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RESEARCH ARTICLE

Physiological response of tomato to trifloxystrobin and tebuconazole: Implications for photosynthetic efficiency

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Abstract

A field experiment was conducted to study the impact of Nativo (trifloxystrobin combined with tebuconazole) on photosynthetic efficiency involved in improving the productivity of tomato. The different concentrations of fungicide, Nativo, were applied at 35-40 days after treatment (DAT) and 55-60 DAT in tomato. Leaf area was significantly reduced by the application of Nativo 75WG (tebuconazole 50 % + trifloxystrobin 25 % WG) at 400 g ha^{-1} in tomato, irrespective of the seasons, thereby reducing the growth analytical parameters such as leaf area index and leaf area duration. Among the treatments, Nativo 75WG at 400 g ha^{-1} in tomato recorded a higher photosynthetic rate, decreased stomatal conductance and transpiration rate. The rate of photosynthesis, chlorophyll index, soluble protein and sugar accumulation were augmented by the treatment Nativo 75WG at 400 g ha^{-1} in tomato, thereby producing maximum dry matter and ultimately, higher yield. All the yield contributing parameters were effectively increased by the foliar spray of trifloxystrobin coupled with tebuconazole in tomato and maximum yield was noticed in Nativo 75WG at 400 g ha^{-1} in tomato. It was concluded that foliar spray of Nativo 75WG at 400 g ha^{-1} during 35-40 DAT and 55-60 DAT in tomato was found to be optimum in increasing the yield to 18 % over control with increased photosynthetic efficiency, nutrient uptake and dry matter accumulation.

Keywords: fungicide; greenness of leaf; leaf area; Nativo; stomata

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated vegetable crops worldwide, valued both for its economic significance and nutritional composition. It is an important commercial and dietary vegetable crop and is consumed fresh, cooked as well and processed. It is the world's largest tropical vegetable crop and known as a protective food for its special nutritive value. Tomato fruits contain high minerals, vitamins, essential amino acids, sugars and dietary fibres (1). The area and production of tomato in India are 0.63 million ha and 11.98 million t and the average productivity is 19.6 t ha^{-1} (2). Tamil Nadu ranks 12th in tomato production among Indian states, with an acreage of 22924 ha, a production of 6.67 lakh t and a productivity of 13.04 t ha^{-1}. Its productivity, however, is frequently compromised by diseases such as early blight, caused by *Alternaria solani,* which disrupts photosynthetic functions, reduces chlorophyll content and accelerates leaf senescence (3). Until recently, the fungicides focused on control of phytopathogens with the sole purpose of reducing inoculum (4). After the launch of modern agrochemicals containing antioxidant compounds such as fungicides belonging to strobilurins (trifloxystrobin, azoxystrobin, pyraclostrobin, kresoxim methyl, etc.) and triazoles (propiconazole, epoxiconazole, tebuconazole, penconazole, etc.), the concept of disease control gained new perspectives, especially when considering the advantages obtained by the action of positive physiological effects on the plants. In the pursuit of sustainable crop protection strategies, the use of combination fungicides that offer both disease control and physiological enhancement has gained considerable attention.

Nativo 75 WG is a water-dispersible granular formulation containing 25 % w/w trifloxystrobin and 50 % w/w tebuconazole. Among these, trifloxystrobin and tebuconazole were formulated together as Nativo® 75 WG, which represents a promising dual-action fungicidal treatment. Trifloxystrobin, a strobilurin class fungicide, inhibits mitochondrial respiration in fungal pathogens and is known to elicit a "greening effect" in plants, characterized by enhanced chlorophyll retention, delayed senescence and improved photosynthetic activity (5). Tebuconazole, a triazole fungicide, interferes with ergosterol biosynthesis in fungi and modulates plant hormonal pathways, potentially influencing stomatal conductance, nutrient uptake and stress resilience (6).

Beyond their fungicidal roles, these compounds have demonstrated positive physiological effects in several crops, including cereals and legumes, by improving chlorophyll content, dry matter accumulation and nutrient assimilation. In tomato, however, the direct impact of trifloxystrobin and tebuconazole on photosynthetic efficiency remains underexplored, particularly in terms of chlorophyll fluorescence parameters, gas exchange traits and pigment stability. Understanding these effects is crucial for optimizing fungicide use not only for disease suppression but also for enhancing crop vigor and yield potential (7).

