*Journal of Food and Agriculture*
*Volume 18, Issue 01, June 2025*
*Print ISSN: 1800-4288, E. ISSN: 2613-8530*
*DOI: https://doi.org/10.4038/jfa.v18i1.5334*

# Temporal Variation of Leaf Spot Disease Incidence in Cinnamon (*Cinnamomum verum*) under Field Conditions in Sri Lanka

M.R. Prathibhani[1], R. Azad[1], K.L.W. Kumara[2], R.A.A.K. Ranawaka[3], L. Jayasekara[4], S. Geekiyanage[2*]

**ABSTRACT**

**Leaf spot disease (LSD) caused by fungus *Colletotrichum gloeosporioides* (Penz.) is a major threat to cinnamon (*Cinnamomum verum*), yet its temporal variation remains poorly understood. This study assessed LSD incidence (LSDI) and severity (LSDS) in 40 cinnamon accessions collected from different regions of the country and grown in the field (WL2, Agro-ecological region, Sri Lanka). Correlations between LSDI and selected morphological traits were also examined. LSDS was determined using a disease assessment key, while tree height (TH), leaf length (LL), leaf width (LW), leaf length-width ratio (LL/LW), petiole length (PL), bark thickness (BT), trunk circumference (TC), and twig diameter (TD) were recorded using the Descriptors for Cinnamon.**

**LSDI ranged from 50% to 100% across all accessions in both years. The mean LSDI was significantly lower in 2018 (76.97) with an average monthly rainfall (MRF) of 95.62 mm, compared to 2019 (87.42) with 189.4 mm MRF ($p<0.05$, Paired T-test). In 2019, LSDS varied among accessions grown in the field collected from different regions, Matara (4.08), Galle (3.30), Kalutara (3.74), Kurunegala (2.00), Ratnapura (2.67), and Hambantota (3.50), comparatively to the LSDS obtained in 2014–2015 (4.50, 4.82, 4.74, 4.60, 3.65, and 3.91, respectively) when the plants were grown in the original regions. Cluster analysis grouped accessions into three distinct clusters at a distance of 9. No significant correlations were found between LSDI and morphological traits ($p>0.05$). Findings indicate that LSDS varies among accessions, and LSDI fluctuates over time, likely influenced by environmental factors. Further research is needed to investigate genetic basis of resistance and environmental determinants of LSD in cinnamon.**

**Keywords:** *Cinnamomum verum*, Disease severity, Leaf spot disease, Temporal variation

[1]*Faculty of Graduate Studies, University of Ruhuna, Matara, Sri Lanka*
[2]*Department of Agricultural Biology, Faculty of Agriculture, University of Ruhuna, Kamburupitiya, Sri Lanka*
[3]*Department of Cinnamon Development, Gunaratna Weerakoon Mawatha, Borakanda, Karandeniya, Sri Lanka*
[4]*Department of Mathematics, Faculty of Science, University of Ruhuna, Matara, Sri Lanka*
* *sudarshanee@agbio.ruh.ac.lk*
*https://orcid.org/0000-0002-3771-2680*

## INTRODUCTION

Cultivated cinnamon (*Cinnamomum verum* J. Presl) belongs to the genus *Cinnamomum* within the family Lauraceae, which comprises approximately 250 species and sub-species distributed across Asia, South and Central America and Australia (Mabberly, 2008). Among these, Ceylon cinnamon (*Cinnamomum verum* J. Presl) is the most economically significant, particularly for Sri Lanka, where it serves as a major export commodity. In 2024, Sri Lanka's cinnamon export generated 226 million USD (Department of Cinnamon Development, 2025). To sustain and enhance this market potential, developing high-quality cinnamon varieties with increased resistance to major pests and diseases is essential. Varietal development requires a thorough understanding of the spatial and temporal variation in disease development across diverse accessions. Sri Lankan cinnamon accessions exhibit substantial diversity in morphological traits and chemical composition, reflecting genetic variability that may influence disease susceptibility (Azad *et al.*, 2016b; 2019a; 2024; Prathibhani *et al.*, 2024).

One of the most prevalent fungal diseases affecting *C. verum* in Sri Lanka is leaf spot disease (LSD), caused by *Colletotrichum gloeosporioides* (Penz.) Penz and Sacc. (Anandaraj and Devashayam, 2004; Kumara, 1999a). LSD can occur at any growth stage, initially appearing as small brown spots on young leaves, which later coalesce into irregular necrotic blotches, leading to scorched appearance on mature leaves. In severe cases, lesions become papery, sometimes forming shot-hole patterns, and infection can spread to stems, causing dieback (Karunakaran and Nair, 1980).

