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Assessing the Impact of Air Pollution on Peri-Urban Agriculture in Lahore City, Pakistan

Farrukh Rana[1*] and Saima Siddiqui[2]
[1,2]Institute of Geography, University 0f the Punjab, Lahore
***Correspondence:** farrukhrana1972@gmail.com

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Agriculture is a sector that is particularly susceptible to the negative impacts of air pollution due to the nature of the industry. Air pollution is a continuous global concern that significantly affects numerous sectors. In direct reaction to the increasing worries about the potential adverse impacts of air pollution on agricultural activities, we conducted an extensive research project that centered on eight specific plant varieties, namely cabbage, brinjal, bitter gourd, round gourd, okra, zinnia flower, vinca rosea, and red sunflower. The research leverages the capabilities of remote sensing to collect and analyze aerial and satellite imagery, providing a comprehensive view of agricultural areas and their interaction with air quality. To conduct an in-depth analysis of the effects that air pollution has on the expansion and maturation of plant life, these plants were grown in two distinct habitats (polluted and non-polluted) for a period of 21 and 42 days. The results of this study showed that contaminated environment cause plants to experience serious morphological and physiological disruptions. These disturbances included inhibited growth, disrupted photosynthesis, and modifications in leaf characteristics such as leaf area, leaf area index, and CF. All these factors have major consequences for food security and ecological balance. These measurements were employed to assess the impact of air pollution on the well-being of plants and their potential productivity. The outcomes of this study highlight how important it is to adopt comprehensive measures to reduce air pollution immediately. It highlights the significance of strong emissions controls, sustainable urban planning, and measures to reforest the earth. By integrating remote sensing technology, we can effectively monitor land use patterns, detect changes in vegetation health, and evaluate the spatial distribution of air pollutants. By addressing the root causes of air pollution and devising solutions, we can safeguard the agricultural sector, enhance environmental health, and ensure a sustainable future for ecosystems and human well-being.

Keywords: Air pollution; Agriculture; Plant species; Crop growth; Morphological changes; Physiological disturbance; Leaf area index; CF; Lahore; Pakistan

Introduction:

Airborne pollutants are substances found in the atmosphere at concentrations exceeding typical levels or in atmospheric regions where they would not naturally occur [1]. The intricate and continually evolving constitution of air pollution is influenced by various factors, including time, location, weather conditions, human activities, and numerous other elements [2]. Due to its dynamic nature, air pollution poses a multitude of challenges to both human well-being and environmental health. Industrial air pollution poses a double dilemma, as it not only poses a threat to human health but also has significant implications for the agricultural sector. The convergence of pollutants and pastoral activities presents significant economic challenges, manifesting in two ways: first, through the direct impact on agricultural productivity, resulting in reduced yields; and second, through the indirect consequences on the welfare of different stakeholders [2]. On a global scale, this issue represents a significant concern that intersects with both political discourse and scientific investigation [3]. Examining the evaluation of these external costs serves a twofold objective: it not only sheds light on the economic feasibility of industrial activities affected by pollution but also provides vital perspectives to guide well-informed policy development. Within this framework, there exists a complex interconnection between industrial pollution, agriculture, and wider socio-economic ramifications, hence necessitating a thorough and meticulous examination [2].

The origin of air pollution arising from industrial activity can be categorized into four main classes [4]. Firstly, emissions of pollutants during the combustion process, such as carbon monoxide, sulfur oxides, nitrogen oxides, and particulate matter, make a substantial contribution to atmospheric pollution [5]. Additionally, stationary activities, such as those encountered in furnaces and refineries, emit a mixture of photochemical oxidants, carbon monoxide, and sulfuric acid fumes into the atmosphere [6]. Additionally, the management of hazardous waste leads to the emission of noxious organic gases [7]. Mobile processes, which refer to self-propelled activities, make a significant contribution to the issue of air pollution by releasing hydrocarbons, nitrogen oxides, carbon monoxide, and particulate matter into the atmosphere [8],[9]. The complex network of industrial sources highlights the necessity for extensive research on the extensive impacts of these pollutants on human health and the environment [2]. The effects of air pollution on agricultural productivity are evident through two primary processes [2]. Initially, contaminants possess the ability to interfere with the biochemical and physiological processes of plants, thereby jeopardizing their overall growth and developmental patterns [10]. Additionally, the phenomenon of acid rain, resulting from atmospheric pollution, has a detrimental impact on soil quality by causing deterioration and reducing the accessibility of vital nutrients necessary for the cultivation of crops. It is crucial to acknowledge that these detrimental impacts are not solely accumulative but also persistent, presenting a prolonged obstacle to the sustainability of agriculture.

The productivity of crops is greatly affected by environmental factors, and air quality is a significant determinant in this context. Several studies have highlighted the substantial adverse effects of industrial air pollution on crop productivity [11],[12]. According to [13], it has been discovered that air pollution has the potential to cause significant losses in crop yields, ranging from 30% to 60%. The extent of these reductions in yield depends on the specific crop and the types of contaminants involved. Several dose-response equations have been developed to evaluate the correlation between pollutant concentrations and the resulting yield losses [14]. Considering the potential of air pollution [2][3][4][4] to disrupt the biochemical and physiological processes of crops [4], it can be implied that other vital factors, including nutrient availability and labor inputs, may also experience alterations. Moreover, it is important to note that industrial air contamination has the potential to interact in diverse ways with a range of influencing factors

[15]. The intricate dynamics between air pollution and agricultural productivity require a thorough comprehension of their varied relationships.

The productivity of crops is significantly impacted by the existing environmental conditions, and air quality has been identified as a crucial factor in determining crop production [16]. The presence of air pollution, specifically, presents a significant risk to the production of crops, leading to negative effects on agricultural yield. The economic impact of air pollution in the United States was substantial in 1997, as evidenced by statistics indicating a range of USD 40-50 billion [2]. In the context of Pakistan, there was a significant decrease in yields observed for three rice varieties during the 2003-2004 season. These reductions in yield added up to 43%, 39%, and 18% for the respective rice varieties when subjected to average seasonal concentrations of O_3 (70 ppb), NO_2 (28 ppb), and SO_2 (15 ppb) [11].

Four alternative approaches are commonly used in the assessment of agricultural losses caused by industrial air pollution. The dose-response equation is dependent on field experimental data to establish a definitive correlation between the concentration of pollutants and the resulting observed or estimated crop losses [17]. Furthermore, the methodology employed in the study was conducted by [18] to examine the impact of SO_2, NO_2, and O_3 on wheat and rice yields is based on a field comparison test strategy, specifically utilizing the open-top chamber method. Additionally, the regional comparison method investigates the effects of industrial air pollution on crop output by comparing two locations that share identical natural circumstances and socioeconomic features. One region functions as a control, remaining unaffected by external factors, while the other confronts the challenges posed by industrial air pollution [12],[14]. Finally, the fourth strategy involves estimating by utilizing pre-existing models. [19] Employed a biophysical crop model in conjunction with an economic supply model to forecast and assess the impacts of industrial air pollution on the agricultural sector. The many approaches employed in this study collectively provide significant insights into the complex difficulties presented by industrial air pollution on agricultural landscapes.

A pivotal aspect of this investigation involves the utilization of remote sensing techniques, enabling us to gather a comprehensive perspective of the peri-urban agricultural landscape. By harnessing aerial and satellite imagery, this research seeks to unveil critical insights into land use dynamics, changes in vegetation health, and the spatial distribution of air pollutants. Through these techniques, we aim to provide a holistic understanding of how air pollution influences peri-urban agricultural regions. By integrating remote sensing technology into our research framework, we aspire to furnish data-driven assessments of the interactions between air quality and agriculture in Lahore City. These findings will not only contribute to a more profound comprehension of the challenges faced by peri-urban agriculture but also inform strategies for sustainable land use and environmental preservation in rapidly urbanizing regions like Lahore.

