

Impact of a Kaolin Foliar Film and Soil Water Potential on Leaf Temperature, Yield, and Fruit Quality of Zucchini (*Cucurbita pepo* L.)

JOSÉ ALEXANDER GIL-MARÍN^{1,*}, ALEJANDRO ZERMEÑO-GONZÁLEZ¹, SASIROT KHAMKURE², HOMERO RAMÍREZ-RODRÍGUEZ³, AARON ISAIN MELENDRES-ALVAREZ¹

¹Department of Irrigation and Drainage, Autonomous Agrarian University Antonio Narro. Calzada Antonio Narro 1923, Saltillo 25315, Coahuila, Mexico.

²SECIHTI-Department of Irrigation and Drainage, Autonomous Agrarian University Antonio Narro. Calzada Antonio Narro 1923, Saltillo 25315, Coahuila, Mexico.

³Department of Horticulture, Autonomous Agrarian University Antonio Narro. Calzada Antonio Narro 1923, Saltillo 25315, Coahuila, Mexico

*email: jalexgil2022@hotmail.com

ORCID:

JAGM:0000-0001-9185-0411

AZG:0000-0003-4137-9638

SK:0000-0002-1915-7863

HRR:0000-0003-0876-557X

AIMA:0000-0001-8707-5678

ABSTRACT

This study was based on the hypothesis that foliar application of a kaolin film increases yield and fruit quality under different soil water potential (SWP) levels, and that yield and fruit quality decrease with increasing soil water tension. The objective of this work was to evaluate the effect of foliar application of a kaolin film and three soil water potential levels on leaf temperature, yield, and fruit quality of Carola F1 zucchini (*Cucurbita pepo* L.). The experiment was carried out in the Hydraulic Garden of the Irrigation and Drainage Department, Antonio Narro Autonomous Agrarian University, during the summer of 2023. A randomized block design with a split-plot arrangement was used. The main plot consisted of the irrigation initiation levels based on readings from a tensiometer placed at a depth of 20 cm (20, 35 and 50 kPa), and the subplot consisted of kaolin application, with two levels: with and without application. The experiment included four replications and six treatments resulting from the combination of the three soil water potential levels and the two kaolin treatments. The effect of the mineral protectant on leaf temperature depended on the soil

moisture level. At all soil water potential levels, application of a kaolin foliar film to Carola F1 zucchini plants decreased leaf temperature and increased fruit length, fruit diameter, the number of fruits per plant and overall yield compared with plants without the kaolin film.

Keywords: kaolin foliar film, soil water potential, zucchini, leaf temperature, fruit yield

HIGHLIGHTS

- The application of kaolin increased fruit yield by 12.6%.
- Three tensiometer-based irrigation strategies were evaluated.
- Leaf-temperature differences of up to 17 °C were observed between kaolin-treated and control plants.
- Irrigation of Carola F1 zucchini is recommended when soil water potential reaches 35 kPa.
- The use of kaolin improved zucchini fruit quality.

INTRODUCTION

Recent warming trends and erratic weather patterns affecting agricultural production have highlighted the need for adaptive cultural practices to mitigate the harmful effects of climate variability (Santos & Bokhshoodeh, 2021; Shellie, 2015). Optimizing water use efficiency (WUE), particularly in arid and semi-arid regions, is a priority because water is the main limiting factor for plant growth (Bodner et al., 2015; Brillante et al., 2016; Medrano et al., 2015). In this regard, significant water savings can be achieved by increasing water-use efficiency through careful water resource management, especially under global scenarios in which crop evapotranspiration continues to rise due to heat stress (Pakhira & Jolly, 2023; Zhou et al., 2026). Plants use water extensively, especially in arid and semi-arid regions, because only about 5% of water consumption is used for growth and development, while the remaining 95% is lost through transpiration (AbdAllah, 2017). Therefore, the potential for reducing plant water consumption through the application of antitranspirants is significant (Mikiciuk et al., 2015; Brillante et al., 2016; Glenn et al., 2001; Glenn, 2010; Faralli et al., 2016; AbdAllah, 2017). Many studies have shown that antitranspirants are useful for

regulating plant water status and overcoming the harmful effects of water and/or heat stress, thereby preserving plant growth and yield (Abdel-Fattah, 2013; Mikiciuk et al., 2015).

In fact, the use of antitranspirants has demonstrated significant potential for conserving soil moisture for over longer periods and postponing the onset of extreme drought stress (Faralli et al., 2016; Mikiciuk et al., 2015; Pakhira & Jolly, 2023; Rehman et al., 2023). By mitigating water loss through foliar transpiration, these substances reduce the rate of water extraction from the soil profile, thereby prolonging water availability in the rhizosphere and optimizing water use efficiency (WUE) under deficit irrigation regimes (Ali et al., 2025; Borai et al., 2015; Brillante et al., 2016; Glenn, 2010; Ibrahim et al., 2024; Jifon & Syvertsen, 2003).

Antitranspirants, according to their mechanism of action, are classified into three main categories: (1) metabolic materials, which are chemical compounds that inhibit the complete opening of stomata, thereby decreasing the loss of water vapor through the foliage (Anjum et al., 2011, Ahmad et al., 2024; Shahzad et al., 2025); (2) film-forming materials, which consist of emulsions of wax, latex, or plastic polymers that, when dried on the foliage, form transparent layers that physically prevent the escape of water vapor (Faralli et al., 2016); and (3) reflective materials, which reduce the absorption of solar radiant energy and, therefore, decrease both leaf temperature and the transpiration rate (Glenn et al., 2002). Among the latter, one of the most widely used reflective agents for optimizing crop water status and indirectly conserve soil water is processed kaolin particle film (Glenn, 2016).