Reports indicate the widespread LSD incidence across all major cinnamon-growing regions of Sri Lanka (Kumara, 1999a; Azad *et al.*, 2019b). In the Matara district, LSD was reported to cause 18% foliar damage (Kumara,1999b), although no significant correlation between yield and disease severity was observed. Globally, similar LSD conditions have been attributed to *Colletotrichum* spp. For example, *C. gloeosporioides* was identified as the causal agent on *Cinnamomum zeylanicum* in Taiwan (Fu and Chang, 1999), while *C. capsici* was responsible for red leaf spot in Tamil Nadu, India (Prakasam, 1991). In Karnataka, India, *C. gloeosporioides* led to partial drying of cinnamon seedlings (Bhat *et al.,* 1988), and a recent study identified LSD incidence rates of 50-70% across different locations. Molecular studies have further identified genetic diversity within LSD pathogens, revealing that four out of thirteen isolates in India belonged to *C. gloeosporioides,* while nine were classified as *Neopestalotiopis ellipsospora* with 99-100 % nucleotide similarity to documented strains (Venkataravanappa *et al.,* 2024). Additionally, *C. siamense* was identified as the causal agent of LSD on *Cinnamomum tamala* in Bangladesh, with disease severity ranging from 48% to 74.4% (Momotaz *et al.,* 2023).

Efforts to manage *Colletotrichum* infections have included the use of *Cinnamomum burmanni* leaf extracts to control anthracnose in chilli in Bali, Indonesia (Darmadi *et al.,* 2022). Advanced technologies, including image processing and machine learning, have been proposed for automated cinnamon disease diagnosis (Jayasena *et al.,* 2023). Azad *et al.,* (2019b) developed an LSD assessment key based on accessions from major cinnamon-growing districts in Sri Lanka, Matara, Galle, Kalutara, Kurunegala, Ratnapura and Hambantota, highlighting spatial variations in disease incidence. However, while spatial variability has been studied, temporal variation in LSD incidence and severity remains largely unexplored.

Understanding the temporal variation of LSD is crucial for developing effective disease management strategies and guiding breeding programmes aimed at improving resistance. However, comprehensive data on LSD's temporal variation in Sri Lanka remains scarce. This study aims to evaluate the temporal variation in LSD incidence (LSDI) and LSD severity (LSDS) among cinnamon accessions collected from major cinnamon growing regions of Sri Lanka and to examine correlations between LSDI and key morphological traits to determine potential morphological markers of disease resistance.

## MATERIALS AND METHODS

This study utilized a collection of forty cinnamon accessions from major cinnamon growing areas of Sri Lanka that were established at the Faculty of Agriculture, University of Ruhuna (UoR). These accessions were originally collected from major cinnamon-growing regions of Sri Lanka and documented by Azad *et al.*, (2019a). The study aimed to evaluate temporal variation in LSDI from September 2018 to December 2019, to determine LSDS, and to examine correlations between LSDI and selected morphological traits. LSDS was assessed in 2019 using a disease assessment key.

### *Variation of Average Monthly Rainfall and Temperature During the Experimental Period*

Average monthly rainfall (MRF) and temperature in September 2018 and December 2019 were obtained from the weather station at Department of Agricultural Engineering and Environmental Sciences, Faculty of Agriculture, University of Ruhuna.

### *Morphological Characterization*

The selected morphological traits were recorded following the descriptors for Cinnamon (*Cinnamomum verum*) developed by the Team of TURIS project (Azad *et al.*, 2016a).

### *Leaf Spot Disease Incidence (LSDI) and Leaf Spot Disease Severity (LSDS)*

The disease scale frequency was calculated based on the cinnamon LSD assessment key, which consisted of a 0–9 subjective scale of percentage of diseased leaf area (0 = no infection; 1 = up to 10% infection; 2 = 11–20% infection; 3 = 21–30% infection; 4 = 31–40% infection; 5 = 41–50% infection; 6 = 51–60% infection; 7 = 61–70% infection; 8 = 71–80% infection; 9 = more than 81% infection) which is indicated in Figure 1. The accessions were categorized based on their LSDS levels. To determine LSDI and LSDS, up to 100 mature leaves were randomly selected from each accession. Disease incidence and severity were visually assessed using the LSD assessment key, and the percentage of affected leaves was recorded.

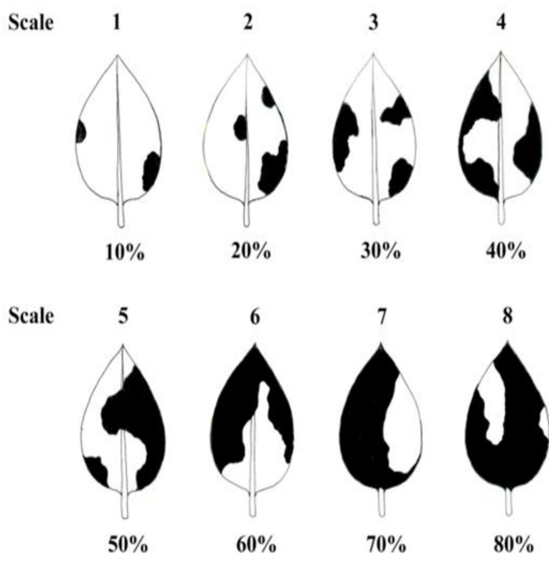



**Figure 1.** The leaf spot disease assessment key developed by Azad *et al.*, (2019b)

LSDI was calculated as the percentage of infected leaves per accession using the formula:

$$\mathrm{LSDI}(\%) = \left(\frac{L_1}{L_T}\right) \times 100 \quad \textbf{(1)}$$

