



Organic Waste-Based Plant Sunscreen Spray for Mitigating Heat Stress and Sunburn in Crop Plants

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Abstract - Rising temperatures and prolonged solar radiation pose serious threats to agricultural productivity, causing leaf scorching, reduced photosynthesis, and significant yield losses. This study presents the development and field evaluation of a bio-waste-derived plant sunscreen spray formulated from banana stem powder, fruit peel powder, used tea waste, and aloe vera gel. The bio-waste ingredients were sun-dried, ground into fine powders, and subjected to controlled hot-water extraction to release bioactive compounds including tannins, polyphenols, flavonoids, pectin, and antioxidants. Filtered extracts were concentrated and blended with freshly prepared aloe vera gel to produce a stable, film-forming foliar spray. The formulation was applied to potted tomato and chilli plants maintained under natural outdoor conditions over a sixty-day observation period, with untreated plants serving as controls. Treated plants consistently exhibited lower leaf surface temperatures, healthier foliage, reduced sun-scorch symptoms, and improved canopy development compared to untreated controls. Temperature measurements confirmed a progressive reduction in leaf surface temperature in the treated group, with differences widening as sunlight intensity increased across the observation period. The spray coating persisted for several days without causing phytotoxic effects or interfering with normal plant growth. The formulation is low-cost, biodegradable, and prepared from widely available agricultural residues, making it a viable and sustainable protective solution for smallholder farmers in tropical and subtropical regions.

Key Words: Plant Sunscreen, Heat Stress, Bio-Waste Extracts, Tomato, Chilli, Foliar Spray, Leaf Temperature, Sunburn Protection, Aloe Vera Gel, Organic Crop Protection

1. INTRODUCTION

Agriculture remains central to global food security and rural livelihoods. In tropical and subtropical regions, however, crops increasingly face the dual challenge of rising ambient temperatures and intensified solar radiation. Prolonged exposure to high sunlight during critical growth stages triggers heat stress responses in plants, manifesting as leaf scorching, edge burning, chlorophyll degradation, reduced photosynthetic efficiency, impaired fruit set, and ultimately lower yields. Crops such as tomato, chilli, capsicum, and brinjal are particularly sensitive to excessive solar exposure, with symptoms ranging

from yellowing and tissue necrosis to severe market-quality loss in fruits.

Conventional protective strategies—shade nets, increased irrigation frequency, and mulching—are labor-intensive, resource-demanding, and often impractical for smallholder farmers managing large cropping areas. Chemical plant protectants, although available, introduce concerns regarding soil contamination, residue accumulation, and rising input costs. A low-cost, eco-friendly alternative that can reduce leaf temperature and UV damage while remaining safe for repeated field use is therefore highly desirable.

Plant-based foliar coatings offer a promising pathway. When applied to leaf surfaces, they can form thin transparent films that partially filter harmful ultraviolet and infrared radiation while still permitting adequate light transmission for photosynthesis. Natural compounds such as tannins, pectin, flavonoids, and antioxidants found in agricultural by-products possess UV-absorbing, moisture-retaining, and radical-scavenging properties that make them functionally suitable for such applications.

This project explores the conversion of three readily available agricultural waste streams—banana stem residues, used tea powder, and citrus fruit peels—into a functional plant sunscreen spray. Aloe vera gel serves as a natural binder to enhance leaf adhesion and film-forming ability. The study documents the complete development pathway from raw material processing through formulation to field application, and evaluates the spray's protective performance on tomato and chilli plants over a sixty-day monitoring period.

2. OBJECTIVES

The primary objectives of this study are:

- To develop an organic waste-derived plant sunscreen spray using banana stem, fruit peel, tea waste, and aloe vera gel through simple extraction and formulation methods.
- To evaluate the spray's effectiveness in reducing leaf surface temperature and sunburn symptoms under natural field conditions.

- To assess the impact of the protective coating on overall plant growth, foliage quality, and canopy development in tomato and chilli plants.
- To confirm the absence of phytotoxic effects and to determine spray stability and practical field-use suitability.
- To promote a sustainable, low-cost approach to crop protection that utilizes agricultural bio-waste and supports eco-friendly farming.

