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# Acidity Trends in Rainfall Worldwide and Their Effects on Plants and Soil

**Muhammad Khudhair Hasan**
Al- Warka University College/Department of Pharmacy, Iraq/Basra
**Nimra Shahid**
Department of Eastern Medicine, Government College University Faisalabad Pakistan
**Ahmad Yar Sukera**
School of Biomedical Engineering and School of Science, Herbin Institute of Technology, Shenzen, 518055, China
**Muhammad Ramzan Kaleem**
Department of Eastern Medicine, Government College University Faisalabad Pakistan
**Sumra Asghar**
Department of Eastern Medicine, University of Poonch Rawalakot Azad Kashmir Pakistan
**Urooj Rehman**
Department of Eastern Medicine, Jinnah University for Women, Karachi Pakistan
**Shawana Maqsood**
Faculty of Eastern Medicine, Hamdard University Karachi, Pakistan
**Saima Siddique**
Department of Eastern Medicine, Government College University Faisalabad Pakistan
**Jawad Ahmed**
Ittefaq College of Allied Health Sciences, Lahore Pakistan
**Muhammad Zeeshan Naeem**
Department of Medical Laboratory Technology, International Institute of Science, Arts and Technology (IISAT University) Gujranwala, Pakistan
**Rimsha Zainab**
Department of Botany, Shaheed Benazir Bhutto Women University, Peshawar Pakistan
**Rabbbiyah Shams**
College of Conventional Medicine, The Islamia University of Bahawalpur
**Minahil Batool**
Department of Eastern Medicine, Government College University Faisalabad Pakistan
**Ameer Muhammad**
Department of Eastern Medicine, Government College University Faisalabad Pakistan

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**Syed Adnan Rahmat**
School of Public Health, Hebei Medical University ,Shijiazhuang, China
**Tahir Hafeez**
CEO/Founder Tahir Hoslistic Healing and Research Institute, Mandi Bahauddin, Pakistan
**Ussama Hafeez**
Department of Public Health, The University of Haripur, Haripur, Khyber Pakhtunkhwa, Pakistan
**Muhammad Tayyab Aslam**
Department of Eastern Medicine, Government College University Faisalabad Pakistan
**Muhammad Akram***
Department of Eastern Medicine, Government College University Faisalabad Pakistan. Corresponding Author Email: muhammadakram@gcuf.edu.pk

## ABSTRACT

Acid rain is of concern sto scientists and environmentalists because it kills nature and can possibly travel a long distance from where it is formed. Acid rain is any form of precipitation, such as rain or snow that increases the acidity of water with a pH value below 5.6. The primary causes of acid rain are some gases in the air, such as sulphur dioxide, nitrogen oxides, ozone, and organic acids. These gases are either natural or anthropogenic. India is the largest emitter of sulphur dioxide and also is experiencing increasing nitrogen dioxide, hence exacerbating the acid rain issue. Vegetation, being stationary, is directly impacted by acid rain. It can impact their growth, the way they metabolize food, and the way they are able to grow. It may be in various forms, such as killing leaves and flowers or altering roots and soil. Acid rain also harms genes that render plants stress-resistant. Acid rain acidifies soil and disrupts important processes such as nitrogen and carbon metabolism, breakdown of plant material, and the way microbes and enzymes work. This piece explains why acid rain happens, the way rainwater pH has varied globally over time, and the impact of acid rain on plants and soil communities.