The main aim of this study is to conduct a comprehensive evaluation of the effects of industrial air pollution on the growth and morphological characteristics of eight different plant species, including both flowering plants and essential vegetables. CF This evaluation is intended to be conducted in two divergent settings, with growth periods extending over 21 and 42 days. Our aim is to perform a comprehensive examination of parameter differences, encompassing leaf length, width, total leaf area, LAI, and CF, in order to enhance our comprehension of the impact of air pollution on plant growth.

Material and Methods:

Study Area:

The city of Lahore, as seen in Figure 1, has been chosen as the primary focus of this research due to its distinct attributes and the specific difficulties it presents. Lahore, a city with a population of 11.13 million inhabitants, has experienced significant urbanization, leading to the establishment of 42 prominent thoroughfares and an expansive road infrastructure. The process of urban growth in this region has been accompanied by a prominent presence of chemical, automotive, manufacturing, and pharmaceutical industries, highlighting its importance as a center for industrial activities [20]. However, the advancement in Lahore has encountered a substantial setback, as the city is currently grappling with a serious problem of air pollution, which has been exacerbated by extensive industrial activities and the large number of vehicles on the streets [21]. Significantly, the occurrence of photochemical haze throughout the winter season in Lahore serves to worsen the existing air quality problems [22]. The climate of the city is characterized by subtropical aridity, exhibiting an average annual temperature of 30°C. June is notable for being the month with the highest average high temperature, reaching 37°C. On the other hand, January is often associated with the coldest temperatures, since it has an average temperature ranging from 7°C to 18°C. Lahore exhibits a notable difference in temperature, with a variation of 16°C seen between the months characterized by the highest and lowest temperatures. The annual average rainfall in Lahore is 838.8 mm, indicating a semi-dry climate. Lahore faces considerable air quality challenges, as indicated by its Air Quality Index (AQI) of 161. The primary contributors to the city's diminished air quality, as per U.S. standards, are Particulate Matter 2.5 (PM2.5) and Ozone (O_3). The deterioration in air quality witnessed in Lahore can be attributed to various factors, including the emission of pollutants from vehicles and industrial facilities. This emphasizes the urgent necessity to address the problem of air pollution in the city.

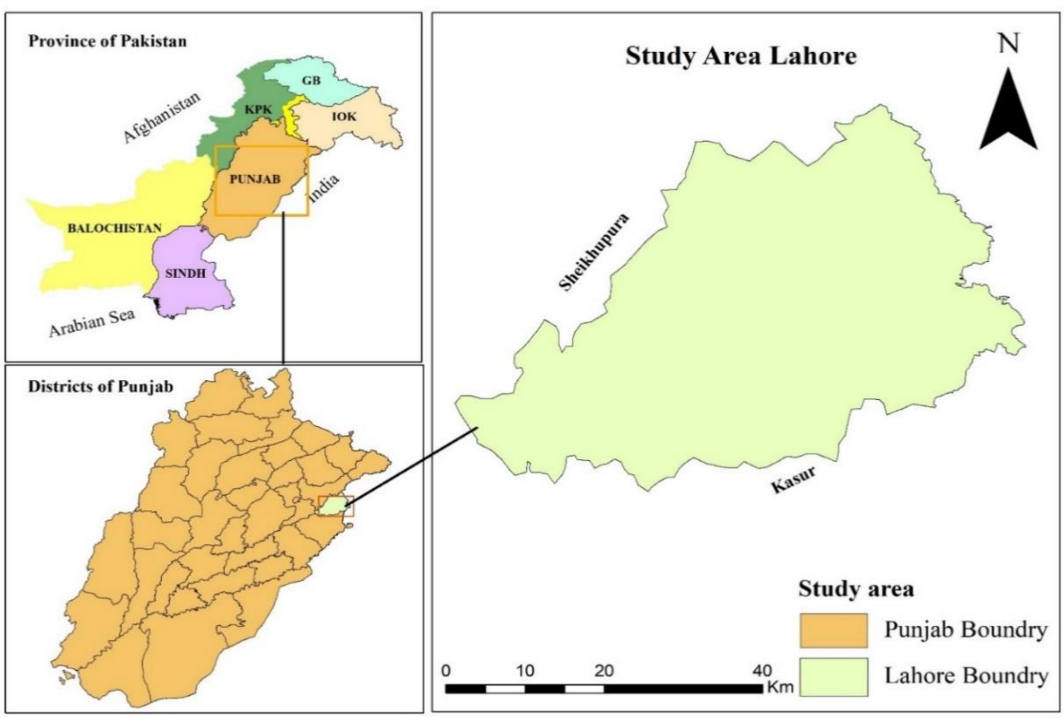

Figure 1: Geographical position of the Study Area in relation to Pakistan

Methods:

In this comprehensive methodology, we outline the approach employed to evaluate the effects of air pollutants on various plant species in both polluted and non-polluted environments. Our study encompassed the assessment of physical parameters and the use of LAI as a critical metric for understanding growth differences. In this study, we also utilized a combination of aerial and satellite remote sensing equipment. Aerial imagery was obtained through the use of unmanned aerial vehicles (UAVs), while satellite imagery was sourced from remote sensing satellites equipped with various spectral bands for comprehensive data collection.

Data Collection: We acquired a series of satellite and aerial images covering the peri-urban agricultural areas of Lahore City. These images were obtained over multiple time intervals, ensuring a comprehensive dataset to monitor changes in vegetation and land use. Image **Preprocessing:** Prior to analysis, all images underwent rigorous preprocessing steps, including geometric correction, radiometric calibration, and atmospheric correction. These steps aimed to ensure the accuracy and consistency of the imagery for meaningful analysis. Vegetation Index **Calculation:** To assess the health of vegetation, we calculated various vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), and others, from the remote sensing data. These indices provided quantitative measures of vegetation health and growth.

Air Quality Data Integration: Air quality data, including pollutant concentrations, were obtained from local environmental monitoring stations and integrated with the remote sensing data to correlate pollution levels with changes in vegetation health and land use patterns. Spatial Analysis: Utilizing Geographic Information System (GIS) software, we conducted spatial analysis to identify areas of high pollution concentration and their proximity to agricultural zones.

Statistical Analysis: Statistical techniques, including regression analysis, were employed to establish relationships between air quality indicators and agricultural parameters.

Selection of Physical Parameters:

To investigate the influence of air pollutants, we focused on three primary pollutants: Sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3). These pollutants were studied across diverse polluted environments, with specific attention given to their impact on selected plant species, including vegetables such as Cabbage, Brinjal, Okra, Bitter gourd, round gourd, and flowering plants like Zinnia flower, Vinca rosea, and red sunflower.

In this scrutiny, we collected three samples of each plant species, carefully cultivating them in both polluted and non-polluted environments. This dual-site approach facilitated meaningful comparisons between pollutant effects on plants in different settings. Visual assessments were conducted to observe and document the impact of air pollutants on plant growth and health, with a particular focus on Sulphur dioxide, nitrogen dioxide, and ozone, which exhibited the most pronounced effects. Study was conducted during the winter season when pollutant levels are typically at their highest, offering an ideal window to capture the combined effects of combustion and other pollutant sources. Assessments were performed at two critical stages of plant growth: 21 days and 42 days after germination.

All selected plant species were part of our sample study, with some cultivated in the polluted site within the main city center of Lahore District and others in a peri-urban area representing a non-polluted site. This enabled the investigation of differences in plant growth attributed to environmental pollution.