3. LITERATURE REVIEW

Research into heat stress effects on crops has grown substantially as global temperatures continue to rise. Studies on temperature-sensitive crops such as tomato and chilli have consistently demonstrated that exposure to temperatures beyond physiological optima reduces pollen viability, impairs fruit set, and decreases overall productivity. Investigations into the morphological and reproductive responses of *Capsicum annuum* and *Solanum lycopersicum* under high-temperature conditions have highlighted the sensitivity of flowering and seed development to thermal stress, underscoring the need for protective field interventions.

At the molecular level, heat stress activates heat-shock proteins, antioxidant defense pathways, and stress-responsive transcription factors. While these endogenous mechanisms provide partial tolerance, they are insufficient against prolonged or extreme solar radiation. Studies examining pollen quality in heat-tolerant versus heat-sensitive tomato cultivars confirm that carbohydrate maintenance in pollen is closely linked to reproductive success under elevated temperatures, and that external protective strategies can complement internal molecular defenses.

On the formulation side, research into bio-based foliar coatings has demonstrated that natural polyphenolic compounds derived from plant residues can absorb UV radiation and reduce oxidative stress on leaf surfaces. Tannins and polyphenols from tea processing residues exhibit strong antioxidant and UV-shielding properties. Citrus peel extracts are rich in flavonoids and carotenoids that contribute to photoprotection. Pectin and cellulosic compounds from banana stem residues provide film-forming and moisture-retention capabilities that improve coating adhesion and persistence on leaf cuticles.

Aloe vera gel has been widely investigated as a natural binder and thickener in agricultural and pharmaceutical formulations due to its gel-forming polysaccharides, primarily acemannan, and its capacity to form stable thin films on biological surfaces. Its incorporation into foliar spray formulations has been shown to enhance adhesion, slow desiccation of the coating layer, and provide mild anti-stress benefits to plant surfaces.

Despite individual advances in bio-based UV protectants and natural foliar coatings, no prior study has comprehensively combined multi-source waste extraction, aloe vera gel binder integration, and controlled field evaluation across a multi-week observation period for smallholder crop species. This study aims to address that gap by delivering a reproducible, cost-effective, and field-validated formulation.



4. MATERIALS AND METHODS

4.1 Raw Materials

Banana stem pieces were collected fresh from local market sources and used for fibre and pectin extraction (Fig. 1). These stems are rich in natural polysaccharides that contribute to gel formation and moisture retention in foliar coatings.

Fig. 1: Banana Stem Pieces

Used tea powder (tea waste) was sun-dried to concentrate its tannin and polyphenol content (Fig. 2). These bioactive compounds are known for antioxidant properties and UV-absorbing capacity, making them suitable as a core protective ingredient in the spray formulation.

Fig. 2: Tea Waste (Sun-Dried)



Mixed fresh fruit peels including orange and lemon varieties were collected and thoroughly washed before drying (Fig. 3). Fruit peels are rich in vitamin C, flavonoids, and carotenoids—natural antioxidants that enhance photoprotective efficacy in the formulation.

Fig. 3: Mixed Fruit Peels



Additional raw materials included fresh aloe vera leaves for gel extraction and distilled water as the extraction solvent throughout all processing steps.

4.2 Plant Materials

Tomato (*Solanum lycopersicum*) and chilli (*Capsicum annuum*) plants were selected as the experimental crops due to their well-documented sensitivity to heat stress and solar radiation damage. Figures 4 and 5 show characteristic heat stress symptoms observed in tomato leaves under high-intensity sunlight conditions, including scorching, browning, and bleaching.



Fig. 4: Leaf Scorching & Browning



Fig. 5: Leaf Bleaching & Spotting

Chilli plants similarly exhibit heat-induced leaf drying and visible stress symptoms when subjected to prolonged direct sunlight (Figs. 6 and 7), making them ideal test subjects for evaluating the protective efficacy of the developed spray.