Kaolin is an antitranspirant and reflective material classified as an engineered clay; chemically, it consists of aluminum phyllosilicate with the molecular formula $(\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_2)$. When sprayed, it coats leaves and fruits with thin films composed of microscopic particles and nanoparticles (Borai et al., 2015; Brillante et al., 2016; Glenn & Puterka, 2005; Moradi et al., 2024). Subjecting kaolin to a thermal calcination process transforms this silicate into a bright white material, which significantly increases its light-reflectance properties in the plant canopy (Glenn et al., 2001). Kaolin particle film reflects ultraviolet (UV) and infrared (IR) radiation while improving the distribution of photosynthetically active radiation (PAR), thereby reducing temperatures of treated leaves and fruits (Glenn, 2012). Consequently, kaolin is used to prevent sunburn in fruits and vegetables (Cantore et al., 2009; Glenn, 2009). It also contributes to water conservation by reducing transpiration in various species, such as clementine (*Citrus × clementina* hort. ex

Tanaka), tomato (*Solanum lycopersicum* L.) (Borai et al., 2015; Cantore et al., 2009; Glenn & Puterka, 2005), and grapefruit (*Citrus × paradisi* Macfad) (Jifon & Syvertsen, 2003; Shellie, 2015; Shellie & King, 2013).

Furthermore, several studies have shown that foliar application of kaolin can protect crops against drought stress (Coniberti et al., 2013; Glenn, 2012). The effectiveness of kaolin in reducing tissue temperature and mitigating environmental stress also significantly influences fruit quality parameters (Aly et al., 2010; Dinis et al., 2016; Glenn et al., 2001, 2003; Glenn & Puterka, 2007; Moradi et al., 2024; Ouerghi et al., 2026; Shellie, 2015; Shellie & King, 2013). In addition, several studies have reported increased yields in various crops following the application of kaolin films, particularly under severe water deficit conditions (Borai et al., 2014; Cantore et al., 2009; Glenn et al., 2003; Khaleghi et al., 2015; Lapointe et al., 2006; Sugar et al., 2005).

Given this background, and based on the hypothesis that regardless of the soil moisture tension level at which irrigation was applied zucchini (*Cucurbita pepo* L.) plants treated with a kaolin foliar film would have higher yield and fruit quality than in untreated plants. Therefore, the objectives of this study were to evaluate the influence of a kaolin particle film and three levels of soil moisture tension on leaf temperature, yield, and fruit quality in zucchini.

MATERIALS AND METHODS

Study Area

The experiment was conducted during the summer of 2023 at the Experimental Agricultural Field of the Hydraulic Garden, which is affiliated with the Department of Irrigation and Drainage at Antonio Narro Autonomous Agrarian University in Saltillo, Coahuila, Mexico (25° 21' N, 101°02' W; 1,765 m a.s.l.) (Figure 1). The region has a hot, dry desert climate with limited winter rainfall and is classified as BWhw(x')e according to the Köppen climate classification system modified by García (2004) and INEGI (2010). Historical climate data show an average annual temperature of 19 °C, average annual rainfall of 325 mm, and average annual evaporation of 1,956 mm (National Meteorological Service, 2020).

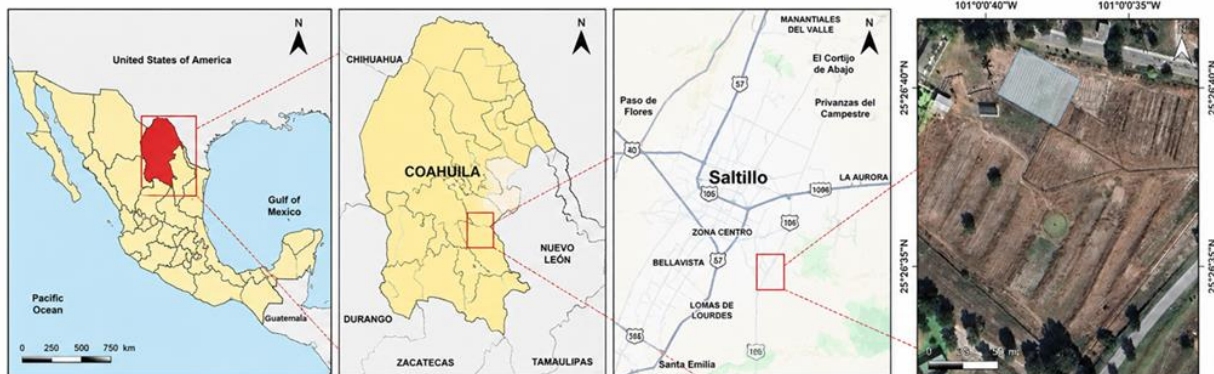


Figure 1. Location of the experimental site at Antonio Narro Autonomous Agrarian University Saltillo, Coahuila, Mexico.

Physical and Chemical Properties of the Soil

Physical analysis of the soil in the experimental area indicated a loam texture, consisting of 44% sand, 34% silt, and 22% clay within the 0–30 cm soil layer (Table 1). The soil had a bulk density (BD) of 1.20 g/cm³, a field capacity of 30.2% and a permanent wilting point of 15.1%. Together, these properties provide moderate water retention and suitable porosity for porosity conditions for zucchini root development.