This study was designed to evaluate the dual role of Nativo 75WG, a combination of trifloxystrobin and tebuconazole, in enhancing physiological traits, especially increasing net photosynthetic rate (Pn) and soil-plant analysis development (SPAD) chlorophyll index and suppressing fungal disease, stomatal conductance (gs) and transpiration rate (E) in tomato. To ensure that the observed physiological benefits were associated with active pathogen suppression, the presence of *A. solani* was confirmed through *in vitro* assays using the poisoned food technique. This validation allowed interpretation of physiological responses in the context of disease control.

Materials and Methods

The investigations were carried out in 2 categories. One at lab condition to determine the effect of fungicide on *A. solani* and second at field conditions in Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore, to evaluate the combined effect of trifloxystrobin and tebuconazole at different concentrations (Table 1) in tomato crop (Hybrid 'Vijaya') during *Kharif* (July 2024 to December 2024) and summer (February 2025 to July 2025). The experimental site is located at 11° E longitude and 77° N latitude at an altitude of 426.8 m above mean sea level. In tomato, the recommended spacing of 60 x 45 cm and fertilizer dose of 200:300:200 kg nitrogen phosphorus potassium (NPK) ha^{-1} was followed. During transplanting, 50 kg N, 300 kg phosphorus pentoxide (P_2O_5) ha^{-1} and 50 kg of potassium oxide (K_2O) were applied as urea, diammonium phosphate and muriate of potash. The physical and chemical properties of soil are mentioned in Table 2. The remaining N and K were applied at of 50 kg ha^{-1} in 3 split doses for tomato at 30, 45 and 60 DAT. Pendimethalin at 2 mL L^{-1} followed by 2 hand weeding at 30 DAT and 60 DAT in tomato, was done to control the weed infestation. Irrigation was given at critical stages of plant growth. In field conditions, no specific disease pressure was induced and disease incidence was found to be less due to the application of Nativo and Mancozeb during the pre-emergence of disease. Hence, foliar application of fungicides was not done in the field.

Table 1. Treatment details

S. No.	Treatment	Dosage (g ha^{-1})	Time of spray
1.	Untreated control	-	
2.	Nativo 75 WG	200	
3.	Nativo 75 WG	300	2 sprays (First spray at 35-40th DAT and second at 55-60th DAT)
4.	Nativo 75 WG	400	
5.	Nativo 75 WG	600	
6.	Mancozeb	1000	

In vitro evaluation of fungicides against *A. solani*

A new fungicide molecule, viz, Nativo 75WG (Bayer Crop Science, Mumbai, India), was evaluated *in vitro* for its fungitoxicity against mycelial growth of *A. solani* by the poisoned food technique. The test fungicides were suspended in sterile distilled water and added to potato dextrose agar (PDA) medium to a final concentration of 25, 50, 100, 200, 300, 400, 500 and 1000 ppm. An 8-mm diameter mycelial disc of each pathogen was cut from a 7-day-old culture and placed in the centre of petri plates containing PDA medium amended with fungicides. PDA medium inoculated with each isolate served as a control. Isolates were obtained from the Department of Plant Pathology, Tamil Nadu Agricultural University, Coimbatore. The plates were incubated at room temperature for approximately 10 days until the control plate was completely covered by the test fungi. Each treatment was replicated three times. The percentage inhibition of growth of the test pathogens was assessed visually from the plates (Fig.1).

Table 2. Soil properties of the experimental field (Tomato)

S. no	Particulars	Values
A. Physical properties (on a moisture-free basis)		
1	Field capacity (%)	31.92
2	Permanent wilting point (%)	16.03
3	Bulk density (g cm^{-3})	1.58
4	Texture class	Clay
	B. Chemical properties	
1	Available N (kg ha^{-1})	193.16
2	Available P_2O_5 (kg ha^{-1})	14.63
3	Available K_2O (kg ha^{-1})	345.47
4	pH (1:2 soil water suspension)	8.52
5	EC (dS m^{-1})	0.85
6	Organic carbon (%)	0.43

Replication and experimental unit

The experiment was laid out in a factorial randomised block design (FRBD) with 3 replications. Each treatment plot measured 3.6 m × 4.5 m, accommodating 60 tomato plants at a spacing of 60 cm × 45 cm. To minimise border effects, guard rows were established around each plot and 5 plants per plot were randomly selected and tagged for physiological and biochemical measurements throughout the experiment. All data were averaged per plot and the plot mean was used as the experimental unit for statistical analysis to ensure valid inference and avoid pseudo-replication.

Observations recorded

Growth parameters

The growth characteristics were recorded at different growth stages in tomato. The observations were taken at the 70th DAT in tomato by selecting 5 representative samples at random from each replication. The methods followed in recording each of these parameters are described below.

