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Use of antitranspirant in maize cultivation as a potential novel approach to combat drought stress in the wake of climate change. A systematic review

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ABSTRACT

The maize crop is highly dependent on rainfall and it is sensitive to drought. However, the planet is experiencing frequent droughts due to climate change which is adversely impacting on the food production. It is crucial that the agricultural sector is adapted to the negative consequences of climate change. The antitranspirants which reduce the water loss through transpiration could be potential novel approach to ameliorate the effects drought on rain fed maize cultivation in most of the countries around the globe. This review has analysed the effects of antitranspirants on the growth, yields, and pathogens and diseases that affect the maize plants and on environment.It has found that antitranspirants help to improve vegetative growth and biological yield of the maize plant by reducing the transpiration rate and improving water use efficiency of the plants. The review has found that chitosan and the fulvic acid have been extensively studied on maize as compared to other antitranspirants .Therefore, antitranspirants could be used to ameliorate the effects of drought on maize crops but there is need to do a cost benefit analysis on whether it is economically viable to use antitranspirants on food crops with low market value like maize. Di-1-p-menthene is reported to cost less money as such there is need to research on how this antitranspirant ameliorate the effects of water stress on maize .There is also a need to research on proper timing of the application of the antitranspirants to the maize plant under dress.

1. INTRODUCTION

Zea mays L., also known as maize, is the third most significant staple food crop in terms of global production [1, 2, 3]. According to Petrovi et al. [4], its global production hit 1.1 billion tons in 2019. However its yields are severely being reduced by extreme high average temperatures and low precipitation owing to climate change [5]. Climate change has a significant impact on agricultural production, particularly in poor nations where millions of people rely on rain-fed agricultural systems for their livelihoods [6]. The drop in seasonal precipitation contributes to an increase in evaporation and evapotranspiration, which coupled with rising temperatures cause crops to experience drought stress [7]. Drought stress has a significant impact on maize growth and productivity [8; 9 ,10, 11]. Drought stress has a significant impact on maize growth and productivity [8, 9, 10] .Numerous studies [11, 12, 8], report that drought alters significantly the morphology, physiology, and biochemistry in the crop plants. The cumulative rainfall amount in the growing season are becoming below average and temporally. The erratic distribution of rains are leading to a failure of the first plantings in several areas [8], resulting in a second round of plantings which is in most cases not feasible.

Adverse weather conditions are anticipated to occur more frequently because of climate change, making smallholder farmers who depend on rain-fed agriculture more vulnerable [13, 14, 15]. In order to save the poor's livelihoods, improve them, and ensure their food security, it is crucial that the agricultural sector should be adapted to the negative consequences of climate change [16, 17]. In order to adapt to a changing climate, several strategies are being encouraged. One crucial method of adaptability is altering farming practices [18]. Examples include adjusting planting times [19] and switching to drought resistant varieties [20, 21]; Diversification towards high value crops [22], integrating the use of climate forecasts into crop decisions [23, 24, 25], Deployment and use of new cultivars [26, 27], increasing irrigation use and diversifying regional agriculture [28, 29], adopting conservation agriculture, and using better soil and water management techniques [30, 31, 18]. According to El-Azm and Youssef [32], agriculture is the largest consumer of freshwater; nevertheless, crop growth and development only use around 5% of the water taken by roots, with the other 95% being transpired by the plant [33, 34, 35].Therefore it is important to focus on increasing water efficiency by implementing novel agronomic practices that save water [36, 37]. In this respect, Bittelli et al. [38] and Iriti et al. [39] a study found that antitranspirants, substances applied to foliage to reduce water loss, can be used to combat the effects of sporadic or episodic drought situations on plants . Therefore, considering the significance of maize in food security and that its yields is usually hampered by droughts and dry spells, use of transpirant will be an option to combat the water stress that plants may experience as the countries continue to experience the drought stresses due to climate change.