Fig. 6: Heat-Induced Leaf Drying in Chilli



Fig. 7: Chilli Plant Heat Stress Symptoms

4.3 Equipment and Instruments

An infrared thermometer was used to measure leaf surface temperature at specified canopy positions (Fig. 8). pH strips

calibrated against standard buffer solutions were used to verify formulation pH throughout preparation (Fig. 9). A lux meter quantified ambient light intensity at plant level to ensure consistent solar radiation exposure across experimental groups (Fig. 10).



Fig. 8: Infrared Thermometer

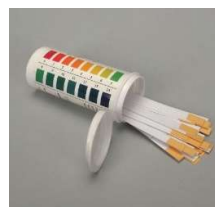


Fig. 9: pH Strips



Fig. 10: Lux Meter

Table 1: Observation Parameters and Expected Effects After Spray Application

Parameter	Instrument / Method	What It Measures
Leaf surface temperature	Infrared thermometer	Heat absorption
Photosynthesis rate	Field observation	Plant activity
Leaf sunburn scoring	Visual rating	Damage by sunlight
Yield analysis	Counting fruits	Productivity

4.4 Raw Material Processing

All collected materials were thoroughly washed, cut into small pieces, and spread on stainless steel trays for sun-drying (Fig. 11). Drying continued for two to four days depending on moisture content and weather conditions, until materials became completely crisp and moisture-free.



Fig. 11: Collected and Cleaned Raw Materials



Fig. 12: Sun-Drying Procedure on Stainless Steel Trays

Dried materials were ground using a high-speed mixer grinder to produce fine, homogeneous powders (Fig. 13). Each powder was sieved to standardize particle size and immediately stored in labelled airtight containers to preserve bioactive compounds.



Fig. 13: Dried Materials



Fig. 14: Ground Powders

4.5 Extraction by Controlled Boiling

Each powder type was boiled separately in measured volumes of distilled water. Banana stem powder was boiled for 20–25 minutes yielding a light-brown pectin-rich extract (Fig. 15). Tea waste was boiled for 15–20 minutes producing a dark-brown tannin-rich solution (Fig. 16). Fruit peel powder was boiled for 25–30 minutes releasing flavonoids and carotenoids into a medium-brown extract (Fig. 17).



Fig. 15: Banana Stem Boiling



Fig. 16: Tea Waste Boiling



Fig. 17: Fruit Peel Boiling

Table 2: Extraction Parameters and Bioactive Compounds Obtained

Raw Material	Boiling Time	Key Compounds Extracted	Primary Function
Banana stem powder	20–25 min	Pectin, cellulose, fibres	Film formation & moisture retention
Tea waste powder	15–20 min	Tannins, polyphenols	UV protection & antioxidant activity
Fruit peel powder	25–30 min	Flavonoids, carotenoids, antioxidants	Photoprotection & pigment shielding

4.6 Filtration

Cooled extracts were filtered through double-layered muslin cloth to remove fibrous residues, producing clear bioactive-rich filtrates (Fig. 18). Filtrates were collected in sterilized glass containers and gently concentrated by mild reheating before formulation.



Fig. 18: Filtration of Boiled Extracts Through Muslin Cloth

4.7 Spray Formulation

Filtered and concentrated extracts were combined in defined proportions (banana stem 30–40%, tea waste 30%, fruit peel 20–30%) and blended with fresh aloe vera gel at 5–10%. The mixture was stirred for 5–10 minutes until uniform. The final formulation exhibited a uniform dark-brown colour and was



transferred into clean, labelled spray bottles for field use (Fig. 19).

Fig. 19: Final Plant Sunscreen Spray in Labelled Bottles

Table 3: Formulation Composition of the Bio-Waste Spray

Ingredient	Proportion	Role in Formulation
Banana stem extract	30–40%	Film formation and moisture retention
Tea waste extract	30%	UV absorption and antioxidant protection
Fruit peel extract	20–30%	Photoprotection and pigment shielding
Aloe vera gel	5–10%	Binding, thickening, and leaf adhesion

4.8 Experimental Design

A Completely Randomized Design was employed with two treatment groups: T1 (Control – no spray) and T2 (Treatment – bio-waste spray). One tomato and one chilli plant were assigned to each group, giving four plants in total. Plants were selected at comparable growth stages and labelled with waterproof identification tags. The control group (Fig. 20) and treated group (Fig. 21) were placed in identical outdoor environments receiving equal sunlight, temperature, and irrigation throughout the study period.