Quantitative Parameters Measured:

We meticulously measured various quantitative leaf characteristics, including leaf length, leaf width, leaf area, LAI, canopy area, and CF. The canopy, positioned above the ground, plays a pivotal role in perceiving sunlight and determining the amount available for photosynthesis. Its efficiency is influenced by factors such as wind, temperature, humidity, leaf shape, water availability, season, and, crucially, air pollutants present in the atmosphere.

Leaf Area Index (LAI) as a Key Parameter:

LAI, a vital parameter in plant ecology, quantifies the amount of foliage in a plant. It offers insights into the photosynthetic active area and its exposure to air pollutants, which significantly impact photosynthesis, transpiration, and respiration processes. LAI was employed as a robust metric to assess growth disparities between polluted and non-polluted environments. Additionally, it determined the potential leaf area available for gas exchange with the atmosphere.

Mathematically, LAI is expressed as LAI = leaf area / ground area (in units of m^2/m^2). It provides valuable information regarding the total leaf area relative to the ground area and is directly associated with sunlight interception by plants. Moreover, LAI serves as a key variable for predicting photosynthetic primary production and evapotranspiration, making it an essential reference tool for understanding crop growth and ecosystem dynamics.

This study highlighted the detrimental impact of air pollutants, particularly NO_2, SO_2, and O_3, on plants, as evidenced by comprehensive measurements and observations. These pollutants interfered with the accumulation of essential resources necessary for plant growth and development. In the following sections, we will delve into the data collected, analyses the specific measurements related to LAI, and discuss how these findings contribute to a holistic understanding of the impact of air pollutants on plant growth in polluted and non-polluted environments.

Results and Discussion:

Physical Parameters Assessment for 21 Days Germination:

In polluted areas, for the first 21 days of germination, the eight plant species under study, generally exhibited smaller dimensions and reduced leaf characteristics compared to their counterparts in non-polluted areas (Table 1). In polluted environments, cabbage plants displayed shorter lengths, narrower leaves, smaller total leaf areas, and lower leaf area indices than those in non-polluted areas. A similar trend was observed in brinjal, bitter gourd, round gourd, okra, zinnia flower, Vinca rosea, and red sunflower plants. These findings collectively indicate that air pollution has a detrimental impact on the growth and morphological characteristics of these plant species. For instance, cabbage plants in polluted areas had lengths ranging from 29.63 cm to 38.6 cm, while those in non-polluted areas grew taller, with lengths ranging from 37.59 cm to 44.704 cm. Similarly, brinjal plants in polluted sites exhibited lengths between 5.63 cm and 11.4 cm, while those in non-polluted sites were larger, ranging from 10.5 cm to 16.5 cm in length. This pattern held true for other plant species as well. In conclusion, the results highlight the adverse effects of air pollution on plant growth, with plants in non-polluted areas generally displaying larger dimensions and healthier leaf characteristics. This underscores the importance of addressing and mitigating air pollution to ensure the well-being and vitality of plant species and their crucial role in maintaining ecological balance.

Table 1: Physical parameters of leaf area, canopy and CF showing plant performance in polluted and non-polluted environment on 21 days germination period for different samples.

Plant Name and Specie		Polluted Site						Non-Polluted Site					
		Length	**Width**	**Leaf Area**	**leaf Area Index**	**Canopy**	**CF**	**length**	**Width**	**Leaf Area**	**Leaf Area Index**	**Canopy**	**CF**
Cabbage (Brassica Oleracea Var. Capitata)	S-1	38.6cm	32.57cm	71.2cm2	5.60cm	28.29cm	0.39 cm2	44.704cm	37.59cm	82.294cm	6.47cm	33.46	0.40
	S-2	32.63cm	27.57cm	60.20cm2	4.7cm	16.34cm	0.27cm2	43.95 cm	41.174cm	85.124cm	6.70cm	36.56	0.42
	S-3	29.63cm	40.01cm	69.64cm2	5.48cm	19.34cm	0.27cm2	44.7cm	37.85cm	82.55cm	6.5cm	30.90	0.37
Brinjal (Solanum Melongena)	S-1	11.4cm	7.35cm	18.75cm2	1.47cm	6.53cm	0.34cm2	16.5cm	10.5 cm	27cm	2.12cm	17.70	0.65
	S-2	8.9cm	5.72cm	14.64cm2	1.15cm	4.80cm	0.32cm2	10.8cm	7.8cm	18.6cm	1.46cm	9.925	0.53
	S-3	5.63cm	4.01cm	9.64cm2	0.75cm	3.12cm	0.32cm2	8.7cm	5.3cm	14cm	1.10cm	6.605	0.47
Bitter Gourd (Momordica Charantia)	S-1	6.3 cm	4.5 cm	10.8cm2	0.850cm	5.6 cm	0.51cm2	8.3 cm	9.1 cm	17.4 cm	1.37cm	9.90	0.56
	S-2	5 cm	7.1 cm	12.1cm2	0.95cm	6.3cm	0.52cm2	7.6 cm	11.1 cm	18.7 cm	1.47cm	11.5	0.61
	S-3	3.9 cm	6 cm	9.9cm2	0.77cm	4.6cm	0.46cm2	5.7 cm	7.6 cm	13.3 cm	1.04cm	6.8	0.51
Round Gourd/Tinda (Praecitrullus Fistulosus)	S-1	10.1cm	7.6 cm	17.7cm2	1.39cm	7.5 cm	0.42cm2	14.3 cm	12.8 cm	27.1 cm	2.13cm	14.3	0.52
	S-2	7.3 cm	5.2 cm	12.5cm	0.98cm	5.1cm	0.40cm2	11.5 cm	10.4 cm	21.9 cm	1.72cm	10.70	0.48
	S-3	6.7 cm	5.2 cm	11.9cm	0.93cm	4.5cm	0.37cm2	11.2 cm	8.4 cm	19.6 cm	0.91cm	8.64	0.44
Okra/Bhindi (Abelmoschus Esculentus)	S-1	2.9 cm	2.3cm	5.2cm	0.40cm	1.8	0.34cm2	4.9 cm	3.5 cm	8.4 cm	0.66cm	3.3	0.39
	S-2	1.7 cm	1.2 cm	2.9cm	0.22cm	0.8	0.27cm2	3.3 cm	2.6 cm	5.9 cm	0.46cm	1.9	0.23
	S-3	1.6 cm	1.5 cm	3.1cm	0.24cm	1	0.32cm2	3.4 cm	2.9 cm	6.3 cm	0.496cm	2.3	0.36
Zinnia Flower (Zinniasp)	S-1	3.2 cm	1.5 cm	4.7cm	0.11cm	1.25	0.26 cm2	6.2 cm	2.9 cm	9.1 cm	0.71cm	3.15	0.34
	S-2	4.6 cm	2.3 cm	6.9cm	0.54cm	1.85	0.26cm2	8.6 cm	4.4 cm	13 cm	1.02cm	5.25	0.40
	S-3	2.3 cm	1.7 cm	4cm	0.31cm	1.01	0.25cm2	6.2 cm	2.8 cm	9 cm	0.70cm	3.3	0.36
Vinca Rosea/Sada Bahar (Catharanthus Roseus)	S-1	0.5 cm	0.1 cm	0.6cm	0.04cm	0.32	0.53 cm2	1.3 cm	0.6 cm	1.9cm	0.14cm	1.2	0.63
	S-2	0.5 cm	0.2cm	0.7cm	0.055cm	0.39	0.55cm2	1.1 cm	0.4 cm	1.5cm	0.11cm	1	0.66
	S-3	0.75 cm	0.2 cm	0.95cm	0.07cm	0.58	0.61cm2	1.3 cm	0.6 cm	1.9cm	0.14cm	1.3	0.68
Red Sunflower (Thithonia Rotundifolia)	S-1	2.4cm	1.8cm	4.2cm	0.33cm	1.1	0.26cm3	5.4cm	2.8cm	8.2cm	0.64cm	2.80	0.34
	S-2	5.6cm	2.3cm	7.9cm	0.622cm	2.3	0.29cm3	7.6cm	4.3cm	11.9cm	0.93cm	4.50	0.37
	S-3	3.7cm	1.45cm	5.15cm	0.40cm	1.4	0.27	5.8cm	3.1cm	8.9cm	0.70cm	3.25	0.36