1.1 Antitranspirants

Antitranspirants are chemicals or substances applied to plant leaves to reduce water loss (transpiration) without significantly altering different critical functions of the plant, like photosynthesis and development [40]. Antitranspirants are classified into three types depending on their mode of action [41]. They include the following; Film-forming antitranspirants, reflective anti-transpirants and stomata closing Antitranspirants [42]. The Film antitranspirants (AT) are water-emulsifiable polymers that provide a physically waterproof covering to seal stomata, hence minimizing water loss through transpiration [43]. It increases leaf resistance to the diffusion of water vapour [41]. Metabolic /Stomatal closing antitranspirants are chemicals that have hormone-like effects on guard cells, causing partial stomatal closure [42, 44]. Reflective antitranspirants are white polymers that coat the leaves and make them more reflective [45, 42]. Reflecting radiation lowers the vapour pressure gradient and consequently lessens transpiration.

Table 1. Classification of anti-transpirants and their some of their examples

Class of anti-transpirant	**Examples**
Film-forming type	Ethyl alcohol, di-1-p-menthene, Plantco (an acrylic emulsion), Dow X2-1337 (a silicon emulsion), Clearspray, Castor bean oil, Mobileaf (a wax emulsion), linseed oil
Stomatal closing type	Abscisic acid, fulvic, Chitosan, K2SO4, kaolin spray
Reflective type	Diatomaceous earth product (Celite), Hydrated lime, calcium , magnesium carbonate ,carbonate, Zinc sulphate, Phenyl mercuric acetate (PMA)etc.

2. METHODOLOGY

This systematic review aims at presenting, and evaluating the effects of antitranspirants on *Zea mays*, and ascertaining the potential of antitranspirants in ameliorating the drought stress in maize in the wake of persistent dry spells as a result of climate change. This review summarizes and evaluates the findings of the research done from 2002 to mid-2023 on the effects of antitranspitans on maize growth , yields ,pathogen, pest and diseases on maize , and the environment. Original research papers indexed in Google Scholar, Web of Science, Wiley, Elsevier, Springer and Science Direct were used. Effects of antitranpirants on the maize, on the pests ,pathogens and diseases affecting maize and on the environmnet were also reviewed and analysed.

3. FINDINGS

3.1 Effects of drought stress on maize growth and yields

Maize crop is usually vulnerable to drought conditions [46]. According to Hussain et al. [47], the world's maize yield and production are declining by 15-20% year as a result of heat and drought. Drought stress has negative effects on maize crop from seedling establishment through vegetative stages to grain formation [48, 49]. The vegetative, silking, and grain-filling phases of maize are the most susceptible to drought stress which results into yield losses [50]. This is due to the delayed spikelet development which causes a larger anthesis-silking interval (ASI), silk senescence, and pollen abortion [51, 52, 53, 54]. It negatively affects the early crop establishment and grain yield potential because of the early tasseling that results in a protracted anthesis to silk interval, [55, 56]. İt alters the distribution of carbohydrates in maize during the vegetative phase, slow down growth and extend the vegetative development phase [53, 57, 58, 59]. Maize plants that are under a lot of water stress initially respond by curling their leaves [60] .

Water shortage prior to onset of anthesis causes tasseling and silking to be postponed by 1-2 and 2-3 days, respectively [61]. This delay in silking causes barrenness due to the exhaustion of the pollen supply before the silk emerges. [62, 56; 51]. Setter et al. (2001) found that 5 days of drought stress before pollination and the first few days after pollination reduces the kernel set in the apical ear regions. Water deficits during the grain-filling stage are deleterious because they limit transportation of photosynthetic products to the grain during the filling stage of maize [61, 63].

A substantial decrease was also recorded in gas exchange attributes which includes Water use efficiency (WUE), instantaneous water use efficiency (WUEi), stomatal conductance (gs), net photosynthetic rate (A), transpiration rate (E), and intercellular CO2 (Ci) [64, 65, 66]. Stomata are the main sites for gaseous exchange and transpiration. Drought stress causes stomatal closure, which lowers transpiration and CO2 absorption and ultimately lowers photosynthetic activity [67, 54, 68, 69]. According to Anjum et al. [59, 64], stomatal closure caused by decreased soil water content which results in less absorption of CO2 absorption, may have contributed to drought-induced reductions in maize plant development, yield, and yield components.