Fig. 20: Control Group (Tomato + Chilli) **Fig. 21: Treated Group (Tomato + Chilli)**

4.9 Spray Application and Monitoring

The formulated spray was applied using a hand sprayer during morning (07:00–09:00) or evening (16:00–18:00) hours to minimize evaporation. Both upper and lower leaf surfaces were coated uniformly at a standardized nozzle distance of 20–25 cm. A fixed volume of 25–40 mL per plant was dispensed at each application. Following treatment, both groups were monitored daily and weekly for leaf surface temperature, colour changes, wilting, sunburn scoring, foliage density, and overall

plant vigour. Observations were documented with written records and photographic evidence.

4.10 Instrument Calibration

Before measurements commenced, all instruments were calibrated. The infrared thermometer was verified against a boiling water reference (100 °C) and adjusted to read within ±0.5 °C. pH strips were tested against standard buffer solutions at pH 4, 7, and 9. The lux meter was verified against a fixed artificial light source of known output. Regular calibration checks were performed throughout the observation period to maintain measurement accuracy.

5. RESULTS AND DISCUSSION

5.1 Formulation Outcome

The hot-water extraction process yielded three distinct liquid extracts, each exhibiting characteristic colouration indicating successful release of target bioactive compounds. Upon blending with aloe vera gel, the combined formulation produced a stable, uniformly dark-brown spray solution with satisfactory viscosity and consistent pH in the range of 5.5–6.5. No phase separation was observed during the observation period for refrigerated samples, and formulations stored at room temperature remained stable and usable for approximately five days before mild colour changes indicated the onset of microbial activity. The spray nozzle produced fine, uniform droplets that coated leaf surfaces without runoff under standard application conditions.

5.2 Spray Application on Crops

Figure 22 illustrates the spray application process on the experimental tomato and chilli plants. Uniform foliar coverage was achieved across both upper and lower leaf surfaces in all



treated plants.

Fig. 22: Spray Application on Tomato and Chilli Plants

5.3 Growth Comparison

Figure 23 shows a side-by-side growth comparison of treated and control plants at the midpoint of the observation period. Treated plants display visibly denser, greener foliage and more upright leaf posture compared to control plants showing early stress symptoms.



Fig. 23: Growth Comparison — Treated vs. Control Plants

5.4 Leaf Temperature Reduction

Temperature measurements recorded across the sixty-day observation period consistently showed lower leaf surface temperatures in the treated group. On Day 1, the treated group recorded 32.0 °C versus 34.5 °C in controls under 48,200 lux. By Day 30, the difference widened to 34.0 °C (treated) versus 39.0 °C (control) under 56,400 lux, and by Day 60 values reached 35.8 °C versus 43.1 °C under 64,500 lux. The progressive widening of the temperature differential as sunlight intensity increased suggests the spray coating provides greater protective benefit precisely when solar heat stress is most severe.

Table 4: Leaf Temperature and Light Intensity Observations Over 60 Days

Day	Treated Leaf Temp (°C)	Control Leaf Temp (°C)	Light Intensity (Lux)
1	32.0	34.5	48,200
10	32.8	36.0	50,800
20	33.4	37.6	53,700
30	34.0	39.0	56,400
40	34.5	40.2	59,300
50	34.8	41.0	60,700
60	35.8	43.1	64,500

Figure 24 graphically presents the leaf temperature trend for both groups across the sixty-day period, clearly illustrating the consistent and widening temperature gap.