$L_1$: Number of diseased leaves, $L_T$: Total number of leaves

LSDS was determined using the method described by (Viriyasuthee *et al.,* 2019), which considered the frequency of different disease severity classes, using the following equation:

$$\mathrm{LSDS} = \frac{\sum(\mathrm{CF} \times \mathrm{SRC})}{(\mathrm{L_T} \times \mathrm{MDI})} \quad \textbf{(2)}$$

LSDS: LSDS of a particular accession, CF: Class frequency, SRC: Score of rating class, $L_T$: Total number of counted leaves, MDI: Maximal disease index

Quantitative morphological data, including tree height (Th), leaf length (LL), leaf width (LW), leaf length-width ratio (Ll/Lw), petiole length (Pl), bark thickness (Bth), trunk circumference (Tc) and twig diameter (Twd) were recorded for all 40 accessions in September 2018.

### *Statistical Analysis*

Accessions were clustered based on variations in these morphological traits, and LSDI values of 2018 (DI1) and 2019 (DI2) through Principal Component Analysis followed by Ward's hierarchical clustering method in R software (version 4.4.3). A Paired T Test was conducted to compare LSDI between 2018 and 2019, determining the significance of temporal variations. Additionally, Pearson Correlation coefficients were calculated at 0.01% level of probability to assess the relationships between LSDI and morphological traits.

## RESULTS AND DISCUSSION

### *Variation of Average Monthly Rainfall and Temperature During Experimental Period*

Average monthly rainfall (MRF) of September 2018 and December 2019 were 95.62 mm and 189.4 mm, respectively. Average monthly temperature of September 2018 and December 2019 were $28^{0}$C and $27^{0}$C, respectively.

### *Leaf Spot Disease Incidence (LSDI)*

Figure 2 illustrates the variation in LSDI among 40 cinnamon accessions across two study years. All accessions exhibited 50% - 100% LSDI in both years, with noticeable variation between accessions and time periods. In 2018, the lowest LSDI was observed in KD5-1 (50.9%), while GB17 exhibited the highest incidence (96.9%). However, in 2019, after consecutive disease occurrences, KD5-1 showed an increased LSDI of 87.9%, whereas GB17 recorded a slightly lower LSDI of 93.9%. The lowest LSDI in 2019, was reported in KE5 (52.5%) while GK17 showed the highest incidence at 100%. Comparatively, in 2018, KE5 and GK17 recorded LSDI values of 70.2 % and 84.1 %, respectively.

A significant temporal variation was observed, with the lower mean LSDI in 2018 (76.97%) when the MRF was 95.62 mm, compared to a higher LSDI in 2019 (87.42%) corresponding to an increased MRF of 189.4 mm, as determined by the paired t-test.

The results suggest a positive correlation between increased rainfall and LSDI, aligning with findings from Kumara (1999a, 1999b), who reported that *Colletotrichum gloeosporioides* infections primarily occur in younger leaves during rainy weather. Younger foliage is highly susceptible to infection, and additional factors such as poor weed management, inadequate pruning, excessive shade, and high planting densities may further contribute to higher LSDI.

***Leaf Spot Disease Severity (LSDS)***

The LSDS of accessions varied from two to nine among 40 cinnamon accessions in 2019 (Figure 3). The lowest LSDS value (2.0) was recorded in KE5, MEA4, RL15, GAK3-1, MKG14 and KD4, while the highest value (9.0) was reported exclusively in Palol- 2. All other accessions had LSDS values ranging from 3.0 and 6.0 on the subjective disease severity scale. When the average LSDS was calculated regional wise as the accessions from Matara, Galle, Kalutara, Kurunegala, Ratnapura, Kandy and Hambantota, and grown at UoR, the values were 4.08, 3.30, 3.74, 2.00, 2.67, 3.43 and 3.50, respectively, in 2019. However, by the time the accessions were collected in June 2014 to April 2015, the average LSDS of cinnamon accessions from Matara, Galle, Kalutara, Kurunegala, Ratnapura and Hambantota were 4.50, 4.82, 4.74, 4.60, 3.65 and 3.91, respectively (Azad et al., 2019b). The comparison of data from 2014-2015 (Azad et al., 2019b) with 2019 shows that the average LSDS is higher in 2014-2015. This may be attributed to a potential decrease in LSD severity over time, environmental differences due to assessments being conducted in two distinct environments and time periods with varying climatic conditions, changes in pathogen virulence, or improved field management practices at the University of Ruhuna (UoR).

