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Review Article

Addressing Soil Acidity Challenges: Promoting Tea Production as Alternative Crop in Ethiopia -- Review

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Abstract

The prevalence of acidic soils in Ethiopia presents a significant obstacle to improving agricultural productivity and restricts the implementation of sustainable farming practices that could enhance food security. Acidic soils are typically defined by their high concentration of hydrogen ions and a lack of essential nutrients, which collectively create an environment that is less conducive to the growth of many vital staple crops. Consequently, farmers faced with these conditions often struggle to achieve optimal yields, which exacerbates food scarcity and undermines economic stability. To effectively combat the issues posed by acidic soils, it is imperative to adopt targeted soil management strategies that are specifically designed to address these challenges. This may include the implementation of soil reclamation techniques that aim to neutralize soil acidity and restore nutrient balance. Additionally, comprehensive initiatives must be undertaken to promote agricultural resilience, which could involve the cultivation of alternative crops that are better suited to thrive in acidic conditions, such as tea. This paper aims to provide a thorough examination of several key aspects related to the development and management of acidic soils in Ethiopia. It will investigate into the processes that contribute to the formation of acid soils, as well as the various types of acid soil present in the country, explore the distribution of acidic soils throughout Ethiopia, highlighting areas that are particularly affected and the implications for local farming practices. Furthermore, the analysis will address the specific impact of soil acidity on crop growth, yield, and quality. It will investigate how soil acidity influences the availability of essential nutrients for plants, thereby affecting the overall health and productivity of crops grown in these conditions. The promotion of tea production in Ethiopia is another critical topic that tea cultivation not only offers a viable alternative crop but also presents opportunities for economic development and diversification in agricultural systems. The mechanisms that confer aluminum resistance in tea plants will be discussed, as well as the ways in which aluminum can stimulate growth in these crops, thereby illustrating the unique resilience of tea plants in acidic environments. By addressing these complex issues holistically, the paper seeks to contribute valuable insights and foster a deeper understanding of how to navigate the challenges posed by acidic soils in the Ethiopian agricultural landscape.

Keywords

Acid Soil, Alternative Crop, Al^{3+}, Camellia Sinensis, Mechanisms, Tolerance

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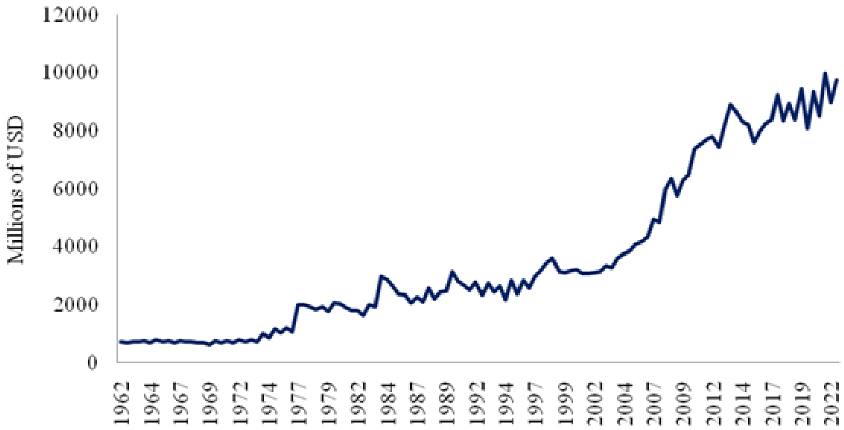
1. Introduction

Soil acidity is a significant abiotic constraint that hinders crop productivity due to low hydrogen potential (pH). It is a prevalent issue in land degradation, affecting approximately 50% of the world's potentially arable soils [1]. Various studies have reported substantial reductions in grain yield under low soil pH conditions. Currently, around 40% of Ethiopia's arable land is affected by soil acidity, with approximately 27.7% moderately acidic and 13.2% strongly acidic [2]. Consequently, most soils have a pH range of 4.5 to 5.5, low organic matter content, and limited nutrient availability [2]. In acidic soils, excessive aluminum primarily damages the root apex and hinders root elongation [3]. Poor root growth results in reduced water and nutrient uptake, leading to constraints in nutrients and water availability for crops grown in acidic soils. The tolerance of crops to acidic soil has become crucial in the agricultural development of humid tropics [4]. The use of tolerant crop varieties is considered the best complement to non-genetic management options for addressing the problem of aluminum toxicity [5, 6].