**Keywords:** PH of the soil, organic acids, plant physiology, yield, and acid rain

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## Introduction

The majority of people globally are using more power as a result of issues like globalization and more cities emerging. The majority of the energy from coal is utilized in generating electricity, and the majority of the oil is utilized for transportation. All these activities add more pollutants and introduce small particles to the environment, which pollutes the air (Singh and Agrawal 2005). Increased energy utilization allows countries to grow and improve the lifestyles of individuals but raises many environmental concerns (Liu et al. 2019). Fossil fuels continue to provide over 80% of the world's energy as the increasing percentage of renewable forms in every region of the world since 2010 (World Energy Outlook 2019). In India, energy consumption grew faster than the world average, and oil use increased 5% in 2018 (Global Energy and CO2 Status Report 2019). Fossil fuel consumption in India increased from 208 million tons per year in 2000 to 708 million tons in 2017 (World Energy Outlook 2019). Acid rain is rain or suspended dry material containing high concentrations of nitric acid ($HNO_3$), sulphuric acid ($H_2SO_4$), and other compounds that contribute to the formation of acid rain, which acidifies rainwater with a pH of less than 5.61. Ducros first used the term in 1845, but Robert Angus Smith (1872) extensively studied it and documented its destructive impacts. Acid rain has numerous natural and anthropogenic sources. Natural sources also include processes like volcanic eruption, decaying plant, lightning, etc. Human sources include burning coal, oil, and natural gas in power generation, and agricultural activity emissions like use of fertilizers and pesticides, rice cultivation, and crop residue burning (Zhang et al. 2007). Acid rain is now an issue of worldwide significance in North America, Europe, and the majority of East Asia (Singh and Agrawal 2007). China is almost endemic for acid rain (Zhou et al. 2019).

India is the world's second-largest emitter of $SO_2$, and $SO_2$ and $NO_x$ emissions, the only major precursors to acid rain, are expected to keep rising through at least 2030 (Li et al. 2017; Andrade et al. 2020). Acid rain frequency has increased in India over the past 40 years (Bhaskar and Rao 2017). Agriculture also emits ammonia ($NH_3$) and other nitrogen outputs into the environment when farmers apply high amounts of fertilizer and pesticides. The products cause acid rain and worsen the problem (Sutton et al. 2017). Acid rain also kills ecosystems, which

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lead to the destruction of forests and decimation of plant and animal populations. Acid rain changes the soil, and it is more acidic (Fei et al. 2020), which affects the soil microbes (Wei et al. 2020). Acid rain kills plants, causing leaf loss, slow development, early leaf fall, and showing injuries such as spots (Bobbink et al. 2010; Du et al. 2017). Those plant components that are exposed to the air, like leaves, are directly impacted. This disallows plants from developing protective waxy coatings on their leaves and permits harmful ions to build up in the plant cells (Shu et al. 2019). Overloads of these harmful ions stress plants by producing toxic chemicals called reactive oxygen species (ROS) (Neves et al. 2009). Acid rain harms water bodies as well, making them too acidic for plants and animals to inhabit (Singh and Agrawal 2007). For all these problems, regulating the release of toxic products that create acid rain is extremely important. Different countries have chosen different strategies to suppress SO2 and NOx emissions. These include upgrading technology and equipment at industrial units and power plants, e.g., efficient furnaces, special boilers, and clean burning technologies like fluidized bed combustion (FBC) or dry scrubbers (Ahmadi 2020). Selective catalytic reduction (SCR), electrochemical reduction, selective non-catalytic reduction (SNCR), and wet scrubbers are employed to reduce NOx emissions (Gholami et al. 2020). Hydroelectricity, solar power, nuclear energy, wind power, and biofuels are gaining ground rather than coal (Mohajan 2018). Motor vehicle emissions are one of the primary causes of air pollution in Indian cities (WHO 2018).

**The Trend of Acid Rain Scenario**

North America, Europe, and China are all experiencing many problems caused by acid rain. Acid rain was first observed by people in the middle 1800s. In 1972, the United Nations met in Sweden and discovered about the environment and cited acid rain as a serious issue of pollution to many countries. Acid rain in Europe increases by 10% since the last 20 years. (Kowalok 1993) The rainfall in Canada, Denmark, and Germany has a pH between 4.2 and 4.5, while in the United States it is around 4.8. Rainfall in Poland in 2018 was from pH 3.64 to 7.36 and averaged 4.52 to 6.58. Rain in Coruña, Spain was 5.55 pH. Rain pH varies from 4.19 to 5.82 with a mean of 4.80 in some European countries such as Austria, Belarus, Croatia, Finland, Ireland, Italy, Norway, Switzerland and UK. The cause of the lowered pH is that there are