Furthermore drought tends to affects the chlorophyll a and b activity [54] which eventually affect photosynthesis because photosynthetic pigments are utilized specifically for capturing light. It was studied that drought reduces the photosynthesis. Drought affects photo-system-II and photo-system I .During mild drought stress, photochemical activity of Photosystem II decreases from QA to PQH2. There is an inhibition of the electron transport chain from the donor side of photosystem II to the photosystem I-end electron acceptor which causes poor transport of electrons through the photo systems. When under stress from drought, Photosystem II is more impacted than Photosystem I [62] resulting in production of free high energy electrons in the leaf.This in turn causes photo-oxidation of chlorophyll and loss of photosynthetic activity [53] . Parthasarathi et al. [70] discovered that drought stress affects the thylakoid membrane, disrupts its processes, and eventually reduces photosynthesis and maize crop productivity. Drought stress ultimately led to a small kernel size. This is because drought causes the ear leaf's capacity for photosynthesis to significantly decrease thereby causing a substantial impact on how the ear and kernel develop as a photosynthesis factory in maize plants [67].

3.2 Effects of antitranspirants on growth parameters of maize under drought stress

Several studies have been carried out to find the effects of antitranspirants on characteristics of maize under drought stress. In a study conducted by Bayat & Sepehri [71] and Kamran et al. [72] found that application of Paclobutrazol (PBZ) and salicylic acid (SA) to maize under different irrigation regimes increase vegetative growth. Antitranspirants application of the salicylic acid, vapour gard, and kaolin clay also promoted growth off the maize crop in terms of number of leaves, leaf area, leaf area index, plant dry matter and crop growth [73,74]. Similar results were also observed when SA was administered exogenously, which led to an increase in plant height and flag leaf weight both fresh and dry [12]. Exogenous applications of ascorbic acid (AsA), salicylic acid (SA), and hydrogen peroxide (H2O2) increased the morphology characterıstıcs of spring maize [75].Guleria & Shweta [44] and Morsy & Mehanna [76] found that exogenous application of Kaolin antitranspirants on maize under water stress resulted in increase in the number of leaves and leaf area index (LAI) . Similar findings were recorded by Gomaa et al. [77], Shedeed, [78] through application of potassium silicate on maize under water stress. In a study by Anjum et al. [64], exogenous application of Brassinolide (BR) improved plant height and leaf area.

Foliar application of chitosan in a study by Mondal, et al. [79] found that the growth of maize improved at early growth stages. A study conducted by Guan [80] by exogenously applying chitosan found that there was an increase in shoot height, root length, and the dry weights of the shoots and roots in both maize seedlings. However, the inhibition of seedling growth was observed upon foliar application of chitosan at a concentration of 0.16%. An increase in Cu content may be the cause of this growth retardation, which eventually led to a reduction in metabolic enzymes [81]. Similar inhibition effect was registered in a study by Nakasato, et al. [82] where it was observed that germination of maize seeds was inhibited when high concentrations of polymeric chitosan/tripolyphosphate on maize were used. On the other hand ,Lizárraga-Paulín et al. [83] and Peña-Datoli et al. [84] found that chitosan coating on maize has no effect on seed emergence rate. Peña-Datoli et al. [84] attributed this to the simultaneous use of fertilizers and salicylic acid as well as the high concentration of the chitosan polymer applied. Furthermore, a study by Martins et al. [85], did not find any improvement in rooot length after applying chitosan. Khan [86] did not find any significant effect of foliar chitosan application on the height, root length, leaf area of the maize crop.Positive results were recorded in a study by Li et al. [87] whereby foliar FA treatment successfully increased root growth in low soil moisture conditions.

Shedeed [78] and Gomaa [88] also found that weekly applications of potassium silicate to the leaves of maize plants, applied at successively higher concentrations, improved plant size (height, stem diameter, leaf area, and number of leaves per plant), as well as the fresh and dry weight of the leaves and stem. Similar findings were recorded by kandi et al. [89], who discovered that foliar application of K- silicate three times resulted in the highest values of growth characteristics. The shoot and root lengths as well as their biomass were greatly increased by silicon priming of maize, especially at 6 mM [90].

3.3 Effects of antitranspirants on biological yield of maize under drought stress

The effects of the antitranspirants on the biological yields of maize under drought stress were reviewed. A salicylic acid (SA) spray applied exogenously has the potential to greatly increase the biological yield of maize. Number of the ears of maize increased [71,74]. Salicylic acid's stimulation of physiological processes may have contributed to the rise in yield in maize, which improved vegetative development and resulted in active translocation of photosynthetic products from source to sink [91, 92]. Similar findings by Shemi et al. [12] who registered higher cob yields under drought stress after administering SA.