Tea (*Camellia sinensis*) is a suitable candidate for this approach, as it thrives in acidic soil conditions, is highly tolerant of aluminum, and even requires aluminum for optimal growth [7, 8]. The cultivation of tea as an industrial crop plays a significant role in rural development, poverty alleviation, and food security in many developing nations. Global tea production is estimated to be worth over USD 17 billion annually, and the global tea trade is valued at USD 9.7 billion, providing a significant revenue stream for exports (Figure 1). Smallholders produce 60% of the tea consumed worldwide, enabling them to create profitable jobs in rural areas and helping households and communities better meet their nutritional and food security needs [9].



Source: [9]

Figure 1. *Global tea trade (millions of USD).*

Consequently, the promotion of tea cultivation in areas of Ethiopia susceptible to soil acidity is a critical factor for rural development, poverty reduction, food security, enhancement of foreign exchange, and the creation of employment opportunities for women and youth, which has been thoroughly examined and documented.

2. Literature Review

2.1. Acid Soil Development Process

Soil acidification is a multifaceted phenomenon influenced by various factors contributing to soil acidity. It can be viewed as the cumulative effect of both natural and human-induced processes that lower the pH of the soil solution [10, 11]. Naturally, soil acidification occurs through mechanisms such as the leaching of basic cations induced by carbonic acid, the weathering of acidic parent materials, the breakdown of organic matter, and the deposition of atmospheric pollutants like SO_2, NH_3, HNO_3, and HCl [12, 13]. Human activities, including the repeated use of acidifying fertilizers such as sulfur or ammonium salts, the exchange of hydrogen ions on root surfaces with soil bases, and the microbial generation of nitric and sulfuric acids, further accelerate soil acidification, potentially resulting in elevated concentrations of soluble Al3+ in the soil solution [14, 15]. The extraction of cations, particularly from soils with limited base reserves due to the cultivation of high-yield crops, contributes significantly to soil acidity [16-18]. Soil acidification persists until a state of equilibrium is achieved between the removal and replenishment of essential cations such as calcium (Ca) and magnesium (Mg), which are lost through leaching and crop harvesting, and are restored through the decomposition of organic matter and the weathering of minerals [6, 19]. As rainfall increases, a threshold is reached where the rate of base removal surpasses the rate at which they are released from non-exchangeable forms. Consequently, regions with high precipitation are more prone to developing acidic soils [20]. Over time, excessive rainfall leaches vital nutrients like Ca, Mg, and potassium (K) that mitigate soil acidity, replacing them with aluminum (Al) from exchange sites [21, 22]. Prolonged application of high nitrogen (N) fertilizer rates, cation loss through leaching, and changes in land use, such as continuous cropping without organic amendments, are among the human-induced factors that exacerbate soil acidity [23, 24]. Hydrogen is introduced through ammonia-based fertilizers (NH_4), urea-based fertilizers ($CO(NH_2)_2$), and organic fertilizers containing proteins (amino acids). The conversion of these nitrogen sources into nitrate (NO_3^-) results in the release of hydrogen ions (H^+), contributing to soil acidity. Additionally, nitrogen fertilizers elevate soil acidity by enhancing crop yields, which in turn increases the removal of basic elements. Therefore, the application of fertilizers containing $NH4^+$ can ultimately lead to increased soil acidity and a reduction in pH [25, 26]. Alterations in land use and management practices frequently affect various physicochemical and biological properties of the soil, which are reflected in agricultural productivity [27]. Soil characteristics such as bulk density, soil organic matter (SOM) content, and CEC degrade due to the transformation of natural forest and range lands into cultivated land. For instance, the SOM levels in grazing and cultivated lands have decreased by 42.6% and 76.5%, respectively, compared to forest soil. Additionally, [28] highlighted the adverse impact of land use or land cover change on certain physicochemical properties of Ferralsols in the humid forest zone of Southern Cameroon, such as clay, silt, and sand fractions. Aluminum saturation increased with soil depth, with top soils showing acidity issues and sub-soils exhibiting Al toxicity.

2.2. Types of Soil Acidity

There are generally two types of soil acidity: active acidity, which arises from high H^+ concentration in the soil solution due to carbonic acid (H_2CO_3), water-soluble organic acids, and hydrolytically acid salts; and exchangeable acidity, which refers to H and Al ions adsorbed on soil colloids. An equilibrium exists between the adsorbed and soil solution ions (i.e. active and exchange acidity), allowing for easy conversion from one form to another. This equilibrium state is of significant practical importance as it forms the basis for soil buffering capacity or its resistance to pH changes. When adsorbed H and Al ions move into the soil solution, its acidity is also known as adsorbed, potential, or reserve acidity. Bases (e.g. lime) added to the soil first react with the active acidity in the soil solution, followed by the gradual release of acidity from the reserve acidity pool into the active form.