Table 1. Physical, chemical, and fertility properties of the soil at a depth of 0–30 cm in the experimental area.

Parameter	Value	Interpretation
Physical Properties		
Texture (Sand / Silt / Clay, %)	44 / 34 / 22	Loam (Medium)
Bulk Density (BD, g/cm ³)	1.2	Adequate
Field Capacity / PWP (%)	30.2 / 15.1	-
Chemical Properties and Salinity		
pH (saturation extract)	8.36	Strongly alkaline
Electrical Conductivity (EC _{ex} , dS/m)	1.19	Non-saline
Total Calcium Carbonate (CaCO ₃ , %)	61.7	Very high
Cation Exchange Capacity (CEC, meq/100 g)	20.55	Medium-High
SAR/ ESP (%)	2.46 / 3.5	No sodium problems
Active Limestone (%)	23.25	High

Available Macronutrients

Organic Matter (OM, %)	2.89	Moderately High
Nitrogen (N-NO ₃ , ppm)	32.78	Medium
Available Phosphorus (P, ppm)	113.85	Very High
Extractable Potassium (K, ppm)	310.75	Moderately High
Extractable Calcium (Ca, ppm)	3705.63	Moderately High
Extractable Magnesium (Mg, ppm)	197.2	Moderately Low
Extractable Micronutrients (ppm)		
Iron (Fe) / Manganese (Mn)	7.18 / 17.52	Moderately Low / Moderately High
Copper (Cu) / Zinc (Zn)	1.25 / 12.99	Moderately High / Very High
Sulfur (S) / Boron (B)	23.62 / 1.70	High / Moderately High

Note: PWP = Permanent wilting point; SAR = Sodium adsorption ratio; ESP = Exchangeable sodium percentage. Analyses and interpretations were based on standard reference values for agricultural production.

Regarding its chemical properties, the soil was classified as strongly alkaline due to its pH of 8.36. Despite this alkalinity, the electrical conductivity of the saturation extract (EC_{ex} = 1.19 dS/m) indicated that the soil was non-saline, remaining below the critical tolerance threshold for *Cucurbita pepo* L. Additionally, high concentrations of total calcium carbonate (61.7%) and active limestone (23.25%) were recorded. The sodium adsorption ratio (SAR_{ex} = 2.46) and exchangeable sodium percentage (ESP_{ex} = 3.5%) confirmed the absence of risks related to clay dispersion or structural degradation associated with sodium accumulation. Regarding soil fertility and nutrient availability, organic matter content (2.89%) and available nitrogen (32.78 ppm) were moderate. In contrast, phosphorus (113.85 ppm) and zinc (12.99 ppm) exhibited concentrations categorized as very high. Among the remaining extractable macronutrients, calcium (3,705.63 ppm) and potassium (310.75 ppm) were at moderately high levels, whereas magnesium (197.20 ppm) and iron (7.18 ppm) were reported at moderately low levels. This suggests the potential induction of iron chlorosis due to the antagonism caused by high calcium concentrations and the alkaline pH of the experimental site.

Physical and Chemical Properties of Irrigation Water

Chemical analysis of the irrigation water showed a pH of 8.28, classifying the water as moderately alkaline. Its electrical conductivity (EC) was 1.03 dS/m, and its total dissolved solids (TDS) concentration was 661.44 ppm (Table 2). Regarding the cation and anion balance, the water showed a predominance of sulfate (4.20 meq/L) and calcium (4.20 meq/L),

followed in decreasing order by sodium (3.15 meq/L), bicarbonate (2.70 meq/L), magnesium (2.21 meq/L), and chloride (1.61 meq/L). The concentrations of carbonates (0.80 meq/L) and potassium (0.41 meq/L) were low. The sodicity indices were an SAR of 1.76 and an adjusted SAR (SARadj) of 1.90. Regarding the nutrient and trace element profile, a high concentration of nitrates (N-NO₃) of 25.16 ppm was observed, while boron remained at a safe level for the crop (0.10 ppm); the rest of the nutrients and heavy metals evaluated were reported as not significant or not detected in relevant concentrations.

Table 2. Chemical composition, salinity indices, nutrient concentrations, and trace elements in the irrigation water used in the experiment.

Parameter	Symbol	Unit	Value	Reference Range
Salinity and Indices				
Hydrogen Potential	pH	-	8.28	6.0 – 8.5
Electrical Conductivity	EC	dS/m	1.03	0.0 – 3.00
Total Dissolved Solids	TDS	ppm	661.44	0 – 2000
Sodium Adsorption Ratio	SAR	-	1.76	0 – 15
Adjusted SAR	(SARa)	-	1.9	0 – 15
Cations and Anions				
Calcium / Magnesium	(Ca ⁺⁺) / (Mg ⁺⁺)	meq/L	4.20 / 2.21	0–20 / 0–5
Sodium / Potassium	(Na ⁺) / (K ⁺)	meq/L	3.15 / 0.41	0–40 / 0–0.5
Carbonates / Bicarbonates	(CO ₃ ⁻⁻) / (HCO ₃ ⁻)	meq/L	0.80 / 2.70	0–0.1 / 0–10
Chlorides / Sulfates	(Cl ⁻) / (SO ₄ ⁻⁻)	meq/L	1.61 / 4.20	0–30 / 0–20
Nutrients and Trace Elements				
Nitrates	(N-NO ₃)	ppm	25.16	0 – 10
Boron	B	ppm	0.1	< 2.0