Exogenous applications of ascorbic acid (AsA), salicylic acid (SA), and hydrogen peroxide (H2O2) increased the yield-related characteristics, and grain yield of spring maize [75]. Yang et al. [93] and Li, & Yu [87] found that FA foliar application under water deficit also resulted in a 19% rise in grain yield. The high grain yield was also registered with the application of foliar spray of kaolin coupled with mulching [94, 95, 96, 76]. However, foliar spray of the FA solution did not change the yield components and harvest index [93]. Anjum et al. [97] found that exogenous application of glycinebetaine (GB) boosted grain yield per plant by 12.94% and 10.68% for the Dongdan-60 and ND-95 cultivars, respectively, and increased the number of kernels per cob. Reduced osmotic potential brought on by net solute buildup in response to water stress may be responsible for GB-induced drought tolerance. The enhanced maize yield was significantly maintained in the fall after the application of chitosan to maize at a 500 (mg l-1) concentration under Ir70 [98].Chitosan helps to accelerate cell growth and development, boosting the activity of essential enzymes in nitrogen metabolism, and promoting nitrogen transfer, it has a significant impact on plant growth and increases yield [79]. Similar findings were registerd by Mondal, et al. [79] with chitosan concentrations of 100 and 125 ppm.This rise resulted from the nitrogen metabolism enzymes which were activated more frequently by the compound chitosan. These enzymes are crucial for plant growth and development.

Shedeed [78] and Gomaa [77] found that foliar application of K-silicate registered the highest values of grain yield and its components.Exogenous foliar application of Brassinolide (BR) significantly increased the plants' growth parameters, yield, and yield component in both drought-stressed and well-watered plants [64]. Growth stimulation could have arisen due to the translocation of the assimilates induced by the foliar BR application which increased grain yield, plant height, fresh and dry weight of the shoots, and higher yield components [99].

In a study by de Souza et al. [100] it was discovered that exogenous application of ABA resulted in an increase in weight of seeds (17.86) and yield of grain (10.45 %) for DKB 390 maize variety under stress. The increased activation of ABA on development of procambium in female inflorescences may be the cause of the maximum yield following ABA treatment [100]. With the help of this stimulus, more phloem can be created, enhancing the plant's ability to remobilize carbohydrates from leaves and stems into grains. Phloem production can increase, which improves the plant's ability to remobilize carbohydrates from leaves and stems and transfer them to grains [101]. A prolonged grain filling duration was encouraged by improvement in the water status and antioxidant defense provided by the application of ABA in 390 DKB [100]. Foliar spray of PBZ by Bayat, & Sepehri [71] on maize significantly decreased the grain yield and 1000-grain weight by 8.60 %and 8.64 % respectively.

3.4 Effects of antitranspirants on gas exchange attributes of maize under drought stress

The effects of antitranspirants on gas exchange were reviewedand the findings are presented in this section. The gas exchange attributes includes, photosynthetic rate, transpiration rate, stomatal conductance, and intercellular CO2 concentration. According to Guleria & Shweta [44], using antitranspirants helps maize plants to use water more efficiently (WUE) by retaining more water in the leaves, accelerating photosynthesis, increasing chlorophyll content, and minimizing water and drought stress. The exogenous application of Brassinolide (BR) in a study by Anjum et al. [64] improved Net rate of photosynthesis, transpiration rate, stomatal conductance and intercellular CO2 under drought. BR application improved photosynthesis (16.08 %), transpiration rate (11.55 %), and stomata conductance (6.52 %), water use efficiency WUE (30.44 %), and intercellular CO2 concentration (3.12 %) under water-deficit conditions. The increase in photosynthesis caused by BR could be attributed to improvements in leaf water balance [64]. WUE is an important trait since it informs about ability of a plant to respond to water stress circumstances .

