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Anti- Transpirants: Plant Raincoats in Reverse

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Climate change has driven intense water- stress pressure on global food production, particularly in rainfed ecosystems, roughly 80% of the farmland depends on rainfall. Almost 99% of water absorbed by plants is lost through transpiration while only the remaining 1% is utilized for metabolic processes. Thus, to increase the water use efficiency and reduce losses, chemical regulation of this mechanism is gaining momentum aimed at drought- management strategy. This leads to the development and introduction of anti- transpirants for enhanced stomatal conductance, turgor- pressure regulation, leaf energy balancing and abscisic acid signaling. This article explores the essence of anti- transpirants, their types, mechanism and successful case studies around the world showcasing their potential in the present- day climate change issues.

Introduction

The escalating hydrological challenge exposes global agriculture to precipitation variability, especially in dryland/ rainfed conditions (Huang *et al.*, 2019, cited in Mphande *et al.*, 2020). Rise in atmospheric temperature further escalates the problem by increasing reference evapotranspiration (ETo), ultimately increasing crop water demand even if precipitation is sufficient (Kocięcka *et al.*, 2023). Against the backdrop of increasing population of 9.8 billion by 2050 and the concomitant need to raise cereal production by roughly 26% over the past levels (Mphande *et al.*, 2020), drought now is identified as the single major abiotic constraint on food security. Antitranspirants are foliar applied chemicals that suppress transpiration loss, offering an easily deployable, agronomically suitable complement to genetic approaches under building drought tolerance.

Physiological Basis of Transpiration and Rationale for the Use of Antitranspirants

Transpiration is the physiological process in which plants loose water in the form of water vapour from the stomata (mostly), lenticular cells and cuticles. It is mainly governed by stomatal conductance (g_s) and leaf- to- air vapour pressure deficit (VPD). Since, CO_2 assimilation is also dependent on the stomatal conductance for the process of photosynthesis, a close relationship is formed as: Water Use Efficiency (WUE) = (CO_2 assimilation/ Transpiration). Hence, any intervention reducing the stomatal conductance (g_s), VPD or the leaf temperature will effectively mitigate the transpiration rates, albeit at the expense of limiting mesophyll CO_2 diffusion and subsequently impair the photosynthetic capacity (Mphande *et al.*, 2020). So, the core rationale behind application of antitranspirant is that, in moisture- limiting conditions, or moisture stress conditions, the marginal benefits of water retention far outweigh the yield penalty associated with reduced carbon assimilation (Kettlewell, 2014). Since, almost 98% of water is lost through transpiration, even a partial reduction (10- 40%) in stomatal conductance can substantially preserve relative water content (RWC), elevate leaf potential, and maintain crop water status during drought events. Studies show, ccorrectly timed antitranspirant applications consistently increase yields and water-use efficiency by 20–45% compared to unsprayed, drought-stressed controls, with kaolin treatments achieving up to 40% irrigation-water savings in deficit-irrigated maize (Youssef & Hozayenb, 2019; Mphande *et al.*, 2020; Kocięcka *et al.*, 2023). Furthermore, AT selection depends on drought dynamics: fast-acting metabolic ATs like abscisic acid (ABA) target acute water deficits during sensitive phenophases, whereas film-forming ATs offer 30–40 days of residual protection suited for extended seasonal droughts (Plaut *et al.*, 2004; Mphande *et al.*, 2020).

Types of Anti Transpirants

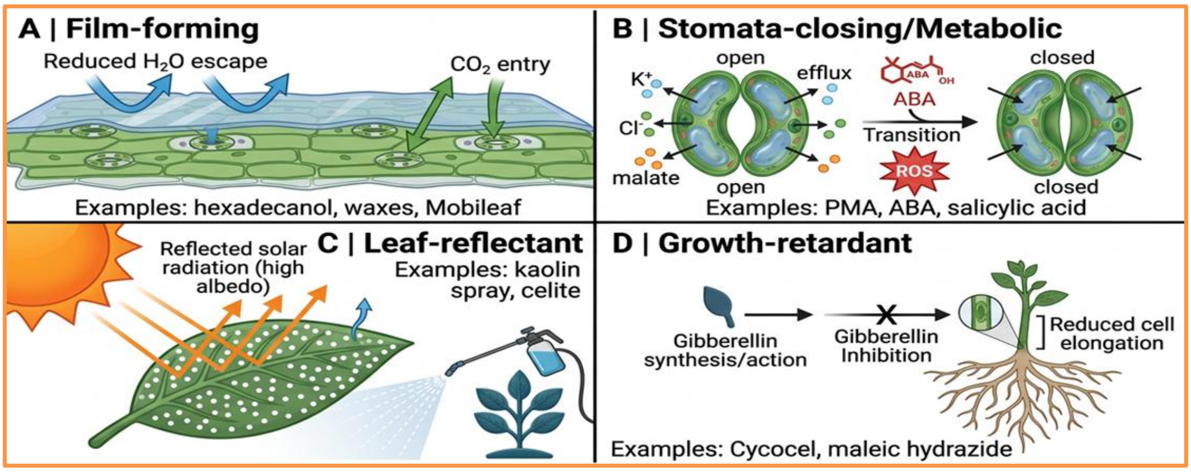
According to their functioning mechanism, Antitraspirants are classified into four major categories. These are:

