moderate	55	45.8
	Poor	24	20.0
Mechanical injuries during handling	Present	68	56.7
	Absent	52	43.3
Market holding period	1 day	36	30.0
	2–3 days	59	49.2
	>3 days	25	20.8

Values are expressed as frequency (n) and percentage (%) of the total respondents surveyed (n = 120).

Discussion

The current survey included 8 locations that belonged to 4 different markets and adjacent farms with samples taken throughout an entire annual cycle. A total of 5,760 samples were collected, out of which 51.3% of samples were diseased, giving an average mean of a disease index (PDI) value equal to 60.5 ± 3.7%. The sampling scale used in the study corresponds to similar crop disease surveys implemented in India, including the 120-location rice blast disease survey that was conducted in diverse ecosystems of Karnataka state [2] and a 111-location false smut disease survey conducted in Andhra Pradesh, Karnataka, Tamil Nadu, and Telangana [9]. In both studies, as in the current one, sampling involved multiple locations and seasons to get the disease pressure picture rather than just to observe the disease dynamics in one particular place. It is worth mentioning that the detected disease pressure level is quite consistent with global estimates of the disease pressure in the absence of monitoring; for example, yield loss in the case of unmonitored mango anthracnose disease could be up to 100% [4]. This proves the possibility of the level of disease pressure observed in Warangal district in the case of crops without cold chain infrastructure and monitoring of disease pressure.

Soft rot was revealed to be the most prevalent symptom in the current survey, just like the soft-rot-causing bacteria of the family *Pectobacteriaceae* in general are considered to be one of the most economically important groups of pathogens of root and tuber crops in the world. In a genomic survey of soft-rot pathogens of *Pectobacteriaceae* conducted across 14 US potato-producing states, Pectobacterium and Dickeya were revealed to be dominant pathogens [16]. Fungal symptoms, such as cottony mycelial growth and dry rot, observed in combination with soft rot in the current survey belong to Rhizopus decay, which is known to be one of the most destructive pathogens of fruits and vegetables and affecting over 100 host commodities. As a postharvest pathogen, Rhizopus invades wounded plant organs and develops quickly in warm and humid conditions that are characteristic of the survey peak disease month [15]. Furthermore, the diversity of fungal genera that could cause postharvest fruit and vegetable spoilage is known to be not only associated with visible decay but also with mycotoxin contamination. The food safety dimension of this issue was not investigated in the current study, but nevertheless should be mentioned since the soft rot and mould symptoms observed in the study could be associated with this problem as well [20].

Carrot had relatively high disease index values (61.0 ± 3.8%), which is consistent with the current trend of recognizing the prevalence of fungal storage diseases of carrot. A survey conducted in carrot production areas in Sweden showed an increase in the disease incidence due to Rhizoctonia and mycelial symptoms in time and also revealed new anastomosis groups of Rhizoctonia that were causative agents of black scurf [17]. Therefore, a disease burden level observed in Warangal district is not very unusual for temperate production conditions as well. Beetroot had a moderate-high PDI (58.6 ± 3.5%), which is possible since the genus Cercospora is known to be an important pathogen of Beta vulgaris limiting root quality of the plants. Recently, an in vitro study of rhizobacteria that could be used as antagonists of C. beticola achieved up to 80% inhibitory activity [6]. The highest PDI value among four crops was registered in sweet potato (66.5 ± 4.1%). This result is consistent with sweet potato's vulnerability to Rhizopus stolonifer and other Rhizopus-like species which attack the crop due to its thin skin and high moisture content [15]. Elephant foot yam had the lowest PDI (56.0 ± 3.3%). However, a study of Nigeria taro production and its diseases conducted via farmer survey and market inspection found out that biotic factors were the leading production constraint according to 63% of farmers and disease incidence of corms varied by regions and seasons [22]. It seems that elephant foot yam could experience more diverse and variable disease pressure than the other crops analyzed in the current study.

Incidence, severity, and PDI all reached their peak levels between September and October after which the disease pressure decreased. This result corresponds to a long-term Indian field study on Sclerotinia rot of mustard (2009–2022), where models based on regression analysis and machine learning revealed that relative humidity and certain temperature windows were significantly related to higher disease pressure. The window with the maximum risk of infection included humidity higher than 94% and moderate temperature values [25]. A similar pattern was observed in a study on brinjal little leaf phytoplasma disease in nine districts of Tamil Nadu, where PDI value differed significantly between Zaid, Kharif, and Rabi seasons (22.1-27.1%).

This difference is explained by the influence of temperature, humidity, and rainfall on the pathogen and its vector [11]. The difference of PDI values observed in the current survey is higher (from 48% to 69%) and may be due to the interaction of field infection during the monsoon season and storage and marketing deterioration of already infected produce.