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higher levels of acidic elements like sulphate, chloride, and nitrate than balancing elements like calcium, magnesium, and ammonium in the air. (Abbasi et al. 2013) The US and Canada lowered pollution along their borders through policies like the Cross-State Air Pollution Rule and litigation.(Ahmadi 2020) These policies lowered sulphur and nitrogen in the air. The research identified the drops in sulphur dioxide and nitrogen oxide emissions, and acid rain, to programs like the Clean Air Interstate Rule, Acid Rain Program, and NOx Budget Program. It further stated that pollution levels are still too high and take a very long time to return to normal in acid-sensitive areas. (Sun et al. 2016)Acid rain is on the rise in cities such as São Paulo and Rio de Janeiro in Brazil, with rain's pH being equal to 3.5 and 4.0. In West Africa, Djougou had 5.19 pH. In western parts of the globe, SO2 is declining, which is advantageous for the environment. But in the eastern parts, especially in south-central Asia, it is worsening owing to a higher number of industries and people. Acid rain has deformed close to two million square kilometres in China, and the area is increasing. Rainwater pH varies between 3.8 and 4.5 in about 44 Chinese cities, and the mean is 5.6. In Japan, on the Japan Sea coast, rainwater pH varies from 4.7 to 5.3. Calcium carbonate carried by dust has the role of reducing the acidity of the rain. In Japan, the Pacific coast Ryori pH was around 5.2 in the 1970s but dropped to less than 4.7 in 2000, signalling an astronomical increase in acidity. (Shah et al. 2000).

**The Annual Trend of SO2 and NO2 Concentrations**

Countries near the equator, such as India, Bangladesh, Pakistan, and Thailand, have experienced the widest fluctuations in these gas levels (Table 6). These changes vary based on the source of contamination, apart from local, regional, and global meteorology (Swartz et al. 2020). Krotkov et al. (2015) wrote about SO2 and NO2 air pollution during 10 years between 2005 and 2015 based on data from Ozone Monitoring Instrument (OMI) on NASA's Aura satellite. They reported that in some places, the pollution increased or decreased significantly, while the trend was the reverse in some other places. During this period, the eastern United States has lost significantly in SO2 by 80% and NO2 by over 40%, primarily because of stricter regulations and improved technology. The European Environment Agency (2013) informed that SO2 emission in Europe decreased by approximately 80% from 1990 to 2011. SO2 concentrations in Western Europe decreased significantly following

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the 1980s and even fell below the limits of OMI to measure. NO2 concentrations did not particularly alter in most regions (Krotkov et al. 2015, 2016). Swartz et al. (2020) studied 21 years of trends in air pollution at South African Cape Point Global Atmosphere Watch (CPT GAW). They observed that the levels of NO2 and SO2 did not change significantly in the long period of 1995–2015, but from 1995–2004, there was a slight reduction in SO2 levels, which then gradually increased from 2005–2009. Between 1996–2002, NO2 levels went down then began to increase, reaching its peak in 2011. Although the most polluted region in the world regarding SO2 is the North China Plain, since 2011, it has experienced a decline with about a 50% declines between 2012–2015. NO2 levels did have their peak in 2011 following an increase by about 50% since 2009.

This increasing peak declined 40% between 2014–2015 due to the fact that the economy was recovering very slowly. These results are in line with what other researchers have indicated in their studies on the subject. Nevertheless, NO2 concentrations rose by approximately 13% every year between 2013 and 2015. As indicated by Ito et al. (2021), SO2 levels in Japan went down by approximately 75% during 30 years (1990–2018). Jang et al. (2017) reported that concentrations of SO2 in Busan, South Korea, increased between 2005 and 2014 due to local sources from vessels. NO2 concentrations, however, remained constant during the period.