a. **Film- forming type:** The plastic and waxy materials, which form a thin semi- permeable layer over the epidermis and stomatal pores, retard water escape by forming a physical barrier. The success is limited, since they reduce the rate of photosynthesis also. This can be overcome by making the film- forming antitranspirant to increase the boundary- layer and cuticular resistance to water vapour while remaining permeable to CO_2 (Mphande *et al.*, 2020). They should be uniform in application and maintain continuity. E.g. Thin film antitranspirants: Hexadecanol, waxes, oils, silicon; Thick film forming antitranspirants: Mobileaf, Polythene, S-60.

b. **Stomata closing type (Metabolic type):** Certain hormones, herbicides, fungicides trigger the opening and closing of stomata through trigger ion efflux (K^+, Cl^-, malate) from guard cells via ABA- responsive signaling, generating Reactive oxygen species (ROS) as secondary messengers to reduce guard- cell turgour leading to partial closure of stomata (Iriti *et al*., 2009; Kim *et al*., 2012, cited in Mphande *et al*., 2020). It should be non- toxic to plants and animals, have longer retention and specificity, should be degradable and relatively inexpensive. E.g. Phenyl Mercuric Acetate (PMA), atrazine, ABA, chitosan, salicylic acid, fulvic acid etc.

c. **Leaf Reflectant Type:** These are thin white, high purity mineral particles like kaolin, that forms a coating on the leave surface and increase leaf reflection (albedo), reducing leaf, temperature, vapour pressure gradient driving transpiration (Glenn, 2012). E.g. Kaolin spray 5%, celite, lime water etc.

d. **Growth retardant type:** These chemicals reduce the shoot growth and increase the root growth, inhibit gibberellin biosyntehsis, enabling the plant to reduce transpiring surface i.e. they increase the root: shoot ratio (Sow & Ranjan, 2021). E.g. Cycocel, phosphon- D, maleic hydrazide (MH) etc.



At cellular level, metabolic antitranspirants act on guard cell apparatus, whereas film-forming and reflective type act on leaf boundary layer without altering guard cell physiology.

The Photosynthetic- Transpiration Trade- Off and the Principle of Phenological Timing

While initial research (1950–1979) dismissed antitranspirants (ATs) for field crops because lower stomatal conductance (g_s) directly decreased net photosynthesis (Das & Raghavendra, 1979), this view has been revised. Because many ATs create asymmetric diffusive resistance—restricting H_2O loss more than CO_2 uptake—intrinsic water-use efficiency (WUE) often increases despite minor assimilation drops (Woolley, 1967; Mphande et al., 2020). Recent research highlights that AT success depends strictly on crop phenology. Studies in cereals highlighted that drought during booting causes severe yield loss via pollen sterility and floret abortion during meiosis and micro gametogenesis (Barber *et al.*, 2015; Dolferus *et al.*, 2011). Applying di-1-p-menthene at flag leaf emergence (GS37–GS39) increases droughted wheat yields, whereas post-anthesis applications (GS55–GS69) depress yields (Kettlewell *et al.*, 2010; Abdullah *et al.*, 2015); a response tied directly to preserved pollen viability (Weerasinghe *et al.*, 2016). Precise developmental timing is now recognized as the critical factor determining AT efficacy.

Case Studies

A. INDIA

Indian agriculture is predominantly rainfed and given the climatic condition prevailing in the country, it comes up as a viable research ground for testing of antitranspirant effects. Several field and pot- experiment trials across various agro- climatic zones result in drought mitigating benefits due to usage of antitranspirants. But, reflecting the resource constraints of Indian smallholder farming systems, regional studies emphasize integrating antitranspirants with complementary moisture-conservation practices—such as residue mulching (Dass & Bhattacharyya, 2017), soil hydrogels (Burondkar *et al.*, 2018; Reddy *et al.*, 2018), and strategic irrigation scheduling (Badukale *et al.*, 2015)—rather than deploying them as standalone inputs.

Location	Crop	Antitranspirant compound	Key finding	Reference
Varanasi, Uttar Pradesh, India	Rice (*Oryza sativa*)	Kaolin (reflective)	Foliar kaolin under submerged and water-stressed inceptisol conditions improved nutrient uptake and grain yield relative to unsprayed, water-stressed controls.	Patel *et al.*, 2019
Semi-arid north-Indian plains (IARI, New Delhi)	Rainfed soybean (*Glycine max*)	Wheat-residue mulch + di-1-p-menthene	Combining residue mulch with a film antitranspirant improved productivity and seed quality of rainfed soybean more than either practice alone.	Dass & Bhattacharyya, 2017
Akola, Maharashtra, India	Indian mustard (*Brassica juncea*)	Kaolin / film-forming AT	Antitranspirant sprays combined with adjusted irrigation frequency significantly improved growth attributes and seed yield under limited irrigation.	Badukale *et al.*, 2015
ICAR-IARI (Pusa), New Delhi, India	Wheat (*Triticum aestivum*)	Chitosan + Pusa hydrogel	Joint application of chitosan and a soil superabsorbent hydrogel raised relative water content and yield components above either input alone under deficit irrigation.	Burondkar *et al.*, 2018
Bihar Agricultural University, Sabour, India	Cereals & vegetables (review)	Film-forming, metabolic, reflective ATs	Regional review concluding antitranspirants are a viable, low-cost strategy for India's largely rainfed (only ~17% irrigated) cropping systems.	Sow & Ranjan, 2021