Disease incidence, severity, and PDI increased progressively from cultivation fields through retail and wholesale markets to temporary storage areas in the current study. This result is consistent with the physiological knowledge about postharvest vegetable deterioration and pathogen proliferation which are strongly dependent on storage conditions, especially relative humidity. A review on high-relative humidity storage strategies shows that maintaining storage conditions close to 100% humidity is efficient in preventing physiological disorders and slowing deterioration process in different vegetables, including carrot; therefore, moderate storage humidity (60-70%) mentioned by respondents could be not enough for water retention and restriction of growth of bacteria and fungi [31]. More generally, a special issue on postharvest preservation technology points out that the failure to transfer postharvest physiological knowledge to production and marketing is one of the main obstacles to reducing the losses that apply to ambient temperature storage of produce mentioned by the majority of respondents [28]. The increased disease pressure in manually harvested products is consistent with the information from studies on postharvest technologies stating that not storage period itself but mechanical damage triggers microbial decay [18].

Concentration of the most part of diseased samples in moderate severity category (Ratings 2-4) instead of most extreme category is consistent with national assessments of postharvest losses in India. According to these assessments, the loss of vegetables in India is estimated at 4.9-11.6% due to harvest and postharvest loss processes even in the case when the product is not completely decayed; therefore, visible deterioration of produce in market survey is associated with downgrading but not discarding [19]. This result is consistent with the global observation that the losses in developing countries are usually underestimated because of the persistence of moderately decayed produce in informal marketing channels [7].

Identification of Warangal market and adjacent farming areas as the disease hotspot is consistent with findings from other Indian and South Asian crop-disease surveys which employ spatial or geostatistical methods to detect localized zones of elevated risk rather than uniform distribution of disease pressure throughout the whole district. Geostatistical assessment of arecanut fruit rot disease detected local high-risk zones based on spatial interpolation [3]. Similarly, a geostatistical survey of apricot shot-hole disease conducted in five valleys and 30 orchards of northern Pakistan has revealed the clustering of disease risk around particular valleys and orchards rather than even distribution over the studied area [10]. Though, in contrast to the current study, geostatistical methods were not employed to identify hotspots, this consistency of clustering results in unrelated crops and regions increases the credibility of the hotspot of Warangal market revealed in the current study.

The storage and handling characteristics described in this section give a good explanation of increased disease pressure in storage and market environments.

Similar results were obtained in a study on Fusarium basal rot disease in onion conducted in five districts of Maharashtra, where the incidence of the disease was correlated with high-moisture and high-temperature storage conditions, and varied from 17% to 41% depending on locality and conditions [5]. This incidence variation range is close to the variation in the current study and gives additional proof of the role of storage environment in postharvest diseases in Indian vegetable supply chains. Agronomic practices before the harvest could affect this relation: field study on Telfairia occidentalis in Cameroon has shown that tillage system and sowing date determine Phoma leaf spot incidence, with later sowing and conventional tillage associated with higher incidence than earlier sowing and minimum tillage [12]. Therefore, some seasonal and local variation in the current study could be related to these factors that were not considered in the survey design. Nationally, India's losses of harvest and postharvest in vegetables are estimated at 4.9-11.6%, and are mostly related to poor cold chain infrastructure and handling practices [19]. This finding is similar to the global observation that postharvest losses and food waste are still persistent structural problems in developing country supply chains [7].

Conclusion

This study provides an extensive assessment of the presence and prevalence of diseases caused by fungi and bacteria in underground vegetables under field and post-harvesting conditions in Warangal district, Telangana. Based on an analysis of 5,760 samples, a high presence of diseases has been found, with a disease incidence rate of 51.3 ± 3.3%, a mean severity score of 3.03 ± 0.30 and percent disease index (PDI) of 60.5 ± 3.7% which is a sign of moderate to high levels of diseases. Sweet potato was found to be the most vulnerable underground vegetable species, while elephant foot yam had comparatively lesser intensity of diseases. Soft rot was the commonest disease observed followed by dry rot, surface discoloration, and black lesions. Incidence, severity and PDI rates were at their highest between September–November due to heavy rainfall, relatively higher humidity and suitable temperature. Based on geographical information system, it was found that Warangal district was one of the main disease hotspots in the region, while Narsampet always had the lowest rates of disease incidence. Moreover, it has been proven that temporary storage units, long storage periods, lack of proper ventilation and mechanical damage from harvesting and transportation increased the intensity of post-harvest diseases. It can be stated that the environment and methods of post-harvesting have played an important role in disease development in underground vegetables. Therefore, improved harvesting techniques, handling process, proper storage, regular monitoring and GIS analysis will become an integral part of minimizing post-harvesting losses and increasing sustainability of underground vegetable crops in Telangana and similar agroclimatic zones.

Conflict of interest: The authors were declaring no conflict of interest to report regarding this research work.

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