Note: Parameters reported in the original analysis as NS (Not Significant) or ND (Not Detected) were omitted from this table to optimize editorial space (Ammonia, Phosphorus, Cu, Fe, Zn, Mn, As, F, Pb, Cd, Cr, Ni). Source: RASPA Laboratory, Durango. 2024

Crop Establishment and Management

The crop established was zucchini (*Cucurbita pepo* L.) hybrid Carola F1, with a 60-day maturation cycle. Direct sowing was carried out on May 7, 2023, placing two seeds per planting spot at a depth of 1 cm. The planting density was 25,000 plants per hectare. This was achieved by maintaining a spacing of 80 cm between rows and 50 cm between individual

plants. Germination occurred 3 days after sowing. The crop was established in an open field, occupying a total area of 460 m². Prior to sowing, the land was prepared by fallowing and two passes with a harrow. Six furrows (60 cm wide × 8 m long), were established for each treatment and covered with black plastic mulch. Irrigation was applied using a drip system with 16 mm-diameter, 6-mil drip tape, an emitter spacing of 20 cm, and an emitter flow rate of 1.3 LPH. The seedbed dimensions were measured to determine its total volume and adjust the irrigation times accordingly (Table 3). At field capacity, the volumetric soil moisture content was 40%, as measured after a 6-h irrigation period using a TDR probe equipped with 20-cm rods (HydroSense II, Campbell Scientific, Inc., Logan, UT, USA).

Table 3. Irrigation duration for each treatment.

Tensiometer reading kPa	Irrigation time
20	1 hour 15 minutes
35	1 hour 45 minutes
50	2 hours 15 minutes

Phytosanitary practices for controlling weeds, pests and diseases was carried out following the conventional commercial practices of the region, ensuring that they did not interfere with the treatments under evaluation.

Experimental Design and Treatments

A split-plot experimental design with four randomized blocks was used. Each experimental unit consisted of a beds measuring 8 m long and 1.20 m wide. The main plot comprised three soil water tension levels used as irrigation criteria: 20, 35, and 50 kPa. Soil matric potential was continuously monitored using tensiometers (Irrimeter Co., Riverside, CA, USA) installed in the active root zone at a depth of 20 cm. The subplot comprised two levels of stress mitigation with kaolin: with and without application (control) (Figure 2). The kaolin film (Surround brand) was applied at a standard concentration of 5% prepared by dissolving 5 kg of the product with 100 L of water. The suspension was applied using a 15-L backpack sprayer at an approximate dose of 0.65 g of kaolin per plant. Applications were made at 15-day intervals, beginning 15 days after germination. After rainfall, kaolin was reapplied to

replace the film removed by wash-off. In total, 10 applications were performed during the crop cycle.

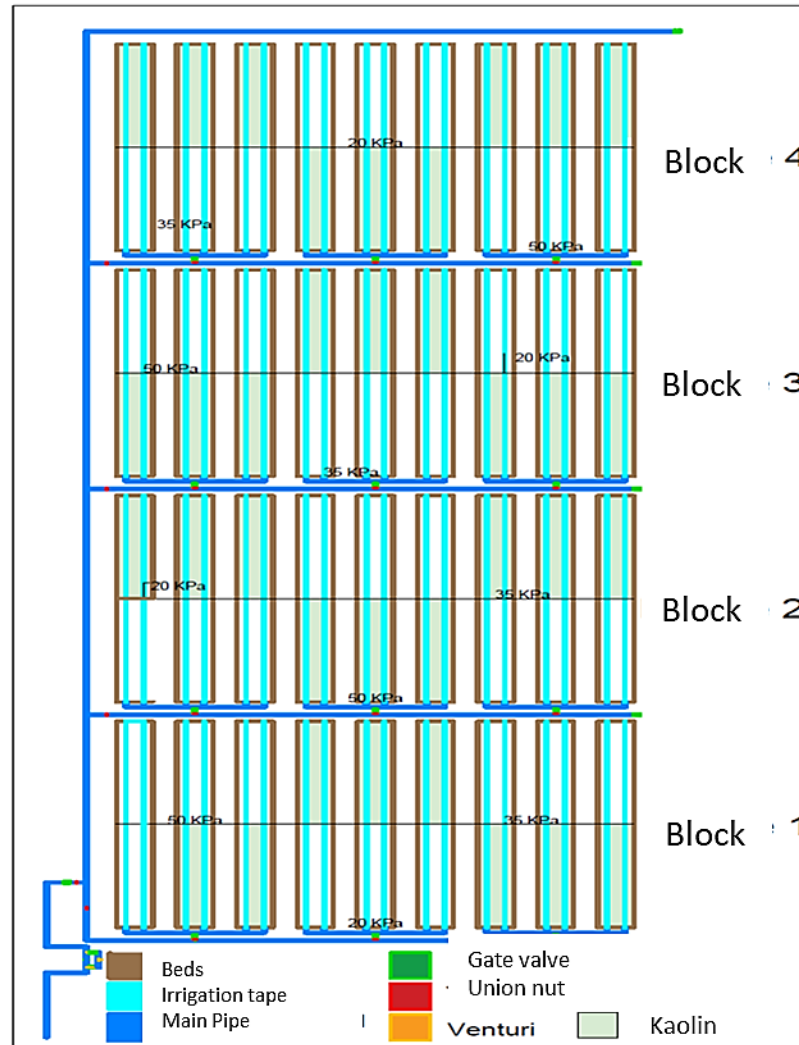


Figure 2. Experimental setup of the split-plot design showing soil water tension levels and kaolin foliar film treatments.