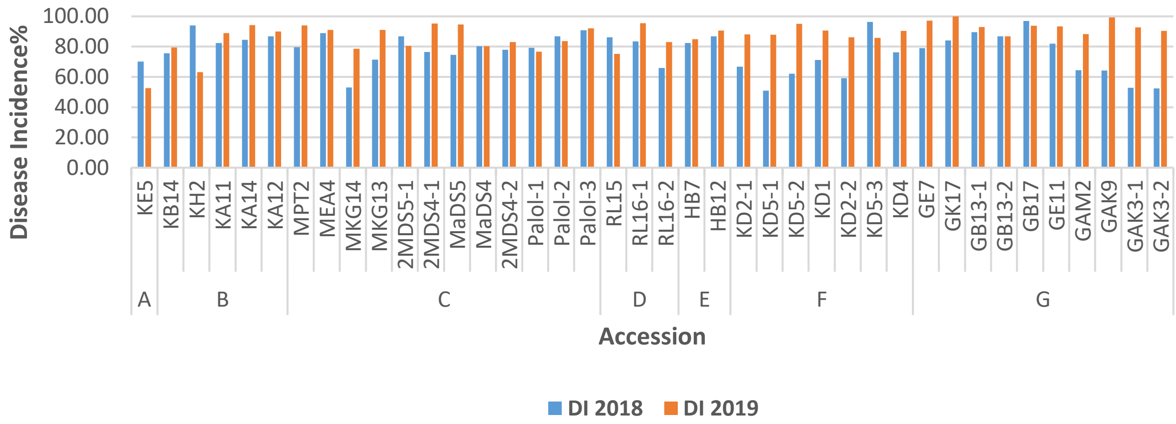



**Figure 2.** Variation of leaf spot disease incidence in cinnamon accessions was established at University of Ruhuna over two consecutive years. (The original locations of accessions, A: Kurunegala, B: Kalutara, C: Matara, D: Ratnapura, E: Hambantota, F: Kandy and G: Galle are indicated).

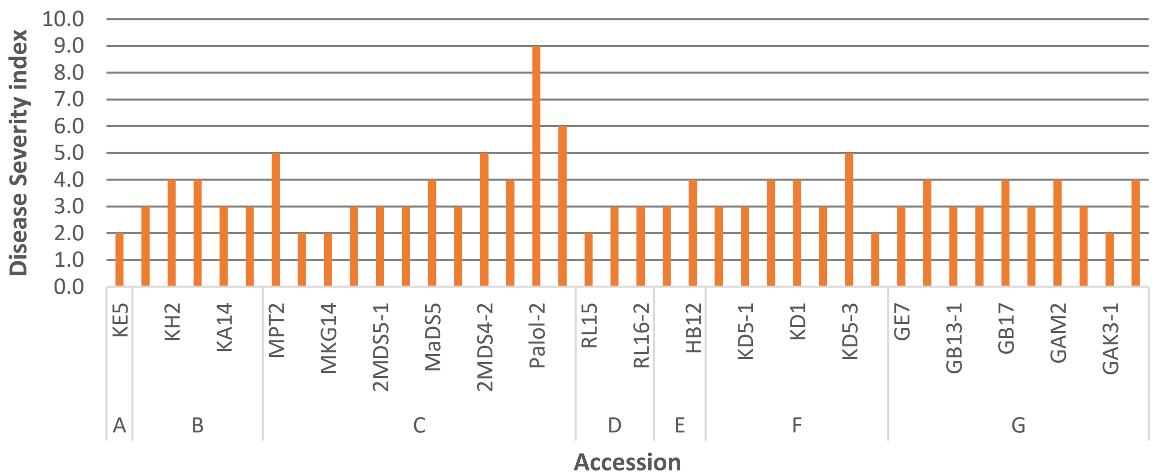
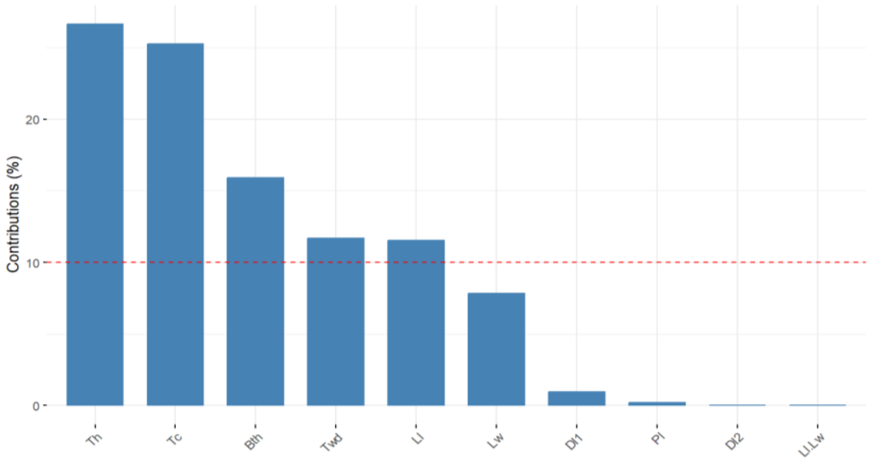
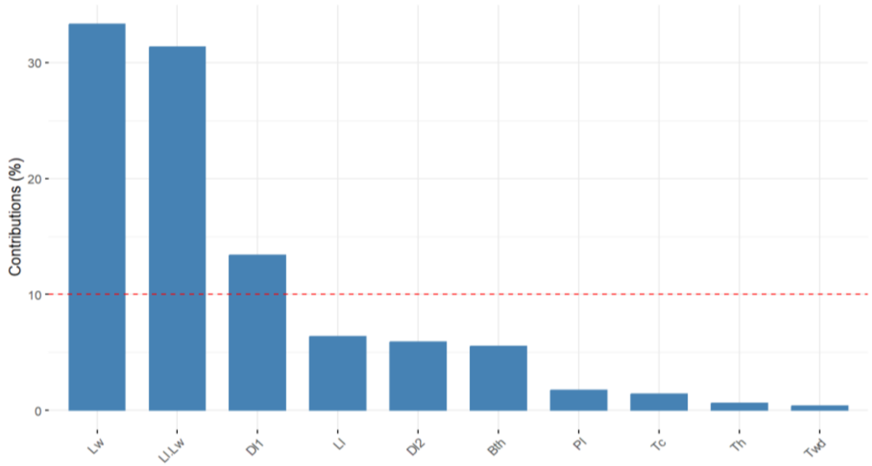