Leaf area index (LAI)

LAI was calculated by following the formula given below (8)

LAI = Leaf area per plant / Ground area occupied per plant

Chlorophyll index

SPAD chlorophyll meter (Minolta model 502, Japan) was used to measure chlorophyll index. The measurements were taken from a physiologically fully expanded leaf in 5 replications/plant and 5 plants from each replication and the mean values were computed.

Chlorophyll fluorescence

The chlorophyll fluorescence was measured using the fluorescence meter (Plant PAM-210 Teaching PAM, Heinz Walz, Germany). The key fluorescence parameters, viz., F_o (initial fluorescence), F_v (variable fluorescence), F_m (maximal fluorescence) and the ratio of F_v/F_m were measured using this instrument. Dark adaptation time was 30 min using leaf clips. Saturation pulse intensity is 8000 µmol m^{-2} s^{-1}. Pulse duration is 0.8 sec. Actinic light level was 1000 µmol m^{-2} s^{-1}

F_v/F_m = Variable fluorescence / Maximum fluorescence

F_v/F_m is a useful ratio that depicts the proportion of quantum yield to a high degree of photosynthesis.

Leaf gas exchange parameters

Gas exchange parameters, viz., rate of photosynthesis and transpiration and stomatal conductance were recorded using an advanced portable CO_2 gas analyser (LI-6400 XT, Licor Inc, Nebraska, USA) an open-type principle. The readings were recorded from 08.00 AM till 12.00 noon on a clear sunny day when the photosynthetically active radiation was more than 1500 µmol photons m^{-2} s^{-1} using a red LED light source. Flow rate was 500 µmol s^{-1}; leaf temperature was maintained at ambient (28-32 °C). Readings were accepted after stabilisation for 2-3 min. Fully expanded third leaf from the top was clamped inside the leaf chamber and held perpendicular to the incident light and the computed values were recorded. The instrument maintained a constant CO_2 flux to the leaf chamber, which was maintained at ambient concentration. Relative humidity (RH) was maintained at a steady level equal to the ambient RH to simulate a condition very similar to that of ambient air. The photosynthetic rate was expressed as µmol m^{-2} s^{-1}. Stomatal conductance was expressed as mmol H_2O $m^{-2}s^{-1}$ and transpiration rate was expressed as mmol H_2O $m^{-2}s^{-1}$.

Soluble protein

Soluble protein content of leaves was estimated from 250 mg of leaf samples homogenised with 10 mL of phosphate buffer, centrifuged the contents and collected the supernatant. The 2 mL of supernatant was mixed with 5 mL of alkaline copper tartarate and 0.5 mL of Folin's reagent. The blue colour developed was measured at 660 nm against bovine serum albumin (BSA) as a standard at different concentrations and the content was expressed as mg g^{-1} fresh weight (8).

Total carbohydrate content

Total carbohydrate content was estimated following the method of DuBois (9). Fresh leaf tissue (0.5 g) was homogenised in 5 mL of 80 % ethanol for extraction. The assay was performed at a wavelength of 490 nm using a spectrophotometer and quantification was based on a glucose standard calibration curve. Results were expressed as milligrams per gram of fresh weight (mg g^{-1} FW).

Yield and its components in tomato

The number of flowers per plant was recorded in the tagged plants from each of the replications of all the treatments from first flowering and the mean value was worked out and expressed as a number. The number of fruits per plant was recorded in the tagged plants from each replication of all the treatments over all the harvests and the mean value was worked out and expressed as a number. Fresh weight of the fruits produced per plot was weighed immediately after harvest and expressed as yield (kg ha^{-1}).

Statistical analysis

The experiment was conducted using a factorial randomised block design (FRBD) with 2 factors and 3 replications. Factor 1 is seasons (S_1 and S_2), factor 2 is treatments (T_1-T_6). Morphological, physiological and biochemical data were analysed with two-way analysis of variance (ANOVA) using the R statistical package (version 23.0) with fixed factors as seasons and treatments and plot mean as experimental unit. Treatment means were compared, using Duncan's multiple range test (DMRT) at a 5 % significance level ($p \leq 0.05$). Standard error of the difference (SEd) and critical difference (CD) values were calculated for treatment (T), season (S) and their interaction (T × S). Graphs were generated in Microsoft Excel 365 and standard error bars (± SE) were included to represent variability across replications. DMRT groupings were annotated above each bar to indicate statistically homogeneous groups.