Leaf Temperature

Daily changes in leaf surface temperature were measured using infrared thermometers positioned horizontally approximately 2 cm from the center of leaf with and without kaolin. Measurements were taken at 1-s intervals and averaged every 30 min using a CR1000 data logger (Campbell Sci, Inc., Logan, Utah) throughout the study period.

Yield and Fruit Morphological Variables

The first harvest was conducted on June 20 (40 DAS), and a total of 10 harvests were completed during the crop cycle. To determine yield variables, five plants per treatment were selected, resulting in a total of 120 evaluated plants. Meanwhile, the variables for fruit length and diameter were measured in a sample of 35 fruits from each treatment.

Average fruit mass was determined using a digital scale with a precision of 0.01 g (Ohaus brand, H-8111 model, USA). Morphological attributes corresponding to fruit length (from the base of the peduncle to the apical zone) and equatorial diameter, measured as the width at the mid-cross-section, were determined using a digital vernier caliper (Mitutoyo brand, Japan) with a precision of 0.01 mm.

Statistical Analysis

The data were subjected to analysis of variance (ANOVA) using a linear split-plot model in a randomized block design. Data processing, verification of normality assumptions using the Shapiro-Wilk test, homogeneity of variance testing using Levene's test, and statistical analyses were performed using IBM SPSS Statistics software (version 29.0; IBM Corp., Armonk, NY, USA) and the SAS OnDemand for Academics web platform (SAS Institute Inc., Cary, NC, USA). For variables in which statistical significance was detected, Tukey's multiple comparison test was applied at a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Leaf Temperature

Table 4 presents the analysis of variance for the leaf temperature under three soil water potential levels and two kaolin treatments. Soil water potential had no significant effect on leaf temperature, whereas the main effect of kaolin and the soil water potential $\times$ kaolin interaction were significant.

Table 4. Analysis of variance for leaf temperature in zucchini (*Cucurbita pepo* L.) under three soil water potential levels and two kaolin treatments at the Hydraulic Garden of the Antonio Narro Autonomous Agrarian University, Saltillo, Coahuila, Mexico.

Source of Variation	Degrees of Freedom	Mean square Temperature
Block	3	0.8395 ns
Water potential (WP)	2	0.261 ns
Experimental error (a)	9	0.2477
Protector (P)	1	55.693 **
WP*P	2	4.3687 *
Experimental error (b)	6	0.2562
Total	23	

The three soil moisture tension levels before irrigation (20, 35, and 50 kPa) did not affect leaf temperature (Figure 3A; Tukey, $\alpha \leq 0.05$). However, the average leaf temperature across the three soil moisture tension levels was 10.24% higher in leaves without the kaolin film than in leaves with the film (Figure 3A) (Tukey, $\alpha \leq 0.05$). The greatest difference in leaf temperature between leaves with and without the kaolin film (3.17 °C) was observed at 20 kPa (Figure 3B; Tukey, $\alpha \leq 0.05$), whereas the smallest difference (0.8 °C) was observed at 35 kPa (Figure 3B). The leaf temperature of plants in treatment one (20 kPa with kaolin film) and treatment five (50 kPa with kaolin film) was lower than that of plants in treatment two (20 kPa without kaolin film), Figure 3C (Tukey, $\alpha \leq 0.05$). These results indicate that average leaf temperature did not differ significantly within the soil moisture tension range of 20–50 kPa. However, previous studies have shown that leaf temperature increases in plants under severe water stress. For example, in maize grown in an arid region with air temperatures above 30 °C, leaf temperature was 1.8 °C higher in plants irrigated at 60% of crop evapotranspiration (ET_c) than in plants irrigated at 100% of ET_c (Zavala-Borrego et al., 2022).