Average LAI, Leaf Area, and CF in Polluted, Non-Polluted Environment for 21 Days of Germination:

Comparing plant growth parameters between polluted and non-polluted environments highlights significant differences. For cabbage, in polluted areas, the LAI is 5.26 cm², while it is 6.55 cm² in non-polluted areas, indicating slower growth in polluted conditions (Table 2). Total leaf area and CF also show significant disparities, with differences of 16.3 cm² and 0.08 cm², respectively (Table 3). Brinjal exhibits a similar trend, with lower LAI (1.12 cm²) and total leaf area (14.3 cm²) in polluted environments compared to non-polluted areas (LAI: 6.55 cm², leaf area: 19.8 cm²) (Table 2). The CF is23 cm². Bitter gourd shows parallel variations: LAI is 0.85 cm² in polluted sites and 1.29 cm² in non-polluted areas, while leaf area and CF differ by 5.45 cm², respectively (Table 3). These differences emphasize the adverse effects of air pollution on plant growth and canopy attributes, underscoring the need for environmental mitigation measures.

In polluted environments, round gourd exhibits a leaf area index (LAI) of 1.1 cm², while it reaches 22.86 cm² in non-polluted settings (Table 2). LAI values for polluted and non-polluted sites differ by 1.58 cm², while leaf area and CF show disparities of 13.6 cm² and 10.81 cm², respectively (Table 3). Okra, in polluted areas, has an LAI of 0.28 cm² compared to 0.53 cm² in non-polluted environments. Leaf area in polluted and non-polluted sites varies by 3.16 cm², while CF 2.19 cm².

Table 2: Average Leaf Area, LAI, and CF in Polluted, Non-polluted Environment for first 21 days of germination

Plant Specie	Polluted Site			Non-Polluted Site		
	Leaf Area	LAI	CF	Leaf Area	LAI	CF
Cabbage	67.0cm²	5.26cm²	0.31cm²	83.3 cm²	6.55cm²	0.39cm²
Brinjal	14.3cm²	1.12cm²	0.32cm²	19.8 cm²	1.56cm²	0.55cm²
Bitter Gourd	10.9cm²	0.85cm²	0.49cm²	16.46 cm²	1.29cm²	9.4cm²
Round Gourd	14.0cm²	1.1cm²	0.39cm²	22.86 cm²	1.58cm²	11.2cm²
Okra	3.7cm²	0.28cm²	0.31cm²	6.86 cm²	0.53cm²	2.5cm²
Zinnia Flower	5.2cm²	0.32cm²	0.25cm²	10.36cm²	0.81cm²	3.9cm²
Vinca Rosea	0.7cm²	0.055cm²	0.56cm²	3.86cm²	0.13cm²	1.16cm²
Red Sunflower	5.75cm²	0.45cm²	0.27cm²	9.6cm²	0.75cm²	3.51cm²

Table 3: Difference in leaf area, LAI, and CF for the first 21 days of germination

Plant specie	Difference In Leaf Area	Difference In LAI	Difference In CF
Cabbage	16.3cm²	1.29cm²	0.08cm²
Brinjal	5.5cm²	0.44cm²	0.23cm²
Bitter Gourd	5.56cm²	0.44cm²	8.91cm²
Round Gourd	8.86cm²	0.48cm²	10.9cm²
Okra	3.16cm²	0.25cm²	2.19cm²
Zinnia Flower	5.16cm²	0.49cm²	3.65cm²
Vinca Rosea	3.16cm²	0.075cm²	0.6cm²
Red Sunflower	3.85cm²	0.3cm²	3.24cm²

Within 21 days of germination, Zinnia flowers in polluted sites exhibit a leaf area of 5.2 cm², whereas it's 10.36 cm² in non-polluted environments (Table 2). LAI differs by 0.49 cm², while CF varies by 3.45 cm². (Table 3) Similarly, red sunflowers display reduced growth in polluted areas, with a total leaf area of 5.75 cm², LAI of 0.45 cm², and a CF compared to 9.6 cm², 0.75 cm², and 3.51 cm², respectively, in non-polluted conditions. The differences in leaf area, LAI, and CF are 3.85 cm²d 3.24 cm², respectively. These findings underscore the detrimental impact of pollution on plant growth, with evident disparities in leaf area, LAI, and CF between polluted and non-polluted environment.

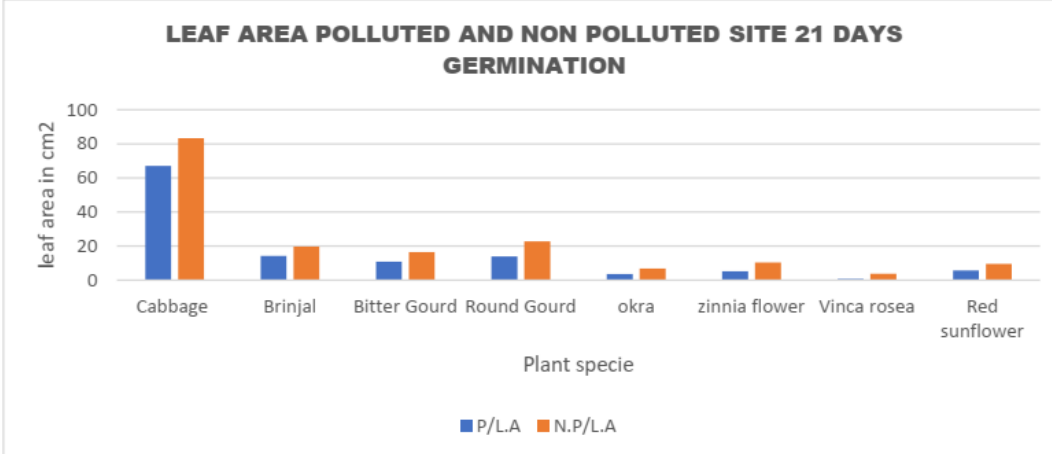

Figure 2: Leaf area of polluted and non-polluted site of selected plant species on 21 days germination period.