2.3. Distribution of Acid Soil in Ethiopia

The distribution of acid soils in Ethiopia poses significant challenges to agricultural productivity and food security in the region. These soils, characterized by high levels of hydrogen ions and a lack of essential nutrients, severely limit crop yields and hinder the growth of important staple crops. Factors such as deforestation, intensive farming, and climate change exacerbate the situation, leading to soil degradation and increased acidity. As a result, farmers struggle to maintain their livelihoods and adapt to changing agricultural conditions, often resulting in reduced income and heightened vulnerability to food insecurity. Moreover, the progression towards soil acidification can have adverse effects on local biodiversity and ecosystem health, impacting water quality and increasing the risk of crop diseases. Approximately 43% of cultivated land in Ethiopia is affected by soil acidity, with Nitosol/Oxisol soils being the primary soil classes affected [6, 29, 30]. These soils are predominantly acidic, with over 80% of Nitosol-derived land being acidic. Notable areas severely impacted by soil acidity in Ethiopia include Ghimbi, Nedjo, Hossana, Sodo, Chencha, Hagere Mariam, and the Awi Zone of the Amhara Regional State [29]. Around 28.1% of these soils are classified as strongly acidic (pH 4.1-5.5), which are typically infertile due to potential toxicities of aluminum and manganese, as well as deficiencies in calcium, magnesium, phosphorus, and molybdenum. Addressing the challenges posed by the spread of acid soils requires the implementation of targeted soil management practices, the promotion of soil reclamation techniques, and comprehensive efforts to enhance agricultural resilience, such as the adoption of alternative crops, which are crucial in Ethiopia [31, 32].

2.4. Effect of Soil Acidity on Crop Growth, Yield and Quality

Soil pH is a critical chemical property of the soil that has a significant impact on plant growth. Soil acidity, with a pH of 5.5 or lower, can hinder the growth of sensitive plant species, but has minimal effect on insensitive species, even at a pH lower than 4. Certain crops, such as cotton, alfalfa, oats, and cabbage, do not thrive in acidic soils and are better suited to neutral soils with a pH range of 7-8. On the other hand, wheat, barley, maize, clover, and beans grow well on neutral to mildly acid soils with a pH of 6-7. Grasses generally tolerate acidic soils better than legumes, and liming to a pH of 5.5 may help control acidity without affecting yield. Legumes, however, require more Ca and perform best between pH 6.5 and 7.5. Some crops, such as millet, sorghum, sweet potato, potato, tomato, flax, tea, rye, carrot, and lupine, are tolerant to acidic soils [33]. Poor plant vigor uneven crop growth, poor nodulation of legumes, stunted root growth, persistence of acid-tolerant weeds, increased incidence of diseases and abnormal leaf colors are major symptoms of increased soil acidity which may lead to reduced yields [33, 34]. Increased acidity is likely to lead to poor water use efficiency due to nutrient deficiencies and imbalance and/or Al and Mn toxicity. High Al concentration also affects uptake and translocation of nutrients, especially immobilization of P in the roots [35, 36], cell division, respiration, N mobilization and glucose phosphorylation of plants [37, 38]. At elevated Al concentrations in the soil solution, root tips and lateral roots become thickened and turn brown, and P uptake is reduced [39]. Roots are commonly the first organs to show injury owing to acid due to Al toxicity; they become stunted, stubbly. With stunted roots, plant's ability to extract water and nutrients, particularly immobile nutrients such as P, is severely reduced [37].

Low pH soil can be detrimental to the health of crops, and so many studies highlight the effects of soil treatments on nutritional parameters. Investigations have been performed linking resistance to soil acidity and protein content in the grain of wheat [40] and corn [41], and seed of soybean [42]. This has the benefit of identifying cultivars with high protein content as well as those capable of growing in otherwise detrimental conditions, necessary information for breeders looking to optimize crops for a particular geographic region. It is worth noting that while protein content is an important parameter, there is little understanding of the impact of soil acidity on indices of protein quality such as amino acid composition or protein digestibility.