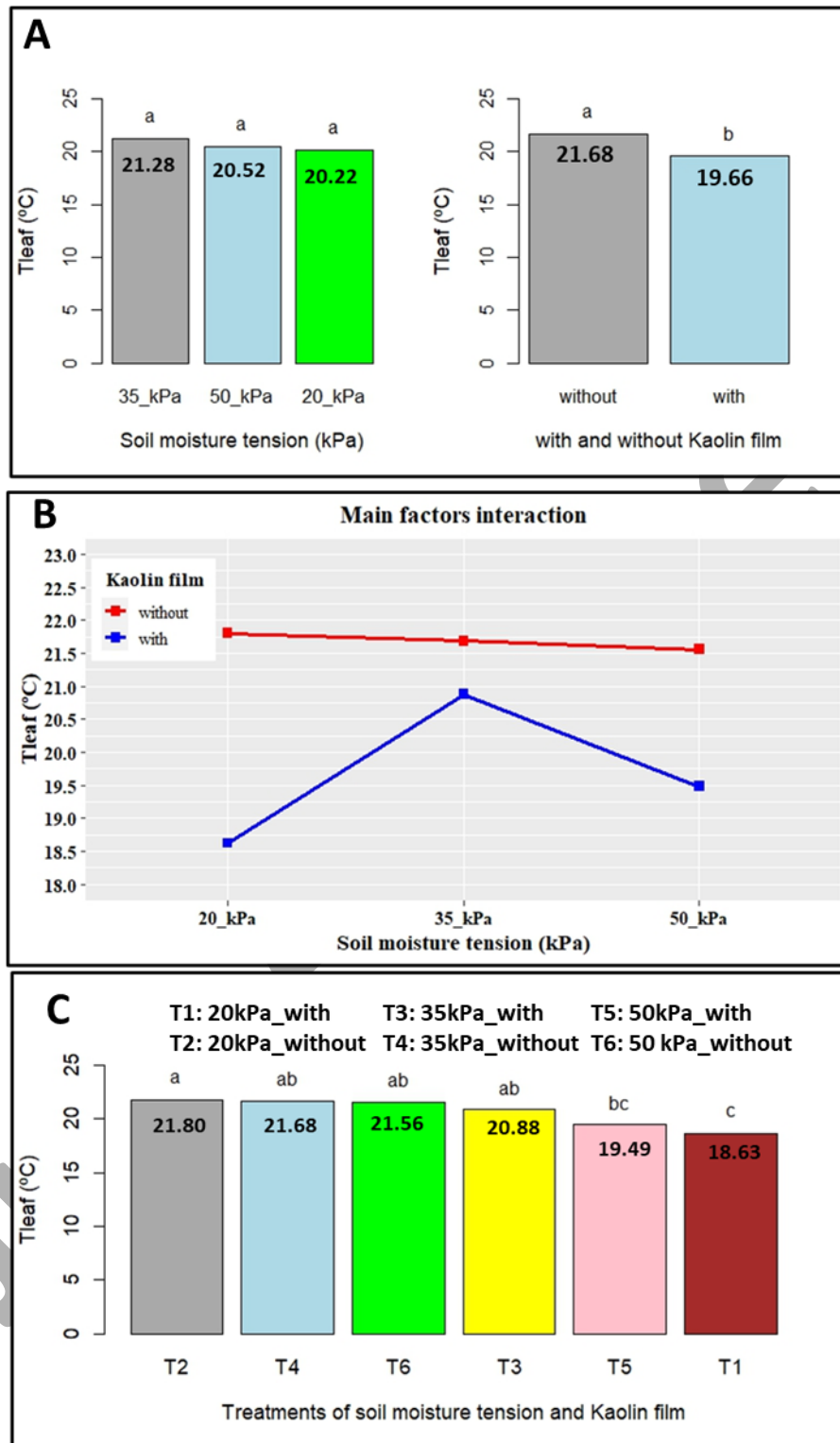


Figure 3. Effect of soil moisture tension and kaolin particle film on leaf temperature of zucchini plants (cv. Carola F1): (A) main effects of soil moisture tension and kaolin application; (B) interaction between the main factors; and (C) comparison of treatment

means. Means followed by the same letter are not statistically different according to Tukey's test ($\alpha \leq 0.05$).

In a study of cape gooseberry leaves, Segura-Monroy et al. (2018) reported that leaf temperature was affected differently by irrigation levels and kaolin application. Cape gooseberry leaf temperature increased by approximately 4.5 °C due to water stress, whereas kaolin treatments resulted in a decrease of approximately 1.4 °C. In pecan orchards, Mahmoudian et al. (2020) recorded the highest leaf temperature (37.5 °C) in the control treatment without kaolin under water-deficit irrigation. The lowest leaf temperature (31.53 °C) was associated with the 7.5% kaolin treatment under full irrigation. These findings suggest that leaf temperature is lower with the kaolin film. This is primarily due to the increased reflectance of incident solar radiation caused by the kaolin film; therefore, by absorbing less radiation, leaf temperature decreases. The use of kaolin in agriculture is not new. In fact, it has been used since the 1930s to protect crops from high temperatures. Its main effect is to increase the reflection of solar radiation. In general, kaolin application reduced leaf temperature under different irrigation levels (Figure 3C). Kaolin, by reflecting sunlight from the leaf surface, reduces leaf temperature and water loss from the leaf and fruit without affecting leaf gas exchange (Jifon & Syvertsen, 2003). Previous results in walnut showed that kaolin application reduced leaf temperature and increased photosynthesis rate and stomatal gas exchange (Gharaghani et al., 2018), consistent with our results.

Figure 4 shows the daily variation in leaf temperature of zucchini plants (cv. Carola F1) treated with or without a kaolin foliar film from June 21 to 25, 2023. Measurements were recorded every second and averaged every 30 min intervals. Leaf temperature varied with weather conditions and time of day. During periods of peak solar radiation (12:00–17:00 h), kaolin-treated leaves had lower temperatures than untreated leaves. This difference was more pronounced on clear days with lower wind speed than on cloudy days with higher wind speed. At approximately 12:00 h on June 23, 2023, the temperature difference reached up to 17 °C. At night, the difference between treatments was smaller. Similar patterns were observed on other dates during the growing season, with kaolin-coated leaves consistently maintaining lower temperatures during periods of high radiation.