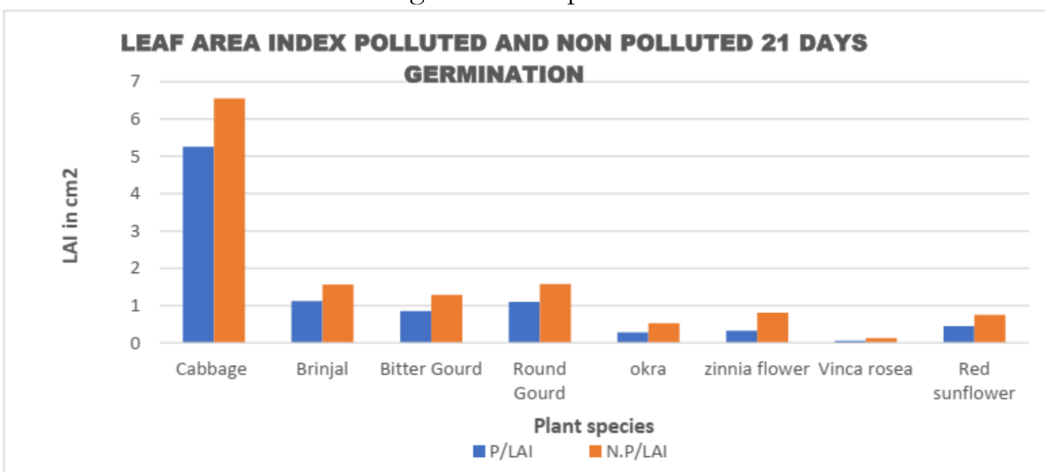

Figure 3: LAI of polluted and non-polluted site of selected plant species on 21 days germination period.

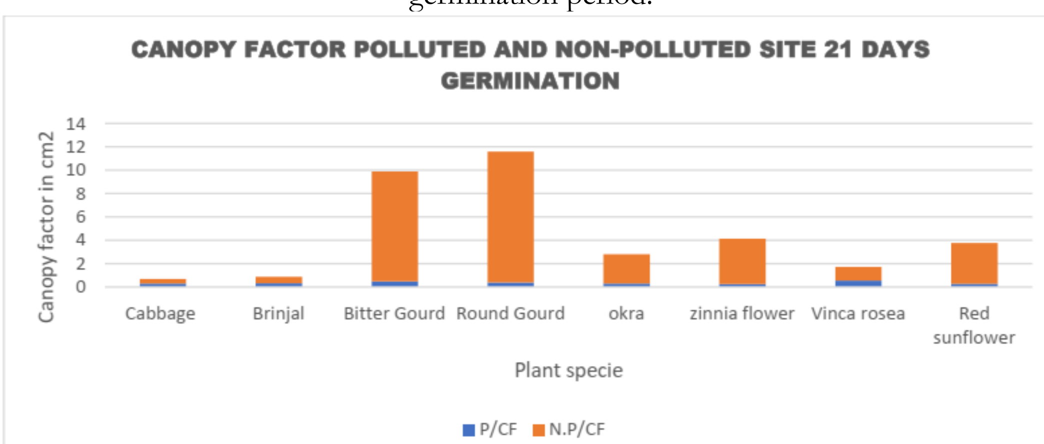

Figure 4: CF of polluted and non-polluted site of selected plant species on 21 days germination period.

Figure 2, 3, and 4 indicate the difference between leaf area, LAI), and CF for selected species for the 21 days of germination. A great difference has seen between the polluted and non-polluted plants samples. This clearly detect the effect of air pollution on the plants. The concern is not only the flowering plants but fruits, vegetables, and cereals too affecting food security. Air pollutants such as nitrogen dioxide, Sulphur dioxide and Ozone affect the plants badly. The sample vegetables of this research cabbage, Brinjal, Bitter Gourd, Round Gourd and okra grown in polluted environment had proved that LAI for Cabbage is 5.26cm^2, total leaf area is 67.0cm^2 and CF. For non-polluted site the leaf is index is 6.55cm^2, total leaf area is 83.3cm^2 and CF is 0.39cm^2. CF difference for leaf area index in polluted and non-polluted site is 1.29cm^2 on same growing period which clearly shows the difference in growth. Same is the case for leaf area where the difference is 16.3 cm^2 and for CF is 0.08cm^2. This clearly proved the detrimental impacts of pollution. In certain parts of the world, the ambient levels of NO_2 have led to reductions and deterioration in both crop and vegetable yields and their overall quality [23], [24]. The negative effect of raised O_3 concentration on crop plants, demonstrated by stomatal limitation, increased Reactive Oxygen Species (ROS) synthesis and, consequently, inhibition of photosynthesis,. Due to these factors decreased in leaf area, LAI or CF occur in polluted site.

Brinjal shows LAI 1.12cm^2 for polluted and 6.55cm^2 for non-polluted environment. Leaf area in polluted environment is 14.3 cm^2 and 19.8cm^2 in non-polluted environment. CF is 0.32 inn polluted and 0.55 in non-polluted environment. The difference in leaf area is 5.5cm^2, 0.44cm^2 for LAI and 0.23cm^2 for CF, the concentrations of O_3 have increased from a pre-industrial level of 10 ppb to about 50 ppb in 2000 and is predicted to reach up to 80 ppb by 2100. Most of this increase was driven by nearly three-fold increase in NOx and CO emissions. O_3 is a highly reactive molecule which induces formation of ROS, including hydrogen peroxide (H_2O_2), superoxide ($O-2$), and hydroxyl (OH) radicals and singlet oxygen in plants. That is why during this research the Brinjal plants of polluted site exhibited a decrease in growth rate.

Bitter Gourd shows same differences for the three parameters. is 0.85cm^2 and 1.29 in polluted and non-polluted environment respectively. Leaf area is 10.9cm^2 and 16.46 cm^2 in polluted and non-polluted environment respectively. For CF the polluted environment shows 0.49cm^2 and non-polluted 9.4cm^2 Round gourd leaf area index in polluted environment and 22.86cm^2 in non-polluted environment. LAI is 1.1cm^2 and 1.58cm2 in polluted and non-polluted site. The leaf area of polluted site is 14.0 cm^2 and 27.6cm2 in non-polluted CF site is 0.39cm^2 and 11.2cm^2 for non-polluted so there is a clear difference in growth and germination at the same period in two different environments. Difference value for LAI for both sites is 0.48cm^2, for leaf area is 8.86cm^2 and canopy factor is 10.9 cm^2.CF and LAI in polluted environment is 0.28cm^2 and 0.53cm^2 in non-polluted site. The leaf area of polluted site is 3.7cm^2 and 6.86cm^2 in polluted and non-polluted site respectively and the CF for polluted site is 0.31m^2 for non-polluted so there is a clear difference in growth and germination at the same period in two different environments. The difference values of LAI for both sites are 0.25 cm^2, for leaf area is 3.16 cm^2 and CF is 2.19 cm^2.

In 21 days, germination time the leaf area for Zinnia is 5.2cm^2 for polluted and 10.36cm^2 for non-polluted site. LAI is 0.32cm^2 and 0.81 cm^2 respectively and CF in Zinnia Flower shows same differences for both sites i.e., 0.25cm^2 and 3.9cm^2 respectively. Leaf area difference in polluted site is 5.16 cm^2 LAI is 0.49cm^2 and CF in 21 days germination. Red sunflower also shows same results lesser values for polluted and better growth parameters in non-polluted site. The total leaf area for red sunflower on 21 days germination is 5.75cm^2 and 9.6cm^2 on non-polluted site. LAI is 0.45cm^2 on polluted and 0.75cm^2 on non-polluted site. CF is 0.27cm^2 on polluted and 3.51cm^2 on non-polluted site. Difference value for leaf area is 3.85cm^2 for both sites. Difference value for LAI is 0.3cm^2 and 3.24cm^2 for CF

These figures clearly identify the effects on vegetable plant growth when the air pollutant was absorbed on their leaves. Leaves that were the food factory of every plant needs to be healthy and its morphology need not to be disturbed. This air pollutant disturbs the efficiency of photosynthesis too. Like these vegetables the flowering plants also did not show any good growth in polluted environment.