**Figure 3.** Variation of leaf spot disease severity across cinnamon accessions established at University of Ruhuna in December, 2019. (The original locations of accessions, A: Kurunegala, B: Kalutara, C: Matara, D: Ratnapura, E: Hambantota, F: Kandy and G: Galle are indicated.)

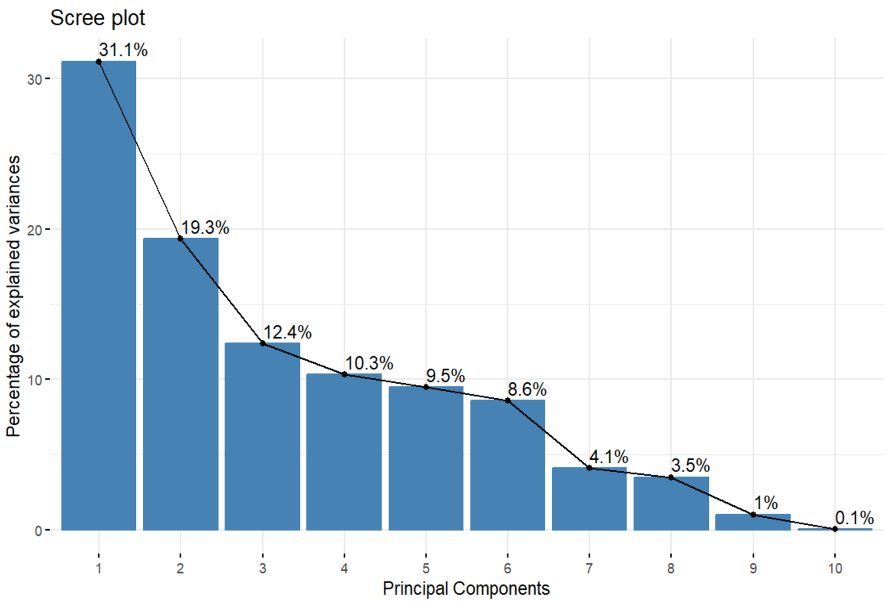
(A)


Contributions (%)
20
10
0
Th
Tc
Bth
Twd
Ll
Lw
Dl1
Pl
Dl2
Ll.Lw

(B)