2.5. Effect of Soil Acidity on Availability of Plant Nutrients

The influence of soil acidity on the availability of plant nutrients is a significant factor that hampers crop production in acidic soils. One of the adverse consequences of soil acidity is phosphorus (P) sorption, which is influenced by factors such as clay mineral composition, pH levels, and the presence of iron and aluminum oxides and hydroxides in amorphous materials. The primary mechanism of P sorption involves the substitution of hydroxyl ions on crystal lattices and the hydration of iron and aluminum by phosphate ions [6]. The capacity for P sorption tends to increase with rising acidity levels. For example, soils in Ethiopia's Rift Valley, specifically Melkassa with a pH of 7.8, exhibit the lowest P sorption due to their relatively low weathering. Conversely, highly weathered soils characterized by minerals such as Gibbsite, Goethite, Kaolinite, and desilicated amorphous materials demonstrate a high to very high capacity for P sorption [43]. Research by [44] indicates that 70-75% of Nitisols in Ethiopia are significantly deficient in phosphorus. The solubility and accessibility of nutrients for plant uptake are closely linked to soil pH [34]. Soil acidity transforms available nutrients into forms that are not accessible to plants. Elevated soil acidity is associated with a deficiency of available calcium, potassium, magnesium, phosphorus, and molybdenum, while simultaneously leading to an excess of soluble aluminum, manganese, and other metallic ions [33, 45, 13]. Furthermore, soil acidity and aluminum toxicity hinder a soil enzyme activity, which in turn suppresses the microbially mediated cycling of nutrients. Additionally, aluminum toxicity and the reduced availability of organic matter due to binding with aluminum and iron may preserve a significant reservoir of organic carbon from microbial degradation in acidic soils [46]. Soil organisms crucial for plant health are affected by soil acidity. When the pH of the soil drops below 5.5; phosphate becomes less available to plants, leading to reduced crop yield. The optimal amount of P in the soil solution for crop growth is between 0.13 and 1.31 kg P ha^{-1}, with crops absorbing about 0.44 kg P ha^{-1} per day. The labile fraction in the topsoil layer ranges from 65-218 kg P ha^{-1}, which can help replenish P in the soil solution. Phosphate sorption occurs through specific adsorption and precipitation reactions. Specific adsorption happens when P anions replace the hydroxyl groups on the surface of Al and Fe oxides and hydrous oxides, while precipitation reactions occur when insoluble P compounds form and precipitate. At very low soil pH (≤4.5–5.0), adding P to soils can result in the precipitation of Al and Fe phosphates, while at high pH (>6.5), insoluble calcium phosphates can form.

2.6. Reaction of Crops to Acid Soil

Over the past ten years, numerous researchers have dedicated their efforts to identifying and elucidating the mechanisms that enable crop plants to withstand toxic levels of aluminum in acidic soils. These mechanisms can be categorized into two primary classes: those that function to prevent aluminum from reaching the root apex and those that facilitate the plant's ability to endure aluminum accumulation within the root and shoot symplasm [47, 48]. Several economically significant plant species are typically recognized for their tolerance to acidic soil conditions. Many of these species originate from regions characterized by acidic soils, indicating that adaptation to such soil constraints is an integral aspect of their evolutionary development [33]. The identification of varieties or species that thrive under high aluminum saturation levels, thereby requiring only a minimal amount of lime, holds substantial practical significance (Table 1). Research aimed at developing acid-tolerant crop varieties, including barley, maize, soybean, and potato, has been actively pursued in various Sub-Saharan African nations over the past decade [49].

Table 1. *Al Tolerance Level of Selected Crop Plant.*

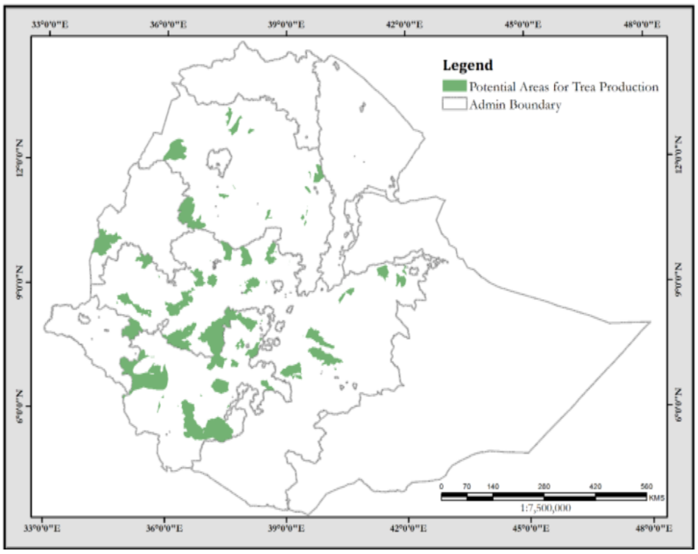
No	Crop Plants	Level of Al Tolerance
1	Tea, Buckwheat, Brachiaria	Highly Tolerant
2	Soybean, Pigeon Pea	Tolerant
3	Rice, Rye	Moderately Tolerant
4	Triticale, Maize, Sorghum, Cabbage	Moderately Sensitive
5	Wheat, Oat	Sensitive
6	Barley, Durum Wheat, Lettuce, Pea	Highly sensitive