The maximum WUE values were obtained with foliar K-silicate spraying applied three times while requiring less watering [77]. Elshamly [102] found that Foliar applications of potassium silicate also registered an increase in water use efficiency in maize cultivars.. Foliar application of kaolin resulted in increase in water use efficiency [76]. Furthermore Yang et al. [93] and Kocięcka & Liberacki [103] revealed that spraying antitranspirants to maize plants resulted in an improvement in grain yield and WUE. In a study that was conducted by Ali & Ashraf [104] it was found revealed both maize cultivars' net photosynthetic rate and stomatal conductance and intercellular CO2 under drought were raised by exogenously applying trehalose. The water use efficiency of maize cultivars under both water-stressed.

Elshamly [98] found that Foliar applications of chitosan with concentrations at 500 (mg l–1) had a significant effects to maintain water use efficiency. Positive responses relating to the high gas exchange were registered after Chitosan application [105, 86]. Veroneze-Júnior et al. [100] discovered that applying chitosan to the BRS 1030 maize variety following nine days without water increased photosynthesis but did not increase stomatal conductance , whereas applying chitosan to the drought-tolerant hybrid (DKB 390) increased both photosynthesis and stomatal conductance. The ability of chitosan to act as an antiperspirant in agriculture may be because when it is deposited in the cell wall, it promotes a decrease in stomatal conductance, raising the resistance of the leaf to water vapor loss and promoting the water consumption by plants to assimilate carbon, which in turn raises biomass production [105]. Anjum et al. [97] found that glycinebetaine (GB) application to maize cultivars improved gas exchange parameters under water deficit condition. GB improved net photosynthetic rate, transpiration rate, and stomatal conductance by 16.28%, 8.33%, and 21.60% respectively .The internal carbon dioxide concentration also improved by 2.32% in Dongdan-60 variety under drought.

In a study conducted by Anjum et al. [106] it was discovered that exogenous FA treatment maintained chlorophyll concentrations and gas exchange, which significantly lessened the effects of drought. Bi et al. [107] and Liao et al. [108] found that water use efficiency was improved significantly by 26.4% after application FA and soil superabsorbent hydrogel. Shemi et al. [12] recorded that all photosynthetic gas-exchange parameters—aside from the intercellular CO2 concentration—were raised by SA, Zn, and GB foliar treatments .Fulvic acid (FA) foliar application on maize cultivars reduced Stomatal apertures and transpiration rate in leaves while retaining higher levels of photosynthetic activity. This happens as a result of activation of ABA signaling pathway by FA which eventually reduces water loss by transpiration [109]. They also observed that there was no effect of FA on the carbon dioxide assimilation capacity of crops [109]. Yang et al. [93] found that FA and SAP application reduced the stomatal conductance and transpiration of maize which in turn increased the water use efficiency per leaf. Furthermore, Li & Yu [87] found that simultaneous application of SAP and the FA improved net photosynthetic rate, decreased transpiration, decreased the plant's water consumption capacity, and improved water usage efficiency. Abd El-Mageed et al., [110] discovered that exogenous Si administration boosted maize's ability to withstand water deficits by improving effectiveness of photosynthesis, stomatal conductance, and cell membrane integrity.

3.5. Effects of antitranspirants on pathogen, pest and disease control of maize

This section presents the findings of the review of papers on the effects of antitranspirants on pathogen, pests and disease control on maize.

In a study conducted by Kumaraswamy et al. [111] found that application of salicylic acid-chitosan nanoparticles (SA-CS NPs) on maize in the field controlled the post-flowering stalk rot (PFSR) disease by 59.4% .In a study by Monjane, et al. [112] it was found that foliar application of chitosan on maize as a pesticide improved the yield component of maize (6.0 t.ha-1). The high yield obtained by treating maize crops with chitosan reinforces the effect of this biopesticide in reducing infections which were observed. This suggests that the observed effect could be responsible for the protection of the plant against blight leaf disease and the corresponding high grain yield.