Contributions (%)
30
20
10
0
Lw
Ll.Lw
Dl1
Ll
Dl2
Bth
Pl
Tc
Th
Twd

**(C)**




**(D)**

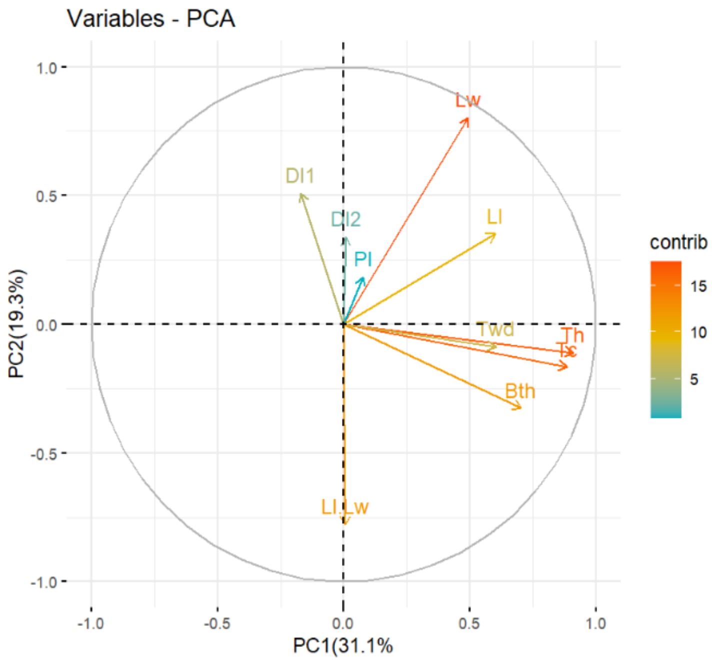



**Figure 4:** Variable correlation plots. A: Scree plot showing the total variance explained by each principal component, B: Contribution of variables to Principal Component 1 (PC1), **C**: Contribution of variables to Principal Component 2 (PC2), **D**: Variable-PCA biplot showing the correlation between variables and principal components. Abbreviations of variables are as follows: tree height (Th), leaf length (LL), leaf width (LW), leaf length-width ratio (Ll/Lw) and petiole length (Pl), bark thickness (Bth), trunk circumference (Tc), twig diameter (Twd), DI1 (disease incidence in 2018) and DI2 (disease incidence in 2019).

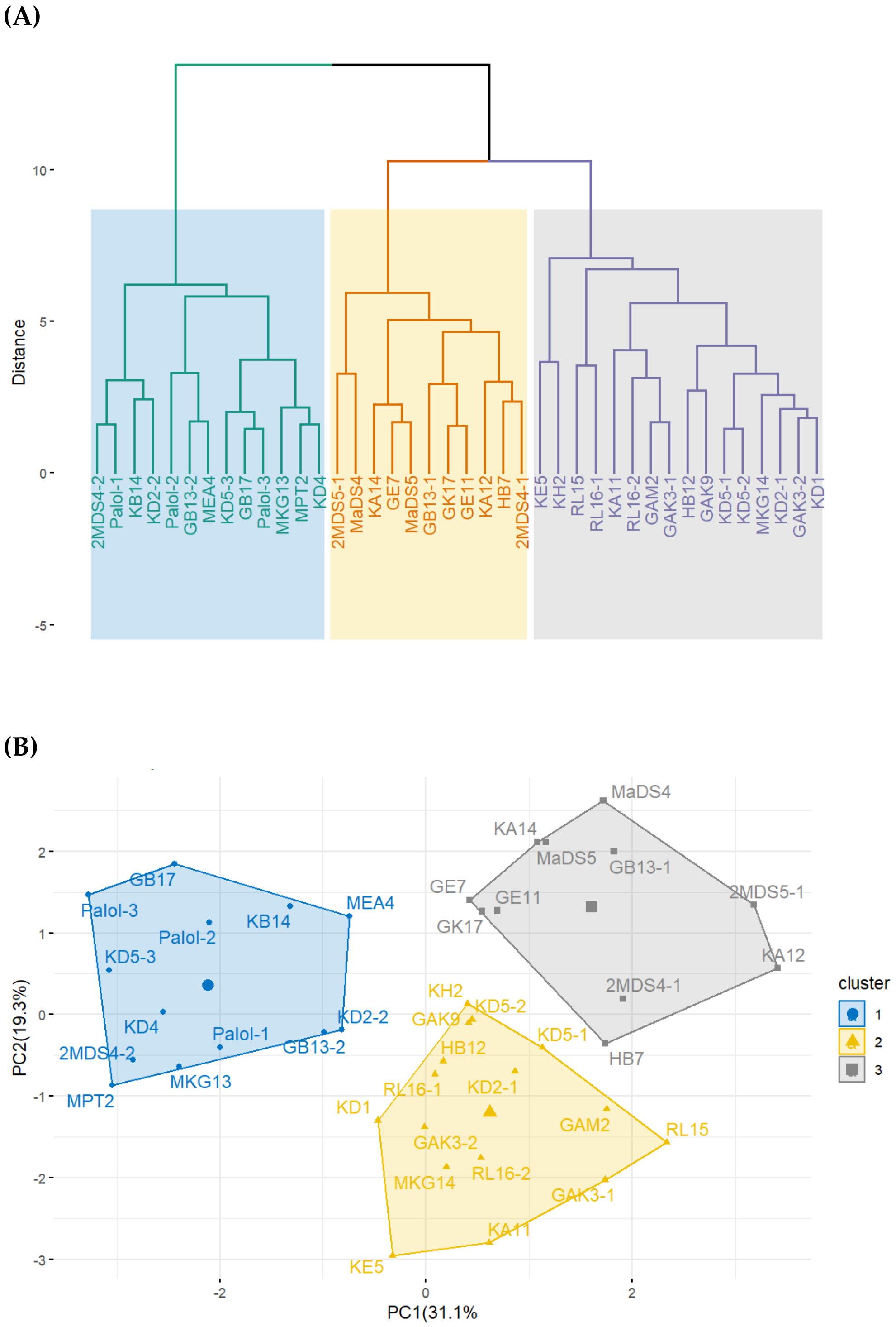



**Figure 5:** Clustering pattern of 40 accessions A: Dendrogram of accessions derived through Ward's hierarchical cluster analysis B: Factor map showing the relationship between accessions and PC1 and PC2 overlaid with hierarchical clustering pattern