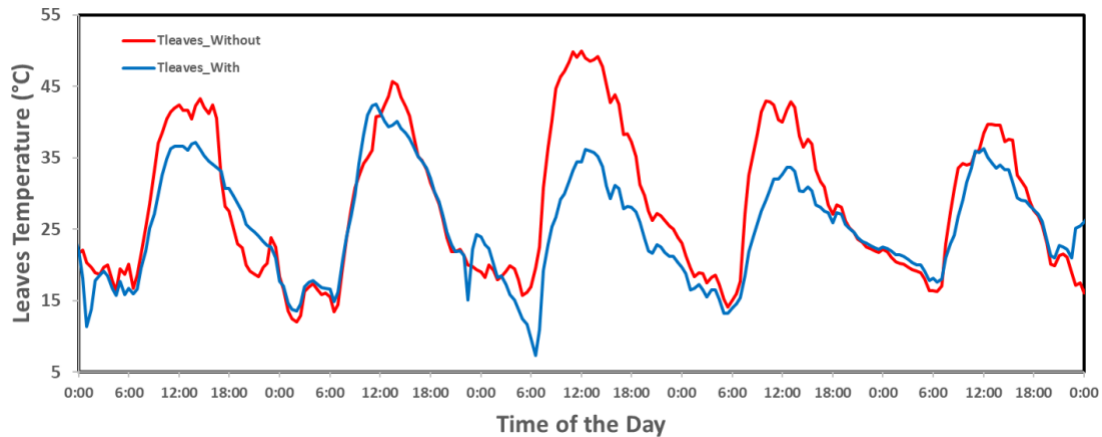


Figure 4. Leaf temperature of the Zucchini crop (Carola F1 hybrid) with and without kaolin film throughout the day, based on 30-min averages of 1-s measurements, from June 21 to 25, 2023.

Heat stress is the main cause of reduced crop yield and fruit quality (Sato et al., 2001; Dumas et al., 2003). Together, these results indicate that heat stress in plants can be mitigated by applying a kaolin film from the beginning of the vegetative stage.

Previous studies on apple, pomegranate, almond, grapefruit, pear, and citrus crops have shown that foliar application of a kaolin film reduces leaf temperature by 1–6 °C (Glenn et al., 2003; Jifon & Syvertsen, 2003; Melgarejo et al., 2004; Wünsche et al., 2004; Lombardini et al., 2005; Rosati et al., 2006; Miranda et al., 2007). In green tea (*Camellia sinensis* (L.) Kuntze), the difference in leaf temperature between plants with and without a kaolin film was 2–4 °C (Anandacoomaraswamy et al., 2000). In contrast, Russo and Díaz-Pérez (2005) found that kaolin application did not affect leaf temperature in pepper plants (*Capsicum annun* L.). By lowering leaf temperature, kaolin helps plants tolerate excessive heat and light, thereby protecting vital physiological processes (Brito et al., 2019). Physiologically, leaf cooling reduces the moisture gradient between the leaf and the surrounding air. Consequently, plants lose less water through transpiration, which helps prevent dehydration and maintain cellular water content. Reducing heat absorption minimizes damage to cell membranes and limits the production of reactive oxygen species (ROS). This protects chloroplasts and prevents excessive-light-induced damage to Photosystem II. When a plant maintains an optimal temperature, its respiration rate decreases, and photosynthetic efficiency improves. Furthermore, cooler leaves expend less energy on physiological maintenance, allowing more

assimilates to be allocated to growth and fruit production (Dinis et al., 2016; Jifon & Syvertsen, 2003).

Fruit morphological variables

Crop growth, development, and yield depend on a combination of factors, including crop genetics, environmental conditions, irrigation scheduling, soil characteristics, fertilization programs, and plant tolerance to stress (Benavides et al., 2017; Mendoza-Macias et al., 2023). In this study, both the kaolin film application and soil moisture tension affected fruit quality parameters. The three soil moisture tension thresholds used for irrigation scheduling (20, 35, and 50 kPa) did not affect fruit length (Table 5) (Tukey, $\alpha \leq 0.05$). However, the kaolin film on the plant leaves affected fruit length, as the average fruit length across all three tension levels in plants treated with kaolin was 5.34% greater than that of plants without kaolin (Table 5) (Tukey, $\alpha \leq 0.05$). Soil moisture tension before irrigation affected fruit diameter, decreasing it by 3.22% at 35 kPa and 4.38% at 50 kPa compared with 20 kPa; however, fruit diameter did not differ significantly between 35 and 50 kPa (Table 5) (Tukey, $\alpha \leq 0.05$). The kaolin film also affected fruit diameter, as the average value in plants with the kaolin film was 2.83% greater in plants with the kaolin film than in plants without it (Table 5) (Tukey, $\alpha \leq 0.05$).

Table 5. Effect of soil moisture tension before irrigation and kaolin foliar film application on the quality parameters of the Carola F1 hybrid zucchini fruit.

Soil Water Potential (kPa)	Fruit length (mm)	Fruit diameter (mm)
20	150.53 A	61.79 A
35	149.64 A	59.86 B
50	148.31 A	59.19 B
p	ns	0.0309
Kaolin film		
With	153.38 A	61.12 A
Without	145.61 B	59.44 B
p	<.0001	0.0361
Interaction p	ns	ns
CV (%)	1.27	2.76

Tukey test ($\alpha \leq 0.05$).