Choudhary et al. [113] found that application of Chitosan Nanoparticles (ChNPs) defended maize agaist Curvularia leaf spot disease. This was done by enhancing antioxidant activity and defense enzymes including phenylalanine ammonia-lyses and polyphenol oxidase. According to a study by Butt [114], the combination of chitosan and *C. pedicellata* extract most successfully stimulated the plant's defense mechanisms against *F. oxysporum* through higher induction of the amount of PR-protein expression. Moreover, Coating of maize seeds with chitosan shown fungicidal activity against Rhizopus sp. and *A. Flavus* [115]. Spraying chitosan on maize plants had a noticeable impact on the occurrence of foliar diseases such leaf spot, leaf gray blight, late wilt, and ear rots, which were reduced by 78.0, 70.8, 76.3, and 78.2%, respectively [116]. Similarly, they discovered that salicylic treatment had a substantial suppressing effect on foliar diseases, with incidences of leaf spot, leaf gray blight, late wilt, and ear rots on maize recorded as 4.2, 10.0, 8.5, and 11.4%, respectively, with reductions of 86.8, 65.2, 75.1, and 63.6% [116] .Another investigation on the possible use of chitosan for reducing both growth and fumonisin production by *F. verticillioides* and *F. proliferatum* on maize discovered that the addition of chitosan prolonged the lag phase and greatly lowered the growth rate of both Fusarium species. Its increasing chitosan concentrations in conjunction with reduction ın water avaılabılıty lengthened the lag phase and reduced mycelia formation in both Fusarium species [117]. Application of Cu-chitosan NCPs have remarkable potential and act as an effective antifungal agent for *Fusarium verticillioids* which causes post flowering stalk rot (PFSR) of maize .It offered crop protection with significant disease control of PFSR (33.9%) at 0.06% Cu-chitosan NCPs [113].

3.6. Effects of antitranspirants on environment

This section presents the findings of the review on the possible effects of the antitranspirants on the environment. Potassium silicate (K- silicate) is a source of highly soluble potassium and silicon. Romero-

Aranda et al. [118] reported that potassium silicate does not contain volatile organic chemicals and that its use won't cause the release of any risky or long-lasting consequences into the environment.Chitosan is reported to lessens the negative effects of agriculture on the environment. Its biocompatibility, biodegradability, and bioactivity have made it useful in agriculture due to its non-toxic qualities [119]. Kaur & Dhillon [120] and Zargar et al. [121] confirms that Chitosan biopolymer has low toxicity. Kocięcka and Liberacki [103] attest that chitosan is environmentally friendly and suggest that it is an excellent substitute to synthetic fertilizers, herbicides, and chemicals for disease prevention.

Mphande et al. [42] posited that the environmental concerns connected with the use of ABA, di-1-p-methene, and kaolin are most likely negligible. ABA can be collected from plants, acquired by microbial fermentation, or synthesized [122], whereas di-1-p-methene is recovered from pine resin [123].Kaolin which is an aluminosilicate (Al4Si4O10 (OH) 8), is obtained from clay [124] and this does not pose any negative impacts in the environment. The kaolin particle film was recognized as an organic pest management tool since it is a natural product with very minimal toxicity to humans, birds, and fish [125]. However, Kaolin treatments promoted the severity of woolly apple aphid (*Eriosoma lanigerum*) infestation.

Furthermore Knight et al [126] and Lalancette et al. [127] revealed that in orchards where kaolin was used, the prevalence of various pests, including the red spider mite and the rose apple aphid (*Dysaphis plantaginea Passerini*), San Jose scale (*Quadraspidiotus perniciosus Comstock*), and western tentiform leaf miner (*Phyllonorycter elmaella Doganlar & Mutuura*), increased. Nevertheless, it decreased the population of polyphagous predators like *F. auricularia*, predatory *Heteroptera* and *Coleoptera*, the red velvet mite (*Allothrombium fuliginosum*), spiders (Araneae) and black ant (*Lasius niger*). Processed kaolin sprays substantially reduced the incidence of *B. oleae* and that of *S. oleae* but had deleterious effect on the abundance and the diversity of the natural enemy, arthropod community [128]. In a study by Kumar Sootahar et al [129] revealed that fulvic acids (FA) considerably lowered soil pH and, by giving microorganisms energy and carbon, have an impact on the development of soil microbial biomass and microbial activity. FA application at 20% concentration reduced uptake of heavy metals like Chromium (Cr), Cadmium (Cd), and Lead (Pb) uptake in the shoot [130].