***Principal Component Analysis and Cluster Analysis***

A Total of 10 variables (8 morphological variables and LSDI from 2018 (DI1) and 2019 (DI2) were grouped into four principal components (PCs), with Eigenvalues >1, collectively explained 73.2% of total variance among accessions (Figure 4-A). PC1 associated with tree height, bark thickness and trunk circumference, explained 31.1% of total variance (Figure 4-B). PC2 associated with leaf width and leaf length to width ratio, accounted for 19.3% of the variance (Figure 4-C). According to variable-PCA biplot, contribution of each variable to the PC1 and PC2 is indicated which is responsible for 31.1% and 19.3% of the total variation in the data set (Figure 4-D). Lw and Ll contribute strongly and are positively correlated to PC1 and each other. Disease incidences in 2018 and 2019 moderately contribute to PC2.

Cluster analysis grouped accessions into 3 distinct clusters at the distance of 9 (Figure 5-A). Although accessions within each of the three clusters were generally grouped together on the factor map, slight variations in their positions were observed in cluster 2 and 3. This may be due to within-cluster differences that are not fully captured by the first two principal components (Figure 5-B).

When LSDI and LSDS data of forty accessions were arranged according to these clusters, cluster 1 exhibited the highest average LSDS index of 4.2. Both cluster 2 and 3 reported average LSDS index of 3.2. These findings indicate that LSDI varies temporally among accessions. However, the variation in morphological traits did not correlate with LSDI, suggesting that disease susceptibility may be influenced by genetic, physiological, or environmental factors, that are not evident in these morphological traits.

The accessions KE5, MEA4, RL15, GAK3-1, MKG14 and KD4 demonstrated the lowest LSDS values, indicating their potential LSD resistant genotypes. Additionally, data on leaf oil constituents from RL15 and MKG14 revealed that eugenol was the main constituent with 74% in RL15 and 65% in MKG14 during the 2018 experimental period (Prathibhani *et al.*, 2024). The combination of low LSDS and high eugenol content in RL15 and MKG14 presents a promising opportunity for future cinnamon breeding programmes. Further evaluations and genetic studies are required to confirm their resistance mechanisms and potential commercial value.

## CONCLUSION

This study demonstrates significant temporal variation in LSDI among cinnamon accessions, with higher disease incidence in 2019, corresponding to increased rainfall levels. Morphological traits showed no significant correlations with LSDI, highlighting the need for further investigations into genetic and environmental influences on disease resistance.

Accessions such as KE5, MEA4, RL15, GAK3-1, MKG14 and KD4 emerged as potential disease-resistant genotypes, with RL15 and MKG14 showing high eugenol content. These findings emphasize the importance of integrating resistance and essential oil composition in cinnamon breeding programmes, ensuring the development of high-quality, disease resistant cultivars for sustainable cinnamon production.

## ACKNOWLEDGEMENT

Authors acknowledge the TURIS 2013 grant from University of Ruhuna and NARP/21/UR/AG/03 grant from the SLCARP, Sri Lanka for financial support.

## REFERENCES

Anandaraj M. & Devasahayam S. (2004). Pests and diseases of cinnamon and cassia. In: Cinnamon and Cassia (eds. P.N. Ravindran, K.N. Babu & M. Shylajah), pp. 239–258. CRC Press, New York, USA. https://doi.org/10.1201/9780203590874

Azad, R., Geekiyanage, S., Senanayake, G., Kumara, K.L.W., Pushpakumara, D.K.N.G., Wijesinghe, K.G.G., Ranawaka, R.A.A.K., (2016a). Descriptors for Cinnamon *(Cinnamomum verum)*. Team of TURIS 2013 Project, University of Ruhuna, 2016. ISBN 978-955-1507-49-7.

Azad, R., Jayasekara, L., Ranawaka, R.A.A.K., Senanayake, G., Kumara, K.W., Pushpakumara, D.K.N.G. and Geekiyanage, S., (2019a). Development of a core collection for Sri Lankan cinnamon germplasm based on morphological characterization using an eco-geographic survey. *Australian Journal of Crop Science*, *13*(9), pp.1473-1485. https://doi.org/10.21475/ajcs.19.13.09.p1561

Azad, R., Jayaprada, N.V.T., Ranaweera, S.A., Ranawaka, R.A.A.K., Jayasekara, L., Senanayake, G., Tamura, H. and

Geekiyanage, S., (2024). Diversity and morpho-chemo correlations of Cinnamon (*Cinnamomum verum* J. Presl) bark oil from Sri Lanka. *Journal of Agriculture and Food Research*, *18*, p.101500. https://doi.org/10.1016/j.jafr.2024.101500

Azad, R., Kumara, K.W., Senanayake, G., Ranawaka, R.A.A.K., Pushpakumara, D.K.N.G. and Geekiyanage, S., (2019b). Intensity of leaf spot and rough bark diseases in cinnamon accessions collected from major cinnamon growing areas of Sri Lanka. *Journal of the National Science Foundation of Sri Lanka*, *47*(3), pp.297-305. https://doi.org/10.4038/jnsfsr.v47i3.9403