B. GLOBAL

Global research across temperate, Mediterranean, semi-arid, and tropical agro-ecosystems confirms that antitranspirants, most studied kaolin and di-1-p-menthene, deliver broadly reproducible benefits across contrasting environments. Studies spanning the cool-temperate wheat belts of the UK and Australia, Mediterranean horticultural systems in Italy and Greece, and semi-arid to tropical regions in Egypt, Nigeria, Iran, Thailand, and Colombia demonstrate consistent efficacy, provided product selection and application timing are aligned with the target crop's specific drought-sensitive phenological stage.

Location	Crop	Antitranspirant compound	Key finding	Reference
United Kingdom (Harper Adams University)	Winter wheat (*Triticum aestivum*)	Di-1-p-menthene (film-forming)	Application at the boot stage (GS45) improved droughted wheat yield by up to 42% via better pollen viability during meiosis.	Kettlewell *et al.*, 2010
Nile Delta, Egypt	Maize (*Zea mays*)	Kaolin (reflective) + deficit irrigation	5% kaolin under 60-80% ETc allowed up to 40% less water use while maintaining or increasing cob length and grain weight.	Youssef & Hozayenb, 2019
Kasetsart, Thailand	Mango (*Mangifera indica*)	Kaolin clay coating	Kaolin coating reduced leaf temperature and improved gas exchange, supporting fruit yield under tropical heat stress.	Chamchaiyaporn *et al.*, 2013
Western Australia, Australia	Wheat (*Triticum aestivum*)	Di-1-p-menthene (film-forming)	Film antitranspirant sustained higher grain number and yield in drought-stressed wheat by preserving reproductive development.	Abdullah *et al.*, 2015
Kano, Sudan Savanna, Nigeria	Tomato (*Solanum lycopersicum*)	Metabolic / film antitranspirants	Antitranspirant sprays mitigated moisture-stress effects on tomato growth and yield under semi-arid Sahelian conditions.	Isa *et al.*, 2017

Limitations and Research Gaps

- **Response variability**: Efficacy depends strongly on genotype, environmental conditions, AT concentration, and application timing, complicating cross-study comparison (Kocięcka *et al.*, 2023).
- **Economic uncertainty**: Few studies provide field-scale cost-benefit analyses, limiting farmer confidence in adoption, particularly for lower-value arable crops (Kettlewell, 2011; Mphande *et al.*, 2020).
- **Non-target ecological effects**: Kaolin, while suppressing some herbivorous pests, has also been shown to reduce populations of beneficial predators such as coccinellids (Pascual *et al.*, 2010).
- **Legacy toxicity**: Phenyl mercuric acetate (PMA), an older stomata-closing agent, is phytotoxic and now banned in most countries, remaining legal only in India for limited agricultural use (Nandi, 1985; Mphande *et al.*, 2020).
- **Mechanistic gaps**: The precise biochemical pathway by which film-forming ATs such as di-1-p-menthene enhance reproductive drought tolerance beyond simple stomatal blockage remains only partially characterized (Mphande *et* al., 2020).

Future Scope

Key priorities for advancing antitranspirant research include refining crop- and cultivar-specific application timings around vulnerable phenological stages, such as meiosis and anthesis in cereals and pulses. Additionally, integrating ATs with complementary moisture-conservation strategies including mulching, deficit irrigation, and superabsorbent hydrogels, offers a practical path forward. Future efforts must also focus on developing lower-cost, bio-based film-forming alternatives like vegetable oils to suit socio- economic condition of the farmers, alongside quantifying off-target ecological impacts and designing selective reflective formulations. Finally, conducting multi-season cost-benefit analyses remains essential to establish robust evidence to support agricultural extension recommendations.

Conclusion

Antitranspirants are an important physiological approach to mitigate drought stress in crops. These reduce stomatal conductance (g_s), leaf temperature, and transpirational flux. By generating asymmetric diffusive resistance, antitranspirants improve intrinsic water-use efficiency (WUE) during critical developmental windows, Global studies in Mediterranean, temperate and tropical systems show yield gains of 20-45% under water deficits with irrigation savings of up to 40%. For Indian smallholder conditions, there is a need for research on the combination of antitranspirants with hydrogels and mulching for maximum efficacy. Ultimately, the match between antitranspiarant selection and phenological timing enables growers to protect sensitive reproductive stages, at the cost of photosynthetic loss, but with substantial yield preservation during severe moisture deficits.

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