Because fruit length did not differ between soil moisture tensions of 20 and 35 kPa, and fruit diameter decreased by only 3.22% as soil moisture tension increased from 20 to 35 kPa, irrigation at 35 kPa would be advisable for Carola F1 hybrid zucchini under limited water availability. This strategy could increase the irrigated area by reducing the volume of water applied per unit area, with minimal effects on fruit quality. Previous studies have reported the effect of irrigation levels on fruit quality in zucchini crops. For example, Gil et al. (2021) found that the length and diameter of fruits from the Shiraz cultivar decreased by 12.03% and 9.36%, respectively, when the irrigation level decreased from 120% to 60% of crop evapotranspiration (ET_c). Similarly, Amer (2011) reported that fruit diameter and length were significantly reduced when the irrigation level is less than 100% of ET_c. Ertek et al. (2004) showed that yield components in summer squash were directly proportional to the volume of irrigation water applied.

The results of this study clearly show that foliar application of a kaolin film increases fruit length and diameter. In this context, Glenn (2009) reported that solar-radiation-reflecting particles can mitigate environmental stress in plants and improve crop yield and quality. In *Ficus carica* L. cv. 'Sultani', Hussien and Kassem (2021) found that foliar application of a kaolin film increased fruit diameter and length. Similarly, Shellie (2015) and Dinis et al. (2017) observed similar results in a grafted grapevine (*Vitis vinifera* L.) cultivar.

Fruit Yield

The three soil moisture tension levels before irrigation did not affect the number of fruits per plant or fruit weight (Table 6; Tukey, $\alpha \leq 0.05$). However, yield (kg/plant) was 13.93% higher at 35 kPa than at 50 kPa and did not differ significantly from that at 20 kPa (Table 6) (Tukey, $\alpha \leq 0.05$). The kaolin film did not effect on fruit weight; however, the number of fruits and yield per plant were 11.06% and 12.80% higher, respectively, in plants with a kaolin film than in plants without kaolin (Table 6; Tukey, $\alpha \leq 0.05$).

Table 6. Effect of soil moisture tension before irrigation and kaolin foliar film application on the yield parameters of Carola F1 hybrid zucchini.

Soil water potential (kPa)	Number of fruits per plant	Fruit weight (g)	Yield (kg/plant)
20	7.5125 A	247.01 A	1.752 AB
35	7.1875 A	243.91 A	1.857 A
50	6.725 A	240.79 A	1.630 B
p	ns	ns	0.0473
Kaolin film:			
With	7.53 A	246.66 A	1.85 A
Without	6.78 B	241.14 A	1.64 B
p	0.0097	ns	0.0072
Interaction p	ns	ns	ns
CV (%)	7.7	2.6	8.8

Tukey's test ($\alpha \leq 0.05$).

Because the number of fruits per plant, fruit weight, and yield were similar at soil moisture tension of 20 and 35 kPa (Table 5; Tukey, $\alpha \leq 0.05$), replenishing soil moisture when tensiometers indicate 35 kPa can be recommended to improve water use efficiency in Carola F1 hybrid zucchini. Contreras et al. (2017) reported that, as soil water content decreases from its maximum retention capacity, water stress occurs, which can lead to a decreased in zucchini (*Cucurbita pepo* L. cv. Victoria) production. Castor bean (*Ricinus communis* L.) yield decreased by up to 157.67% when soil moisture tension became more negative, changing -15 kPa to -75 kPa (Ríos et al., 2014). Similarly, Pereira et al. (2009) observed that the number of flowers in gladiolus (*Gladiolus* L.) decreased when soil moisture tension was greater than -15 kPa.

Similarly, because the number of fruits per plant and yield were higher following kaolin film application of the, foliar application of kaolin could also be recommended to reduce heat stress in plants and increase the yield of the Carola F1 hybrid zucchini. Yield zucchini cultivar 'Syriaca' also increased following foliar application of a kaolin film (Khalili and Nejatizadeh, 2021). In a tomato (*Solanum lycopersicum* L.) cv. 'Rio Grande', yield was 23.8% higher in kaolin-treated plants than in control plants without the kaolin film (Djurović et al., 2016). Faghih et al. (2019) indicated that apple trees (*Malus domestica* L.) cultivars 'Golab'

and 'Shaf-Abadi' had higher yields and greater water-use efficiency with the application of a kaolin foliar film than trees without kaolin application. However, other studies have reported no favorable effects of kaolin on crop yield. For example, Ćosić et al. (2015) reported that foliar application of kaolin to bell pepper plants (*Capsicum annuum* L.) cv. 'Elephant Ear' did not increase average fruit weight or yield.

CONCLUSIONS

Leaf temperature showed that the effect of the mineral protectant depended on the soil moisture level. At all soil moisture tension levels (20, 35, and 50 kPa), application of a kaolin foliar film to Carola F1 hybrid zucchini plants decreased leaf temperature. The greatest difference in leaf temperature between leaves with and without the kaolin film (3.17 °C) was observed at 20 kPa, whereas the smallest difference (0.8 °C) was observed at 35 kPa. On June 23, 2023, during peak solar radiation hours, a difference of up to 17 °C was observed. At night, the temperature difference between leaves with and without kaolin was smaller. Regarding fruit yield and quality, it was observed that at any soil moisture tension level (20, 35, and 50 kPa), application of a kaolin foliar film at all soil moisture tension levels increased fruit length, fruit diameter, the number of fruits per plant and yield, compared with plants without the film. Because fruit length, fruit weight, the number of fruits per plant, and yield were similar at 20 and 35 kPa, it is recommended to irrigation of zucchini is recommended when the tensiometer reading reaches 35 kPa.

The use of kaolin may serve as a useful agronomic strategy to protect the crop from heat and light stress and maintain productivity under conditions of limited water availability.

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