Source: [50]

2.7. Tea Production Promotion in Ethiopia

Tea was first introduced in Ethiopia in 1927, making it a relatively new crop with a recent foray into commercial production. The primary reason for establishing tea farms in Ethiopia was to decrease imports and meet the growing local demand. Initially, all tea consumed in Ethiopia was imported, mainly from Kenya, resulting in a significant outflow of foreign exchange. However, since the 1980s, the increase in domestic tea production has not only satisfied local needs but also enabled the country to export and earn foreign currency. Currently, tea companies in Ethiopia are focused on expanding production and enhancing productivity, which is expected to have a substantial impact on the country's economic growth and export activities. Ethiopian tea is now emerging as a competitive product in the European market and has become a significant source of revenue for the national treasury. The country has numerous opportunities for the development of its tea industry, including favorable weather and soil conditions for high quality tea production (Figure 2), a skilled labor force, low wage levels, preferential access to the European Union markets, and proximity to Middle-East markets. A variety of challenges have been hindering its progress, including insufficient focus on the tea sub-sector, inadequate land use planning, capacity constraints, lack of connections among stakeholders, and conflicts of interest, among others that need to be addressed. Despite these obstacles, the tea industry in the country has great potential for growth and success. There are promising opportunities for investment in large-scale commercial tea production, as well as modern tea blending and packaging facilities. While tea cultivation was previously limited to large private farms, small-scale tea out-growers are now emerging near existing plantations in Southwest Ethiopia. The government has recently established the Ethiopian Coffee and Tea Authority (ECTA) to oversee interventions across the value chain and achieve development goals. Furthermore, continuous harvesting of tea leaves can support local factories and new agro-industry parks and villages in the country [51].

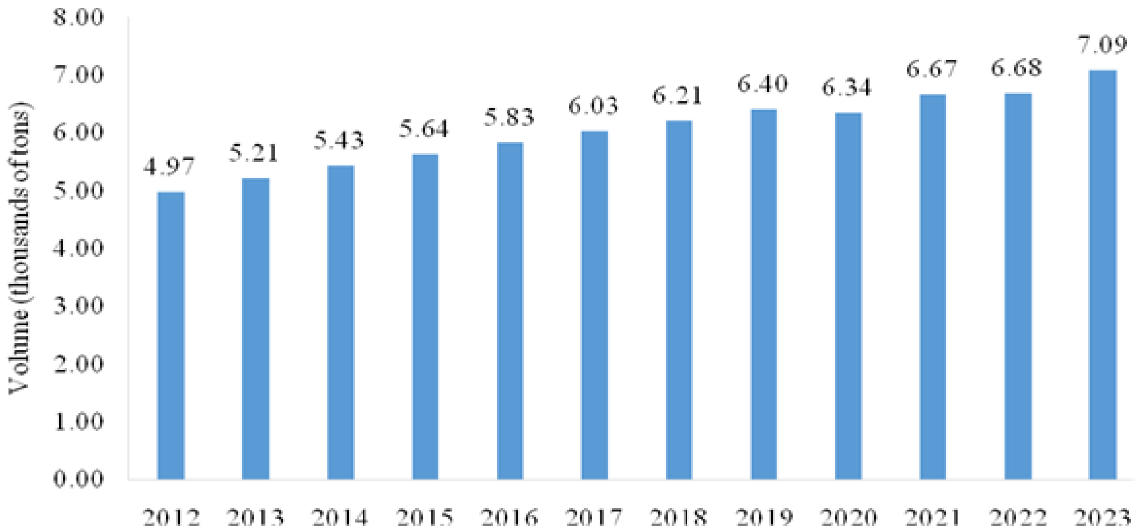
Despite the favorable environmental conditions for the production of quality tea in Ethiopia, the advancement of tea production and productivity has been impeded by technological limitations and the direct adoption of production packages from abroad, primarily due to the underdeveloped state of tea research in the country. As a result, there is a lack of research recommendations for increased production and productivity, scarcity of tea germplasm, and a limited number of large-scale processing factories and cottage industries within the country. With the current expansion of small-scale farmers or out-growers, there is an urgent need to develop effective extension services and establish a robust tea research program in the country. Therefore, the national tea research team must be well-equipped with the necessary materials, scientific knowledge, financial resources, and human resources in all relevant research disciplines to address the technology gap at all levels of production, processing, and marketing to align with the proposed tea expansion in the country. Additionally, there are conflicting interests in land use planning for the expansion of large tea plantations in natural forest areas, necessitating an investigation into the development of tea-based agro-forestry systems for the full participation and benefit of local communities. Future interventions should focus on the sustainability of large-scale tea plantations and the conservation of remaining forest areas, taking into account economic, social, cultural, and environmental aspects [51]. It is crucial to address the coordination issues within the country's research system, which consists of federal and regional research institutes as well as higher learning institutions, in order to enhance the effectiveness of research aimed at finding solutions to challenges in the national tea production program.