Physical Parameters Assessment for 42 Days Germination:

In the context of the 42-day germination period, it's evident that air pollution continues to exert a noticeable impact on the growth and morphological characteristics of the studied plant species in polluted areas when compared to their counterparts in non-polluted areas (Table 4). Cabbage plants in polluted sites displayed lengths ranging from 44.44 cm to 57.94 cm, while those in non-polluted areas exhibited greater lengths ranging from 123.44 cm to 137.73 cm. A similar trend was observed in brinjal, bitter gourd, round gourd, okra, zinnia flower, Vinca rosea, and red sunflower plants, with plants in polluted areas consistently showing reduced dimensions compared to those in non-polluted areas. For example, brinjal plants in polluted areas had lengths ranging from 8.44 cm to 17.1 cm, whereas those in non-polluted areas achieved greater lengths, ranging from 15.75 cm to 24.75 cm. This pattern persisted across all studied plant species. In conclusion, the results from the 42-day germination period reiterate the detrimental effects of air pollution on plant growth and morphology. Plants in non-polluted areas consistently displayed larger dimensions and healthier leaf characteristics, underlining the need for effective pollution control measures to preserve the vitality of plant species and their ecological contributions.

Table 4: Physical parameters of leaf area, canopy and CF showing plant performance in polluted and non-polluted environment on 42 days germination period for different samples.

Plant Name and Specie		Polluted Site						Non-Polluted Site					
		Length	**Width**	**Total Leaf Area**	**LAI**	**Canopy**	**CF**	**Length**	**Width**	**Total Leaf Area**	**LAI**	**Canopy**	**CF**
Cabbage (Brassica Oleracea var. Capitata)	s-1	57.94cm	48.85cm	106.795cm	8.4cm	64.59	0.60	123.44 cm	9.7cm	133.14cm	10.48cm	90.93	0.68
	s-2	57.94cm	41.35cm	99.29cm	7.8cm	30.69	0.30	127.68 cm	10.05cm	137.73cm	10.84cm	71.13	0.53
	s-3	44.44cm	60.015cm	104.45cm	8.2cm	32.68	0.31	123.82cm	9.75cm	133.57cm	10.51cm	61.80	0.46
Brinjal (Solanum Melongena)	s-1	17.1cm	11.025cm	28.12cm	2.21cm	12.2	0.43	24.75cm	15.75 cm	40.5cm	3.18cm	23.48	0.57
	s-2	13.37cm	8.58cm	21.95cm	1.72cm	8.75	0.39	16.2cm	11.7cm	27.9cm	2.19cm	15.85	0.56
	s-3	8.44cm	6.015cm	14.45cm	1.13cm	5.53	0.38	13.05cm	7.95cm	21cm	1.65cm	10.21	0.48
Bitter Gourd (Momordica Charantia)	s-1	8.5cm	6.1 cm	14.6cm	1.14cm	11.8	0.80	11.7	12.0	23.7	1.86cm	20.9	0.88
	s-2	7.2 cm	9.1 cm	16.3	1.28cm	13.1	0.80	10.5	13.7	24.2	0.146cm	21.5	0.88
	s-3	5.9 cm	7.4 cm	13.3	1.04cm	9	0.61	8.2	10.5	18.7cm	1.47cm	14.2	0.75
Round Gourd/Tinda (Praecitrullus Fistulosus)	s-1	12.7cm	10.5cm	23.2	1.82cm	16.6	0.71	17.1	14.9	32cm	2.51cm	26.3	0.82
	s-2	10.5 cm	8.2 cm	18.7	1.47cm	12.5	0.66	13.5	12.6	26.1cm	2.05cm	20.9	0.80
	s-3	8.9 cm	8.3 cm	17.2	1.35cm	10.3	0.59	13.2	11.6	24.8cm	1.95cm	19.9	0.80
Okra/Bhindi (Abelmoschus Esculentus)	s-1	4.5 cm	5.2cm	9.7	0.76cm	4.6	0.47	6.7	5.1	11.8cm	0.92cm	6.7	0.56
	s-2	3.9 cm	3.5 cm	7.4	0.58cm	3	0.40	6.1	4,1	10.2cm	0.80cm	4.8	0.47
	s-3	3.2 cm	3.7 cm	6.9	0.54cm	2.6	0.37	7.7	4.0	11.7cm	0.92cm	6.4	0.54
Zinnia Flower (Zinnia sp)	s-1	5.7 cm	3.2 cm	8.9	0.70cm	2.1	0.23	8.5	4.8	13.3cm	1.04cm	6.5	0.48
	s-2	6.6 cm	3.7 cm	10.3	0.81cm	3.1	0.30	10.9	6.8	17.7cm	1.39cm	10.5	0.59
	s-3	4.8 cm	3.2 cm	8	0.62cm	1.9	0.23	8.9	4.9	13.8cm	1.08cm	7.8	0.56
Vinca Rosea/Sada Bahar (Catharanthus Roseus)	s-1	1.7 cm	1.2 cm	2.9	0.22cm	0.8	0.27	3.0	1.2	4.2cm	0.33cm	1.7	0.40
	s-2	1.7 cm	1.4cm	3.1	0.24cm	1.1	0.35	3.5	0.9	4.4cm	0.34cm	2.4	0.54
	s-3	2.2 cm	1.5 cm	3.7	0.29cm	1.4	0.37	3.2	1.2	4.4cm	0.34cm	2.1	0.47
Red Sunflower (Thithonia Rotundifolia)	s-1	4.5 cm	3.2 cm	7.7	0.60cm	2.8	0.36	6.8	4.5	11.3cm	0.88cm	4.8	0.42
	s-2	7.6 cm	4.2 cm	11.8	0.92cm	4.5	0.38	10.1	6.7	16.8cm	1.32cm	7.3	0.43
	s-3	5.9 cm	3.9cm	9.8	0.77cm	3.7	0.37	7.1	6.2	13.3cm	1.04cm	5.6	0.44

Average LAI, Leaf Area, and CF in Polluted, Non-polluted Environment for 21 Days of Germination:

Table 5, and Table 6 shows the comparison of polluted and non-polluted environment. For cabbage the total leaf area is 103.5cm^2 in polluted and 134.8cm^2 and for LAI the value is 8.13 cm^2 and 10.7 cm^2 respectively. For CF it is 0.4cm^2 and 0.53cm^2 respectively. Total leaf area for Brinjal is 21.5cm^2 in polluted environment and 29.8cm^2 in non-polluted environment is 1.68cm^2 in polluted and 2.34cm^2 in non-polluted environment while CF is 0.42cm^2 and 0.53cm^2 respectively. For Bitter Gourd the total leaf area is 14.7cm^2 in polluted and 22.2cm^2 in non-polluted environment. For Round Gourd the total leaf area is 19.7cm^2 and 27.6cm^2 respectively and LAI is 1.54cm^2 and 2.17cm^2 in non-polluted environment

Table 5: Comparison of leaf area, LAI and CF for selected plant species on 42 days germination period

Plant Specie	Polluted Site			Non-Polluted Site		
	Leaf Area	**LAI**	**CF**	**Leaf Area**	**LAI**	**CF**
Cabbage	103.5cm^2	8.13 cm^2	0.40cm^2	134.8cm^2	10.7 cm^2	0.55cm^2
Brinjal	21.5cm^2	1.68 cm^2	0.4cm^2	29.8 cm^2	2.34 cm^2	0.53cm^2
Bitter Gourd	14.7cm^2	1.15 cm^2	0.73cm^2	22.2 cm^2	1.15 cm^2	0.83cm^2
Round Gourd	19.7cm^2	1.54 cm^2	0.65cm^2	27.6 cm^2	2.17 cm^2	0.80cm^2
Okra	8cm^2	0.62 cm^2	0.41cm^2	11.2 cm^2	1.11 cm^2	0.52cm^2
Zinnia Flower	9.06cm^2	0.71 cm^2	0.25cm^2	14.9 cm^2	1.17 cm^2	0.54cm^2
Vinca Rosea	3.26cm^2	0.25 cm^2	0.33cm^2	6.63 cm^2	0.33 cm^2	0.47cm^2
Red Sunflower	9.76cm^2	0.76 cm^2	0.37cm^2	13.8 cm^2	1.81 cm^2	0.43cm^2

Table 6: Difference in leaf area, LAI and CF for polluted and non-polluted sites on 42 days germination time.