3.7 Re-evaluation and potential of antitranspirants on maize cultivation

Many countries continue to encounter persistent dry spells that are greatly affecting the yields of crops including maize which is a staple food in many countries especially in Africa [131]. Maize is known to be sensitive to drought stress, which has a detrimental impact the development of reproductive organs, the generation of biomass, and the characteristics of the yield [132]. Webber et al. [133] predicted that drought stress will have a greater impact on maize than winter wheat in terms of yield losses due to climate change. Short-term water deficiencies have been linked to dry weight losses (28-32%) during the rapid vegetative development stage and dry weight losses (66-93%) during the tasseling and ear formation stages (57; 67,134 , 107,135]. The period of grain filling following pollination is another stage of maize that is susceptible to drought stress [136].

Therefore with the current persistent dry spells that the planet is experiencing due the global climate change, use of antitranspirants could be the helpful to ameliorate the effects of drought stress and achieve a significant yields. This review has established studies have shown that the antitranspirants improve the maize growth parameters as wells as yields by reducing the transpiration rate and the stomatal conductance. Furthermore, other antitranspirants helps to control pathogens, pests and diseases in maize cultivars. Among the antitranspirants reviewed in the study, chitosan is the most studied antitranspirants on maize together with its derivatives. It is followed by kaolin, and potassium silicate. Other antitranspirants that have been studied on maize include salicylic acid, fulvic acid, ABA, BR and GB. Studies on the effects of di-1-p-methene on maize growth and yields under drought stress are rare. However, studies of di-1-p-methene on other arable crops and horticultural crops have revealed significant positive impacts [137, 138, 42]. Therefore there is need for more research the potential of the di-1-p-menthene antitranspirants on maize cultivar.

However ,the fact that antitranspirants in other studies have been found to have negative effects or no impact at all, calls for researchers to find out which antitranspirants could be better for maize cultivation. It is also imperative that appropriate concentration should be used if the good results are to be attained. Furthermore, since many studies are based on effects of antitranspirants on the growth and yields of the maize cultivars, there is need for further research on the impact of these on the organisms like insects, arthropods and even birds to establish if the foliar application of particular antitranspirants in the maize field does not affect the ecological balance.

Although maize is the mainstay food in many countries, its market value is low in comparison to other grains like rice and wheat. In addition, maize is usually grown by stamalholder farmers for subsistence i many countries[139, 140]. Therefore the adoption of agronomic technology of using of antitranspirants to ameliorate the effects of drought stress requires the farmers to make the cost benefit analysis . Farmers needs adopt the antitranspirants that require less money. Subsequent utilization of antitranspirants in agronomy has been limited, probably due to costs [141]. Francini et al. [123] records that di-1-p-menthene antitranspirants cost less money. However, Kettlewell [142] and Janawade & Palled [143] stated that the number of research studies that examine the cost-benefit analysis of using ATs in agricultural output is rather few. Therefore, there is need for clear and evidence based information on the economic feasibility of using antitranspirants in crop production [42].Studies on nutritional values of the maize grain after use of antitranspirants are very scanty as such this review recommends that studies be conducted to evaluate the nutritional status of the grain.

4. CONCLUSION AND RECOMMENDATION

The review has highlighted the importance of antitranspirants on the maize from the papers published from 2002 to 2023. There has been more studies done to determine the drought ameliorating effects of chitosan and Fulvic acid on maize as compared to other antitranspirants such as Sacylic acid, Potassium Silicate and ABA Kaolin, glycine betamine, Brassinolides, Trehalose and Paclobutrazol.The study has found that more studies done on maize used the stomatal closing antitranspirants as compared to the other classes. In general the review has established that antitranspirants help to improve the vegetative growth of the maize, reduce transpiration, yield as well as promoting water use efficiency of the plant.Furthermore the study has also established that there is need to do further research to find if it is economically viable to use antitranspirants on low value crops such maize as it may be expensive for the subsistence farmers [42]. There is also need for further research to find the best stage of development of the maize where application of antitranspirants will be more effective. Studies on nutritional values of the maize grain after use of antitranspirants are very scanty as such this review recommends that studies be conducted to evaluate the nutritional status of the grain.

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The Declaration of Conflict of Interest

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The Declaration of Ethics Committee Approval

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The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of ETOXEC in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Environmental Toxicology and Ecology and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Environmental Toxicology and Ecology.

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