Source: [51]

Figure 2. *National Suitable Areas for Tea Production.*

The global consumption of tea has been on the rise, with 7.09 thousand tons consumed in 2023. Over the past decade, world tea consumption has grown by 3.3% (Figure 3), presenting a significant opportunity for tea-producing nations to cater to this growing demand.



Source: [52]

Figure 3. *Volume of tea consumption worldwide (2012-2023).*

The continuous rise in domestic tea consumption and global demand is expected to support the sustainable production and supply of premium tea products, prompting the Ethiopian government to take proactive measures in boosting private investments and engaging out-growers in key areas across the country. The Tea Initiative implementation, spearheaded by the Oromia Regional Biro of Agriculture, has been initiated in Western Oromia, specifically in Jimma, Buno Bedele, and Ilu Ababora Zones.

2.8. Al Is a Special Element for Tea Growth

Tea plants thrive in acidic soil with a pH ranging from 4.0 to 5.5, as this environment allows for the release of active soluble Al ions. The presence of Al^{3+} ions in plants typically leads to various cellular damages, including plasma membrane disintegration, cytoskeletal disruption, and DNA damage. These effects hinder root growth and function, ultimately impacting crop yield, especially when plants are subjected to additional environmental stressors like water scarcity and nutrient deficiencies. Exposure to low concentrations of Al^{3+} ions (less than 50 μM) can quickly inhibit root growth in most plant species, with varying levels of Al tolerance observed across different plants. For instance, rye exhibits significantly higher Al tolerance compared to barley, wheat, and triticale, showcasing approximately 2-3 times greater tolerance [53, 54]. In marked contrast, the tea plant is considerably more Al tolerant than almost all other known crops and many tree species (including aspen and red oak) (Table 2). In general, tea can withstand a concentration of at least 1000 μM Al without negative effect on normal growth [7, 55-58]. The roots of the tea tree harbor the majority of total plant Al (>60% of total Al), and a substantially higher Al content is found in young or fine roots than in mature roots [55]. By contrast, the shoots accumulate up to 30, 000 mg/kg of Al in old leaves on a dry weight basis, and less Al (<600mg/kg) is present in young leaves [59]. Surprisingly, given the general toxicity of Al, the tea plant not only is Al tolerant but actually requires Al for healthy growth [7, 54, 8]. For example, it is well known that Al^{3+}, but not low pH, directly stimulates the growth of tea plants and other acidophiles, including *Melastoma malabathricum*, *Hydrangea macrophylla*, and *Melaleuca cajuputi* [60]. An experimental range of external Al concentrations (0.3-2.5 μM) that is lethal to most plants increases the biomass of tea seedlings of various cultivars by 30%-200% [7, 8, 55-58].

During the initial period of Al exposure, tea root growth, including that of the primary root, lateral roots, and root hairs, is dramatically promoted, whereas shoot growth remains largely unchanged, implying that Al more effectively promotes tea root growth than shoot growth. In addition to its effects on intact tea plants, Al also stimulates the growth of excised tea roots in liquid culture and of suspension-cultured tea cells in a simple salt solution [61, 62], suggesting that the response of tea to Al occurs not only at the level of the intact plant but also at the tissue and cellular levels. Under Al supply, tea roots grow more vigorously and are mostly white in color. Because the white: brown root ratio is positively correlated with healthy growth [63], Al appears to be an indispensable element for tea growth and development.

Table 2. Responses of various crops and tree species to aluminum.