Results

The experiments were conducted during 2024-2025 to evaluate the effects of different fungicide concentrations and cropping seasons on morphological, physiological, biochemical and yield parameters of tomato. The data collected were subjected to appropriate statistical analyses and significant findings are summarised below.

The fungicides, viz., Nativo 75WG, Mancozeb, were evaluated *in vitro* for their fungitoxicity against mycelial growth of *A. solani* at different concentrations, viz., 25, 50, 75 and 100 ppm and the results are presented in Fig. 1. The experiment revealed that the fungal growth was inhibited by all the fungicides, with varied levels of

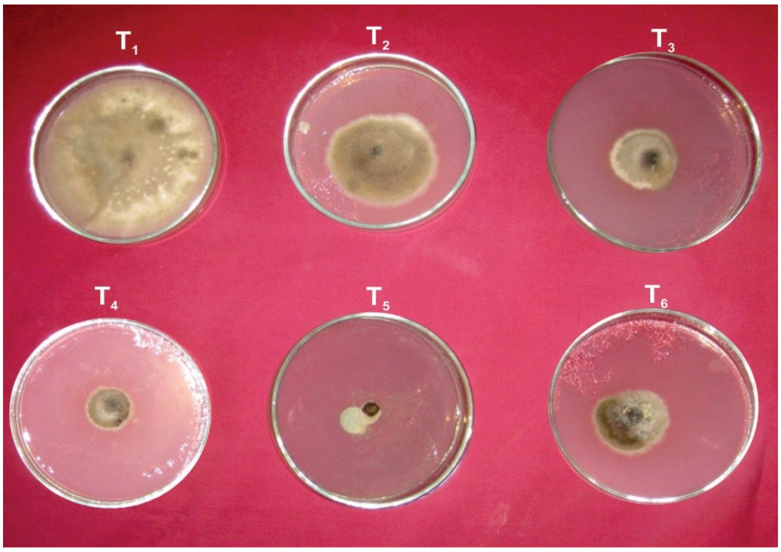

Fig. 1. Effect of different concentrations of Nativo on mycelial growth of *A. solani*. T1 – Control; T2 – Nativo 75 WG at 25 ppm; T3 – Nativo 75 WG at 50 ppm; T4 – Nativo 75 WG at 75 ppm; T5 – Nativo 75 WG at 100 ppm and T6 – Mancozeb at 100 ppm.

concentration and the extent of inhibition increased with the increase in concentration of fungicides. Among them, Nativo 75WG at 75 ppm inhibited the fungal growth completely, while Mancozeb was not effective in arresting the fungal growth completely, even at the higher concentration of 100 ppm.

The response of plants to the spray of fungicide and seasons was studied and it was obvious that the treatments could significantly influence LAI, irrespective of the seasons (Table 3). Considering the cropping seasons, higher values of LAI were noticed in S_1. Irrespective of the concentration of chemical applied, the maximum LAI was observed in S_1(0.6734) and the lowest in S_2 (0.6661). Foliar spray of fungicide significantly decreased the leaf area index, indicating that the application of fungicide decreased the leaf area. T_1 recorded the maximum value of LAI at 0.6980 when compared to other treatments and the lowest LAI was recorded in T_5 (0.6376). The interaction between seasons and fungicide treatments was examined and no significant differences were observed among the treatment combinations.

Fungicidal treatments in tomato exerted a significant effect on chlorophyll index (Table 3). The increase in concentration of the fungicide could significantly promote the chlorophyll index. Considering the seasonal influence on chlorophyll, S_1 could register a higher chlorophyll index than S_2. The treatment mean values differed significantly among themselves. Among the different fungicide concentrations, T_4 recorded the peak chlorophyll index of 47.4, followed by T_3 (46.1) and the lowest in T_1(41.6). Analysing the interaction effect between the season and different concentrations of fungicide, significant variation was observed. Nevertheless, the interaction of S_1 along with T_4 recorded the highest value (48.6), followed by S_1T_3 (47.2) and the lowest in S_2T_1 (40.6).

The study on the influence of fungicide treatments and cropping seasons showed that the seasons alone could cause a significant difference in the F_v/F_m ratio. However, no significant difference was observed with the application of the fungicide. Comparing the seasons, higher F_v/F_m was recorded in S_1 (0.785), when compared to S_2 (0.727). The influence of different concentrations of fungicide and their interaction with the cropping seasons was observed to show non-significant variation between them.