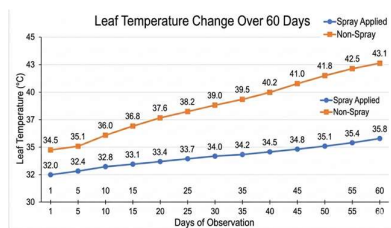


Fig. 24: Leaf Temperature Change Observations During 60 Days

5.5 Visual and Growth Observations

Throughout the observation period, treated plants maintained visually healthier foliage compared to controls. Leaves in the treated group remained firm, well-hydrated, and retained deeper green colouration into the later weeks of the experiment. The untreated control plants began exhibiting leaf edge drying, curling, and mild discoloration from the third week onward, with symptoms intensifying in correlation with increasing sunlight intensity. Sun-scorch scoring consistently rated treated leaves lower in damage severity than controls. No phytotoxic responses such as chemical burn marks, stomatal blockage indicators, or abnormal leaf drop were observed in the treated group. Overall plant vigour, including stem thickness, leaf density, and canopy coverage, was qualitatively superior in treated plants over the final three weeks of observation.

5.4 Mechanism of Action

The protective effect of the formulation is attributed to the combined action of its constituent bioactive compounds. Tannins and polyphenols extracted from tea waste are well-established UV absorbers that reduce the direct photonic load reaching leaf epidermal cells. Flavonoids and carotenoids from fruit peel extracts contribute to radical scavenging, limiting oxidative damage from excess solar energy. Pectin and cellulosic compounds from banana stem create a cohesive film that reduces direct conductive heat transfer to leaf tissue and slows evaporative water loss from the cuticle. Aloe vera gel enhances film adhesion and persistence, ensuring that active compounds remain in contact with the leaf surface across multiple days. Together, these mechanisms produce a measurable reduction in leaf thermal load and oxidative stress without impeding the light transmission required for photosynthesis.

5.5 Cost and Practical Viability

All raw materials used in the formulation are widely available agricultural products that carry negligible or zero market value at the point of collection. The processing steps—sun-drying, mechanical grinding, boiling extraction, and simple blending—require no specialized laboratory infrastructure and can be performed at farm level using basic equipment. Total estimated material cost per litre of formulated spray is below INR 50, making it highly affordable for smallholder farmers. The absence of synthetic chemicals eliminates regulatory barriers to adoption and residue-related risks to produce safety. The formulation is biodegradable and leaves no persistent environmental residues, aligning with sustainable agriculture and circular economic principles.



6. CONCLUSION

This study demonstrated the successful development and field validation of an organic waste-based plant sunscreen spray formulated from banana stem extract, tea waste extract, fruit peel extract, and aloe vera gel. The complete process—from raw material collection and drying through extraction, filtration, formulation, and field application—was carried out using simple, low-cost methods accessible to smallholder farming operations.

Application of the spray to tomato and chilli plants over a sixty-day outdoor observation period produced consistent and measurable protective outcomes. Treated plants exhibited progressively lower leaf surface temperatures than untreated controls across the full duration of the study, with the temperature differential widening as light intensity increased from approximately 48,000 lux to over 64,000 lux. Treated plants also maintained healthier foliage, lower sun-scorch severity, better moisture retention, and improved overall plant vigour compared to controls. The spray produced no phytotoxic effects and degraded naturally without harmful residues.

The results confirm that bioactive compounds naturally present in common agricultural by-products—tannins and polyphenols from tea waste, flavonoids and carotenoids from fruit peels, pectin and fibre from banana stem—can collectively deliver meaningful foliar photoprotection when combined into a stable, binder-supported formulation. The incorporation of aloe vera gel as a natural adhesive and film-forming agent was critical to coating persistence and uniform leaf coverage.

Future work should explore larger-scale field trials across diverse crop species and agroclimatic zones, optimization of extraction concentrations and blending ratios for maximum photoprotection, RFID or QR-coded batch tracking for farm-level quality control, and integration with precision agriculture platforms to schedule application based on real-time solar radiation forecasts. With further refinement, the bio-waste plant sunscreen spray holds strong potential as a practical, scalable, and environmentally responsible solution for protecting crops against the intensifying challenge of solar heat stress under changing climate conditions.

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BIOGRAPHIES



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