No	Common name	Species	[Al] for a significant inhibition of root growth (μM)[a]	References
1	Rice	*Oryza sativa*	<30(15.48)	[64, 65]
2	Barley	*Hordeum vulgare*	<5(1.27)	[66]
3	Rye	*Secale cereale*	<50(24.32)	[67]
4	Wheat	Triticum aestivum	<20(9.66)	[68, 69]
5	Sorghum	*Sorghum vulgare*	<(27)[b]	[70]
6	Maize	*Zea mays*	<(6)[b]	[71]
7	Buckwheat	*Fagopyrum esculentum*	<25(12.93)	[72]
8	Tomato	*Solanum lycopersicum*	<25(6.72)	[73]
9	Rice bean	*Vigna umbellata*	<25(3.62)	[74]
10	Soybean	*Glycine ma*	<20(6.3)	[75]
11	Rapeseed	*Brassica napus*	<25(12.93)	[76]
12	Aspen	*Populus tremula*	<250(59.5)	[77]
13	Honey locust	*Gleditsia triacanthos*	<50(12)	[78]
14	Red oak	*Quercus rubra*	<120(75.97)	[79]
15	Sugar maple	*Acer saccharum*	<250(64.6)	[79]
16	Beech	*Fagus sylvatica*	<500(143.5)	[79]
17	Red spruce	*Picea rubens*	<250(55.32)	[80]
18	Tea	*Camellia sinensis*	>1000(195.7)	[56-58, 81]

[a] The rough threshold concentration above which Al causes obvious root growth inhibition in most ecotypes of a species is shown (inhibition rate 30%-60%). The concentration of bioactive Al^{3+} given in parentheses was calculated using Visual MINTEQ software (https://vminteq.lwr.kth.se/). Bioactive Al concentrations for sorghum, maize, and honey locust are provided in the references. [b] These references only provided the concentrations of bioactive Al^{3+}.
Source: [82]

2.9. Mechanisms of Al Resistance in Tea Plants

The mechanisms of resistance to aluminum toxicity have been the subject of extensive research across various plant species; however, the intricate chemistry of aluminum has resulted in a limited understanding of these mechanisms. It is widely hypothesized that different plant species utilize a variety of aluminum tolerance mechanisms. These mechanisms can generally be classified into two primary categories: A) Avoidance mechanisms that facilitate the external detoxification and exclusion of aluminum, and B) Tolerance mechanisms that involve the internal detoxification of aluminum [83].

2.9.1. Al Exclusion or Avoidance

The first approach is Al exclusion, where Al^{3+} ions are prevented from entering the root apex by the secretion of Al chelators, such as organic acid anions, into the rhizosphere [47].

2.9.2. Al Tolerance or Internal Detoxification

Al tolerance involves sequestration or compartmentalization of Al^{3+} ions once they enter the root cytosol (symplastic detoxification) and modification of the root cell wall to change its Al-binding capacity (apoplastic detoxification) [84]. Because tea is an Al hyper accumulator, Al tolerance is likely to be the major mechanism by which it copes with Al. After being taken up, most of the Al is chelated and accumulated in the roots of numerous plant species. However, a few plant species, such as tea plant, buckwheat, and hydrangea, are capable of translocating large amounts of Al from the roots to the shoots [85]. Research based on Al nuclear magnetic resonance spectroscopy indicates that various chemicals, including phenolics, oxalate, fluoride, and citrate, are involved in chelating Al^{3+} ions for detoxification in tea roots and shoots [86]. Phenolics, particularly the catechins, have been shown to be the primary Al chelators in tea leaves [87], with catechins and their derivatives making up as much as 30% of leaf dry weight [88]. It is therefore likely that phenolics function in Al tolerance both inside and outside the cell. By contrast, in tea roots, oxalate has been proposed to be mainly responsible for Al detoxification [56], and increased levels of Al–oxalate complexes within tea roots are correlated with increased exposure to Al. Furthermore, Al stimulates oxalate secretion from tea roots [89], which to some extent prevents Al from entering root cells. In addition, during root-to-shoot Al translocation, an Al– citrate (1:1) complex was found to be the major form of Al in the xylem sap [90], and other chemicals, such as fluoride, may also play a role in Al detoxification in tea [91]. Al chelation may therefore be a primary strategy for efficiently maintaining Al at non-toxic levels following uptake by tea plants. Next, the mechanisms whereby Al is distributed organically and sub-cellularly also make tea plants highly tolerant of Al. Following attempts to determine the location of Al in tea roots and shoots, Al was observed predominantly in root hairs, root tips, and the leaf epidermis [92, 86], suggesting a tissue preference for Al storage. Thus, tea plants to some extent use both tissue and cellular level compartmentalization strategies to detoxify Al.

2.9.3. Mechanisms of Tea Plant Growth Stimulation by Al

Several different mechanisms have been proposed as possible explanations for the Al stimulation of tea growth, including that Al (1) activates a proton ATPase in the plasma membrane, and thus alleviates proton toxicity at low pH [60]; (2) stimulates P absorption in tea roots [7] (3) promotes the growth of beneficial microorganisms on the root surface [93] (4) replaces some function of B [94] (5) stimulates the uptake of N, Ca, Mg, K, and Mn [55, 86] (6) reduces Fe uptake and transport, thus alleviating Fe toxicity [95] (7) elevates the activities of antioxidant enzymes, leading to increased membrane integrity and delayed lignification and aging [96] and (8) enhances photosynthesis, resulting in higher carbohydrate supply and better protection against reactive oxygen species [8].