Azad, R., Ranawaka, R.A.A.K., Senanayake, G., Kumara, K.W., Pushpakumara, D.K.N.G., Wijesinghe, K.G.G. & Geekiyanage, S., (2016b). Morphological variation of cinnamon (*Cinnamomum verum* Persl) germplasm in Matara District of Sri Lanka. *International Journal of Minor Fruits, Medicinal and Aromatic Plants (IJMFM&AP)*, 2(1), pp. 6-14. https://doi.org/10.1515/opag-2018-0025

Bhat, M.N., Hegde, R.K., Hiremath, P.C. and Naid, K.S., (1988). A note on the occurrence of a die-back on cinnamon in Karnataka. Current Research in University of Agricultural Sciences Bangalore. 1998: 17(11): 153. https://doi.org/10.5555/19912303860

Darmadi, A.A.K., Suriani, N.L., Darmayasa, I.B.G., Suaskara, I.B., Gari, N. and Fudholi, A., (2022). Cinnamon Leaf Extract to Control Anthracnose Disease on Chilli Plants in Bali: A Novel and New Potential. *International Journal of Pharmaceutical Research (09752366)*, *13*(1). https://doi.org/10.31838/ijpr/2021.13.01.155

Department of Cinnamon Development, 2025. Annual Performance Report 2024. Department of Cinnamon Development. 74 pp.

Fu C. H. and Chang T.T., (1999). Anthracnose of cinnamon. *Taiwan Journal of Forest Science.* 14: 513-515.

Jayasena, C., Subasinghe, G., Ekanayake, U., Nanayakkara, S., Chandrasiri, S. and Nadeeshani, M., (2023). CinnaSense: Enhancing Cinnamon Quality and Health with Image Processing. In *2023 5th International Conference on Advancements in Computing (ICAC)* (pp. 173-178). IEEE.

Karunakaran, P. and Nair, M.C., (1980). Leaf spot and dieback disease of *Cinnamomum zeylanicum* caused by *Colletotrichum gloeosporioides*. *Plant Disease*. 64(2): https://doi.org/220-221. 10.5555/19801362670

Kumara K.L.W. (1999a). Effect of some agronomic practices on the incidence of leaf spot disease

(*Colletotrichum gloeosporioides*) in cinnamon (*Cinnamomum zeylanicum* Blume) in southern region of Sri Lanka. SLAAS University of Ruhuna Seminar on “Pest control in the next millennium”, SLAAS, Colombo.

Kumara, K.L.W. (1999b). Study of leaf galls, leaf spots and scab-like condition of cinnamon (*Cinnamomum zeylanicum* Blume) in Matara District. In *Proc. Sri Lanka Assoc. Adv. Sci* (Vol. 29). Nov. 03rd 1999, Colombo, Sri Lanka. 65-29.

Mabberley D.J. (2008). Mabberley’s Plant Book: a Portable Dictionary of Plants, their Classifications and Uses, 3rd edition. Cambridge University Press, Cambridge, UK.

Momotaz, R., Alam, K.M., Arifunnahar, M., Islam, M.N., Alam, M.M., Hossain, M.M. and Siddique, S.S., (2023). *Colletotrichum siamense* leaf blight/spot: Characterization of a newly identified disease on *Cinnamomum tamala*. *Journal of Basic Microbiology*, *63*(8), pp.915-929. https://doi.org/10.1002/jobm.202300053

Prakasam, V., (1991). Red leaf spot of Cinnamon in Lower Pulney hills of Tamil Nadu. Indian Cocoa, Arecanut and Spices Journal. 14(3):123. https://doi.org/10.5555/19922317024

Prathibhani, M.R., Azad, R., Ranaweera, S., Jayasekara, L., Ranawaka, R.A.A.K., Senanayake, G., Abeynayake, S. and Geekiyanage, S., (2024). Variation in plant morphology and leaf essential oil composition of a representative *Cinnamomum verum* collection from Sri Lanka. *Journal of the National Science Foundation of Sri Lanka*, *52*(1), pp. 3-16. https://doi.org/10.4038/jnsfsr.v52i1.11086

Venkataravanappa, V., Sonavane, P., Muralidhara, B.M., Suryanarayana, V., Madhu, G.S. and Shivaraj, D.T., (2024). Characterization of *Colletotrichum gloeosporioides* and *Neopestalotiopsis ellipsospora* causing leaf spot and blight diseases of cinnamon in high humid tropic region of western Ghats. *Indian Phytopathology*, pp.1-8. http://dx.doi.org/10.1007/s42360-024-00790-6

Viriyasuthee, W., Saksirirat, W., Saepaisan, S., Gleason, M.L. and Jogloy, S., (2019). Variability of Alternaria leaf spot resistance in Jerusalem artichoke (*Helianthus tuberosus* L.) accessions grown in a humid tropical region. *Agronomy*, *9*(6), pp.268. https://doi.org/10.3390/agronomy9060268