Plant Specie	Difference L. A	Difference LAI	Difference CF
Cabbage	31.3cm^2	2.57cm^2	0.37cm^2
Brinjal	8.3cm^2	0.66cm^2	0.13cm^2
Bitter Gourd	7.5cm^2	0cm	0.1cm^2
Round Gourd	7.9cm^2	0.63cm^2	0.15cm^2
Okra	3.2cm^2	0.49cm^2	0.11cm^2
Zinnia Flower	5.84cm^2	0.08cm^2	0.29cm^2
Vinca Rosea	3.37cm^2	0.22cm^2	0.14cm^2
Red Sunflower	4.04cm^2	1.05cm^2	0.06cm^2

Table 6 indicate that comparing the growth of eight different plant species in polluted and non-polluted environments, it becomes evident that air pollution has varying effects on different plants. Cabbage exhibited a notable difference between the polluted and non-polluted environments. In the polluted site, it had a significantly smaller leaf area (31.3 cm^2 less) compared to the non-polluted site. The LAI was also reduced by 2.57 cm^2, and the CF dropped by 0.37 cm^2, indicating that air pollution hindered cabbage growth and development. Brinjal showed a moderate response to air pollution. While it had a smaller leaf area (8.3 cm^2 less) in the polluted environment, the difference in LAI was minimal (0.66 cm^2), and the reduction in CF was slight (0.13 cm^2). This suggests that brinjal was somewhat resilient to the effects of air pollution compared to other species.

Bitter Gourd exhibited consistent growth across both polluted and non-polluted environments, with no significant differences in leaf area or LAI. However, there was a minor reduction of 0.1 cm^2 in CF in the polluted environment. Round Gourd displayed noticeable differences between the two environments. In the polluted site, it had a smaller leaf area (7.9 cm^2 less), a lower LAI (0.63 cm^2 less), and a reduced CF (0.15 cm^2), indicating that air pollution had a detrimental impact on its growth. Okra showed a moderate response to air pollution. Its leaf area was smaller (3.2 cm² less) in the polluted environment, and there was a reduction of 0.49 cm² in LAI and 0.11 cm² in CF.

Zinnia Flower displayed significant differences in growth between the two environments. In the polluted site, it had a smaller leaf area (5.84 cm² less), a lower LAI (0.08 cm² less), and a reduced CF (0.29 cm²), highlighting the negative impact of air pollution on its development. Vinca Rosea exhibited moderate differences between polluted and non-polluted environments. It had a smaller leaf area (3.37 cm² less) in the polluted site, along with a reduction of 0.22 cm² in LAI and 0.14 cm² in CF. Red Sunflower displayed significant differences in growth between polluted and non-polluted environments. In the polluted site, it had a smaller leaf area (4.04 cm² less), a lower LAI (1.05 cm² less), and a reduced CF (0.06 cm²), indicating that air pollution had a notable adverse effect on its development. In summary, these findings highlight the diverse responses of different plant species to air pollution. While some plants, like bitter gourd, showed resilience, others, such as cabbage and red sunflower, experienced significant hindrances in growth and development when exposed to polluted environments. These variations underscore the importance of understanding how specific plant species respond to air pollution, as this knowledge can inform strategies for mitigating the negative effects on agriculture and ecosystems.

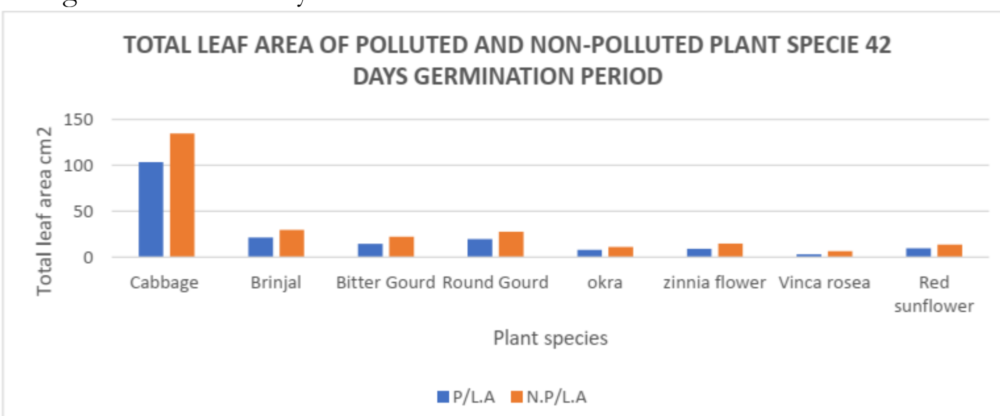

Figure 5: Difference of polluted and non-polluted environment for total leaf area for 42 days germination Period.

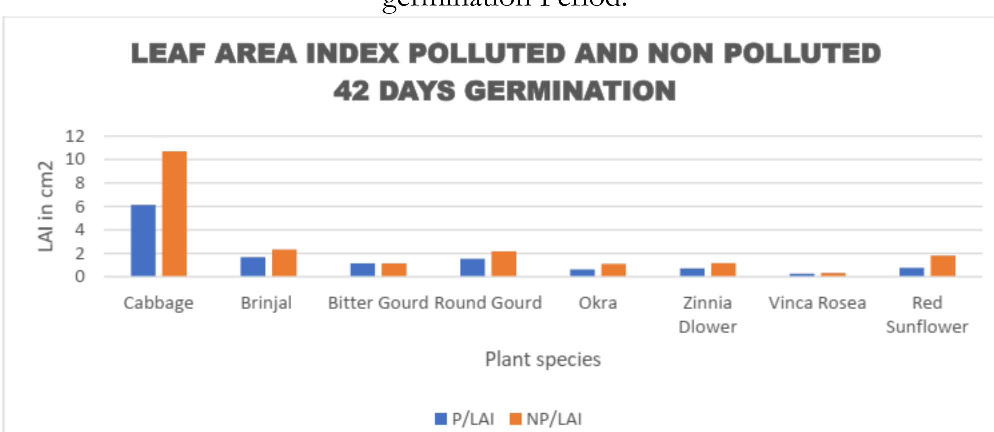

Figure 6: Difference of polluted and non-polluted environment for leaf area index for 42 days germination Period.