Al is an essential nutrient for tea and for other plants that are well adapted to acid soils. Al meets the requirements for being a nutrient for tea in that (1) Al has a direct beneficial effect on tea growth, (2) tea plants grow poorly and cannot even complete their life cycle in the absence of Al, and (3) the physiological role of Al in tea growth is irreplaceable (Al cannot be replaced by alternative elements). In line with this proposal, several elements not previously considered to be nutrients, including silicon (Si) and nickel (Ni), are now known to be essential nutrients that promote the growth of certain plants. Furthermore, very recent research reveals that Al is required for the maintenance of tea root meristematic activity, probably because nuclear-localized Al^{3+} ions function in the protection of DNA integrity [81]. In addition to hormonal signaling, the promotion of root growth by Al could occur via various alternative mechanisms. For instance, Al stimulates the excretion of caffeine from tea roots to inhibit callus deposition in root tips, and it is possible that this callus deposition may prevent cell-wall extension and subsequent root elongation [89].

2.10. Designing Future Crops for Acid Soils

As acid soils account for a substantial portion of the world's cultivatable land area, a large number of crop species, including many tree crops (90% of coffee species, 60% of cocoa, 100% of oil palm), legumes (35% of soybean), root and tuber crops (60% of white potatoes, 80% of sweet potatoes, 100% of cassava), and cereals (20% of barley, 20% of maize, 13% of rice), are susceptible to Al stress [16]. With increasing nitrogenous fertilizer inputs and increasing rain acidification, soil acidification is becoming much more of a problem than it was in the past. For example, soil pH in the major Chinese crop-production areas has decreased by 0.13-0.8 in the past decades [26]. In addition, Al toxicity has been identified as an important contributor to forest decline [97]. Therefore, the development or selecting of Al-tolerant species is not only fundamental for sustaining agricultural production and global food security but also essential for forest restoration and thus, in some ways, for improvement of the global ecological environment. However, tea plants are not only extremely tolerant to Al but also actually require Al for optimal growth, they perhaps provide a better model for future Al-tolerant crops: more than simple Al tolerance, such crops could exhibit Al stimulation of growth and productivity, making them completely adapted to acid soils. Because tea plants possess highly efficient versions of many of these Al-resistance mechanisms, molecular identification of the key responsible genes is an important topic for future tea research. Achieving this important step is highly dependent on advances in tea research and specifically on an enhanced understanding of how tea plants utilize Al and how Al stimulates tea growth at both the molecular and genetic levels. In particular, the future discovery of the key genes and pathways that mediate the Al-dependent growth promotion of tea plants will enable molecular breeding of these mechanisms into other crops.

3. Conclusion

Soil acidity is one of the major abiotic constraints affecting crop productivity which is caused by a low potential of hydrogen (pH). Different Scholars reported that 43% of the Ethiopian cultivated land is affected by soil acidity and need special care using appropriate acid soil management practices. The use of tolerant crop varieties is considered to be the best complement to non-genetic management option for combating Al-toxicity problem. Tea is a good candidate for this approach, as it prefers acid soil conditions, is highly tolerant of Al, and even requires Al for optimum growth. The tea as industrial crops has an important role in rural development, poverty alleviation, and food security in many developing nations like Ethiopia. Having the above listed potential tea production promotion have very important impact in the future of Ethiopian economy and citizen's wellbeing.

Abbreviations

pH	Potential of Hydrogen
USD	United States Dollar
Mg	Milligram
Kg	Kilogram
SO_2	Sulfur Dioxide
NH_3	Ammonia
HNO_3	Nitric Acid
HCl	Hydrochloric Acid
Al_3^+	Aluminum Ion
Ca	Calcium
Mg	Magnesium
K	Potassium
H^+	Hydrogen Ion
N	Nitrogen
Al	Aluminum
NH_4	Ammonium
$(CO(NH_2)_2)$	Urea
NO_3^-	Nitrate Ion
SOM	Soil Organic Matter
CEC	Cation Exchange Capacity
Mn	Manganese
Fe	Iron
P	Phosphorus
ECTA	Ethiopian Coffee and Tea Authority
DNA	Deoxyribonucleic Acid
µM	Micromolar
ATPase	Adenosine Triphosphatase
Si	Silicon
Ni	Nickel

Author Contributions

Mohammedsani Zakir Shehasen is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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