**Growth and Yield**

Acid rain damages the agricultural ecosystem through inhibiting crop growth and reducing crop yields (Singh and Agrawal 2004). Herbaceous plants, i.e., grasses, are more vulnerable to acid rain than woody plants (Heck et al. 1986). Two-seed-leaved plants, i.e., dicots, are more damaged by acid rain than single-seed-leaved plants, i.e., monocots (Evans 1988; Knittel and Pell 1991). Acid rain affects plant morphology in different ways. For instance, it tenuates the waxy cuticle on leaves (Cape 1986), removes minute hairs from leaves, alters cell shape, causes collapsing mesophyll cells, blocks the minute pores on leaves, and forms scar tissue (Da Silva 2005). The negative impacts of simulated acid rain (SAR) on plant morphology are yellowing of leaves, killing of parts of the plant, withering, wilting, early senility, stunted growth, infection by pathogenic organisms, and even plant death (Milton and Abigail 2015). In a study by Milton and Abigail (2015), the effect of SAR was taken into

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consideration in okra plants at different levels of pH—1.0, 2.0, 3.0, 4.0, 5.0, 6.0, and 7.0 (which was the control) from seeding to the time when plants attained maturity. Plants wilted when acid rain with pH 1.0 was used. With pH 2.0, leaves turned yellowish and started to wilt earlier. Yellowing was seen on the edges of the plants at pH 3.0. Yellowing, black spots, and white powdery fungal growth were seen on the leaves at pH 4.0 and 6.0. Acid rain stress induces alteration in the soil microbe and fungi associated with plant growth promotion. Acidification reduces the number of nitrogen-fixing bacteria in the soil and hinders the release of nutrients from the soil. Moderate acidity results in increased mycorrhizal fungi, which assist in the removal of heavy metals. It also induces infection by pathogenic microbes and alters the root environment. PM is plasma membrane, Ca2+ is calcium ion, Mg2+ is magnesium ion, and Al3+ is aluminum ion.

**Physiological and Biochemical Performances**

As Lee and others noted in 1981, acid rain can physically and chemically harm a large portion of plants. The pigments in plants that are responsible for food synthesis are especially harmed by air pollution, and these pigments can show how acid rain can harm plants. The plants respond differently towards acid rain, but they all have fewer leaves of chlorophyll when it is raining acid. Acid rain affects food crops too, but the extent of plant damage varies with the kind of plant, age of the plant, intensity of the acid, and surroundings (Tong and Zhang 2014). Copolovici et al. (2017) found that when Phaseolus vulgaris plants were subjected to acidic solutions with a pH of 4.0 and 4.5, their photosynthesis-based traits like how easily their stomata open and how much carbon dioxide they absorb lowered significantly. After two hours, their rate of uptake had returned to normal, but their stomata opened more extensively with greater acidity. Moreover, Odiyi and Eniola (2015) justified that the leaves of cowpea that were treated with acid rain and had pH 2.0 and 3.0 had fewer contents of chlorophyll than those of pH 7.0, which served as the control. Maximum PSII efficiency, as Fv/Fm, is a valid parameter to check how the plants are functioning in terms of photosynthesis. A decrease in Fv/Fm suggests that plants are stressed, either as a result of ineffective use of light energy or through damage to PSII (Liu et al. 2018b). In rice, under acid rain treatment at pH 3.5 and 2.5, Fv/Fm decreases but does not change drastically at pH 5.5 in

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comparison to control. This means that extremely acidic rain not only affects regions of photosynthesis but also harms the internal structure inside the chloroplast (Wen et al. 2011). Sun and others (2016) have studied the effects of acid rain on chloroplast structure, photosynthesis, activity of ATP synthase, gene expression, hydrogen ions within the cells, and water content in rice seedlings. They found that at less than pH 4.5, the structure of the chloroplast does not differ significantly but is broken down. Acid rain at less than pH 4.0 decreased leaf water content and inhibited the production of some of the ATP synthase, leading to a loss in the activity of the ATP synthase, photosynthesis loss, and degradation of the chloroplast structure. But at pH 4.5, there was enhanced production of the components of the ATP synthase and activity, which favoured the plants. It suggests that acid rain affects the growth and formation of plants by changing the cell's interior acidity, affecting how the plant produces ATP and to what extent the photosynthesis occurs.