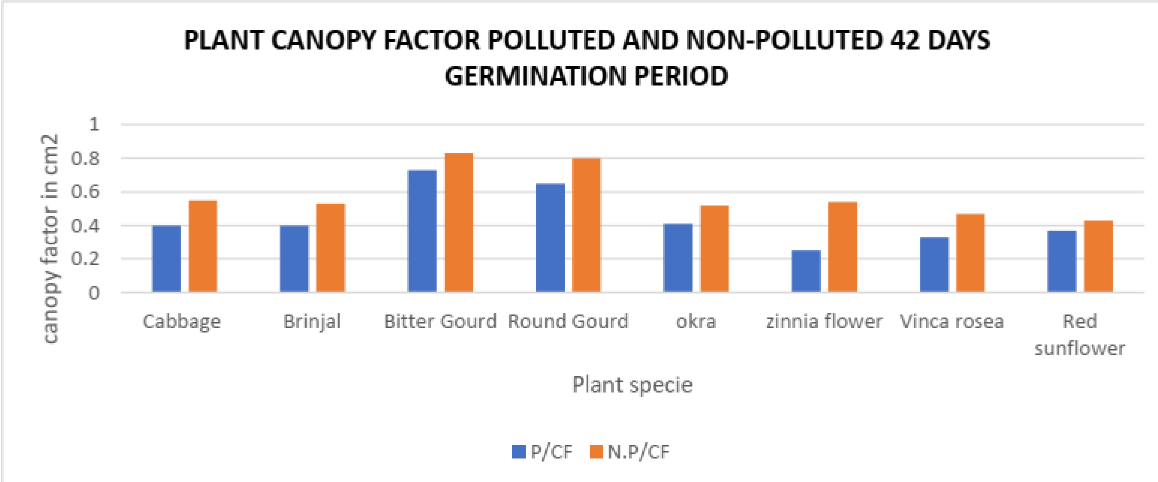

Figure 7: Plant canopy Difference of polluted and non-polluted environment for 42 days germination Period.

This study underscores the significant morphological and physiological changes observed in all the investigated plant species when exposed to air pollution. These changes manifested as reductions in key morphological attributes, including leaf length, width, total leaf area, LAI, canopy, and CF, within the polluted environment. Figure-5, 6, and 7 indicate the difference between leaf area, LAI, and CF species for the 21 days of germination. The slower growth across these parameters in plants from the polluted site, compared to those from the non-polluted site, provides compelling evidence of the adverse effects of severe air pollution in urban areas like Lahore. The presence of fundamental pollutants in the city's environment, as highlighted in Chapter Four, plays a pivotal role in shaping these outcomes.

In the 42-day seedlings, similar trends emerged as in the 21-day samples, with values consistently lower in the polluted site compared to the non-polluted site. For instance, in cabbage, the total leaf area was 103.5 cm^2 in the polluted environment and 134.8 cm^2 in the non-polluted environment, while LAI values were 8.13 cm^2 and 10.7 cm^2, respectively. The CF exhibited a similar pattern at 0.4 cm^2 in the polluted site and 0.53 cm^2 in the non-polluted site. Nitrogen dioxide, despite being vital for plant growth, can become problematic when absorbed in excessive amounts. These aerosols generated by pollution can interfere with photosynthesis by reducing incoming sunlight, ultimately diminishing yields.

For other species, such as brinjal, bitter gourd, round gourd, and okra, similar trends of reduced growth parameters were evident in the polluted environment. Sulphur dioxide and ozone, both prevalent air pollutants, disrupt essential processes in plants, including photosynthesis and metabolism, leading to visible symptoms like chlorosis and leaf dryness. Additionally, these pollutants can inhibit photosynthetic mechanisms, promote stomatal opening, and consequently increase water loss. The cumulative impact of sulphur dioxide, nitrogen oxides, fluorides, and ozone compound the adverse effects on plant yield, highlighting the intricate relationship between air pollution and plant growth. In flowering plants, this study further demonstrates that air pollutants can significantly hamper growth rates, potentially affecting the crucial process of flowering, as photosynthesis, a key driver of flowering, is hindered.

Discussion:

The results of this study highlight the significant influence of air pollution on many plant species, spanning both morphological and physiological dimensions. Our study examined the impact of air pollution on eight plant varieties over 21 and 42 days in both polluted and non-polluted environments. Air pollution significantly inhibited plant growth, disrupted photosynthesis, and altered key leaf characteristics. Remote sensing technology was used to assess air quality's spatial impact on agriculture. This underscores the need for urgent measures to reduce air pollution and emphasizes the role of remote sensing in monitoring and understanding this relationship.

In a comprehensive manner, it was observed that plants subjected to contaminated surroundings displayed discernible decreases in crucial morphological characteristics, such as the length and width of leaves, the overall leaf area, the LAI, as well as the canopy and CF. The observed effects were particularly pronounced when doing a comparative analysis between plants originating from contaminated locations and those originating from non-polluted regions. The extensive modifications observed in the morphology of plants provide persuasive evidence of the detrimental effects caused by severe air pollution, particularly in urban areas such as Lahore.

Significantly, the discrepancies in growth metrics remained present and even became more pronounced in seedlings aged 42 days, as compared to their counterparts aged 21 days. Consider cabbage as an example, wherein the overall leaf area exhibited a reduction from 134.8 cm^2 in the unpolluted setting to 103.5 cm^2 in the polluted location, accompanied by a simultaneous fall in LAI and CF. The findings provide insight into the diverse effects of air pollution on the growth and development of plants. Nitrogen dioxide, a vital component for the growth of plants, can serve to alleviate nitrogen deficit. However, it is important to note that excessive uptake of nitrogen dioxide might give rise to potential hazards. In addition, the existence of aerosols produced because of pollution has a detrimental impact on plant development and crop productivity by dispersing sunlight and diminishing the amount of light accessible for photosynthesis.

Brinjal, bitter gourd, round gourd, and okra, which are all essential constituents of the human diet, exhibited comparable patterns of diminished development characteristics in contaminated surroundings. Sulphur dioxide and ozone have been identified as prominent agents that impair crucial biological processes, including photosynthesis and metabolism. The manifestation of this disruption is evident through observable symptoms such as chlorosis, desiccation of leaves, and the presence of papery patches on leaf surfaces. Moreover, these contaminants induce the process of stomatal opening, resulting in an augmentation of water loss. The combined effects of sulphur dioxide, nitrogen oxides, fluorides, and ozone contribute to the exacerbation of damage to plants, highlighting the complex relationship between air pollution and plant growth. This study provides additional evidence that air pollutants have a significant impact on the growth rates of flowering plants. This can possibly disrupt the crucial process of flowering, as impaired photosynthesis impacts this key stage in the plant's life cycle.

This study offers significant findings regarding the adverse impacts of air pollution on the growth and development of plants. The implications of these findings extend beyond metropolitan areas and encompass agricultural regions as well. This is because air pollution has the potential to adversely impact food security by reducing crop production and compromising the quality of crops and vegetables. Addressing the issue of air pollution in a comprehensive manner is of utmost importance to ensure the protection of both plant health and human well-being. This entails the reduction of emissions of various pollutants such as nitrogen dioxide, sulphur dioxide, and ozone, as well as the implementation of methods to alleviate their detrimental effects on plant life, so promoting a sustainable and thriving ecosystem.

Conclusion:

This study highlights the substantial and adverse effects of air pollution on plant species, as evidenced by observable changes in their physical and biological characteristics in polluted areas when compared to unpolluted locations. The results indicate that plants exposed to pollution exhibit diminished growth rates, decreased leaf area, reduced leaf area index, compromised canopy development, and a decline in CF. Nitrogen dioxide, sulphur dioxide, and ozone have been identified as significant pollutants that have a detrimental impact on plant health. These pollutants are associated with observable symptoms including chlorosis (yellowing of leaves) and leaf desiccation. The findings underscore the imperative of mitigating air pollution, not alone for the well-being of individuals, but also for the conservation of botanical ecosystems and the maintenance of food stability. The integration of remote sensing technology has been instrumental in shedding light on the spatial dynamics of pollution and its impact on agriculture. It has provided a comprehensive view of the intricate relationship between air quality and plant life. The implementation of comprehensive strategies aimed at reducing the emissions of pollutants and mitigating their adverse effects is of utmost importance to establish and maintain a sustainable and flourishing ecosystem. Given the increasing environmental difficulties, it is crucial for politicians, companies, and communities to collaborate to address the issue of air pollution and ensure the protection of human and ecological well-being.

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