**Impact of AR on Genetically Modified Plants**

Recent studies by Raju et al. (2021) compared the effects of different pH of sulphuric acid on onion root. The researchers found that sulphuric acid with pH levels of 3.8, 4.08, and 4.4 was toxic to the root system and changed the genetic composition in the root cell compared to pH levels of 4.63, 5.32, and 7.0. pH 3.8 and 4.08 sulphuric acid minimized root size, i.e., smaller roots compared to the roots treated with pH 7.0. Mean root length and values that were established for every pH of sulphuric acid are presented in Table 8. It was found through research that low pH sulphuric acid, say 3.8, reduced the values of cells at different stages of division by inhibiting the process of cell division and reducing the mitotic index. This caused changes in the number or integrity of chromosomes. They also indicated some chromosomal abnormalities such as bridges and fragments of chromosomes, nuclear damage, micronuclei, polyploidy, binucleated nuclei, wandering chromosomes, and sticky chromosomes. 2-D gel electrophoresis proteomic analysis in Arabidopsis thaliana indicated that genes involved in the light reaction of photosynthesis, i.e., electron transport chain and light-harvesting complexes of photosystem I and II, were down regulated. Conversely, plant defence genes were activated where plants were treated with sulphuric acid (Liu et al. 2013). Camellia sinensis has also been investigated

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using transcriptomics where it is shown that photosynthesis, nitrogen, sulphur, and carbohydrate metabolism genes were regulated using sulphuric acid-treated plants (Zhang et al. 2020). Six genes for light reaction were down regulated, two of which are coding proteins of the PSII light-harvesting complex, two PSII subunits, one PSI subunit, and one ferredoxin-NADP+ reductase (FNR). Sulfuric acid thus harms leaves that disrupt light-harvesting and electron transport in PSII and PSI and leaves the plant vulnerable to fixing carbon.

Genes for starch and sucrose metabolism and glycolysis, for example, the phosphoglycerate kinase gene (PGK3), pectin methylesterase genes (PMEPCRA), enolase gene (LOS2), phosphoglycerate dehydrogenase gene (EDA9), and amidophosphoribosyl transferase gene (ASE2), were also down regulated under acidic pH 2.5 conditions. Deb Nath et al. (2020) assayed tomato plants from a greenhouse treated with sulphuric acid of pH 2.5 and a control of pH 5.6. 182 genes were up-regulated, 1046 were down-regulated, and 17,486 were not regulated. The result used 15 genes to validate if the data of gene expression were appropriate. They consisted of 11 genes related to plant secondary metabolites and 4 stress-responsive genes, including genes of bZIP, ERF, MYB, and WRKY protein families, which were silenced in treated plants.

**Conclusion**

Acid rain is a mammoth environmental issue that has been destroying nature for centuries. As the world is becoming industrialized and industries expand, air pollution has been increasing in pace, particularly from sulphur dioxide and nitrogen dioxide, which are the primary causes of acid rain. Humans used to believe that acid rain was primarily an issue in affluent, developed nations, but now it is occurring in numerous poor, developing nations as well. India, China, and Brazil are all experiencing increased acid rain. In hot, equatorial areas such as the tropics and subtropics, research indicates that acid rain is increasing and becoming more acidic upon falling. Acid rain destroys vegetation, forests, grasslands, and soil, impacting how they develop and function. Acid rain can alter the manner in which plants develop, the way their genes function, and even allow killer plants to dominate by a process known as allelopathy. Acid rain is also altering the physical and chemical structure of soil and the microscopic life forms within it. There have been attempts

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in certain developed nations to minimize acid rain through implementing rigorous pollution rules. But for developing nations, there should be a constant watch on the degree of pollution and strong regulations must be implemented in order to prevent the same. Also, there are more nitrogen oxides that are altering the composition of acid rain, so more studies have to be conducted to understand how such changes influence plants, animals, and soil. More studies are needed, particularly in countries like India and globally, to understand more about how acid rain would impact plants and ecosystems in the coming years and how various plants respond to such stresses. This can lead to improved environmental protection schemes.

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