The impact of fungicide spray and growing seasons could significantly influence the rate of photosynthesis. The seasons S_1 and S_2 were observed to influence the photosynthetic rate (Fig. 2) significantly. The season S_1 showed the maximum rate of photosynthesis (40.80), whereas the minimum (35.44) was registered in S_2. From the data, S_1 proved to be better than S_2. Considering the fungicide treatments, it was revealed that the fungicide spray increased the photosynthetic rate significantly. T_4 was observed to have a higher rate of photosynthesis (42.45), followed by T_3 (40.07) and the lowest (35.23) in T_1. Comparing the interaction effect of seasons and fungicide treatments, the treatment S_1 in combination with T_4 maintained a higher photosynthetic rate than the other treatments. The maximum rate of photosynthesis (44.89) was observed in the treatment S_1T_4, followed by S_1T_3 (41.98) and the minimum in S_2T_1 (32.87).

The analysis of data on stomatal conductance (Fig. 3), subjected to different concentrations of fungicides and seasonal conditions, exhibited significant differences between them. Considering the seasonal influence on stomatal conductance, S_2 could register higher stomatal conductance when compared to S_1, irrespective of the stage (Table 3). Considering the levels of fungicide

Table 3. Effect of Nativo (Trifloxystrobin and tebuconazole) on growth parameters of tomato

Treatment	Leaf Area Index			Chlorophyll Index			Chlorophyll fluorescence (Fv/Fm ratio)		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
T_1	0.7065	0.6896	0.6980^{a}	42.6	40.6	41.6^{d}	0.722	0.774	0.748^{NS}
T_2	0.7020	0.6839	0.6929^{ab}	46.4	44.2	45.3^{abc}	0.724	0.781	0.753^{NS}
T_3	0.6753	0.6724	0.6739^{bc}	47.2	45.0	46.1^{ab}	0.719	0.797	0.758^{NS}
T_4	0.6631	0.6679	0.6655^{cd}	48.6	46.3	47.4^{a}	0.728	0.784	0.756^{NS}
T_5	0.6452	0.6300	0.6376^{de}	43.5	41.4	42.4^{cd}	0.736	0.782	0.759^{NS}
T_6	0.6482	0.6528	0.6505^{e}	45.2	43.1	44.2^{bc}	0.732	0.793	0.763^{NS}
Mean	0.6734	0.6661	0.6697	45.6	43.4	44.5	0.727	0.785	0.756
	T	S	T x S	T	S	T x S	T	S	T x S
SEd	0.0048	0.0028	0.0068	0.243	0.140	0.344	0.005	0.003	0.007
CD (p = 0.05)	0.0098	NS	0.0139	0.495	0.286	NS	NS	0.006	NS

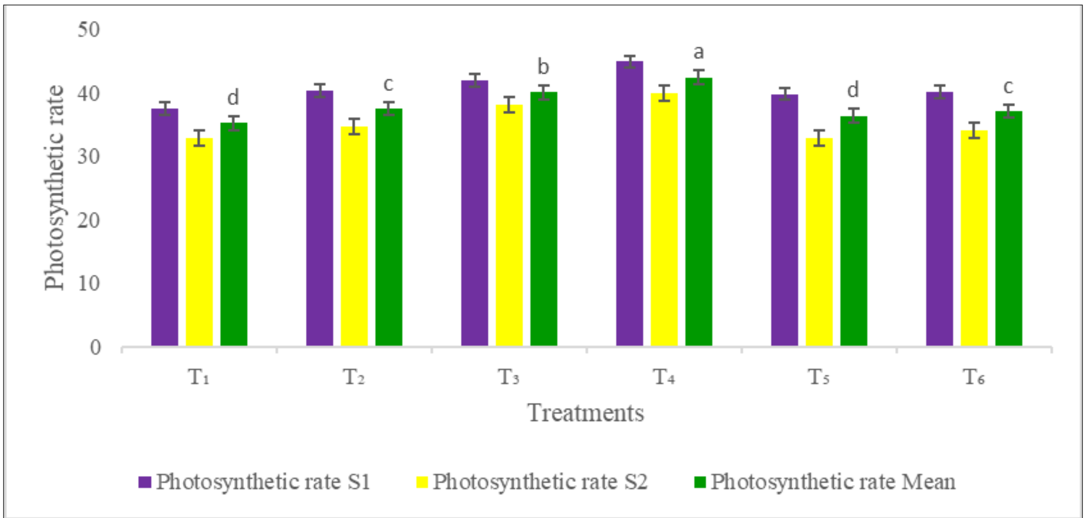

Fig. 2. Effect of Nativo on photosynthetic rate (µmol CO_2 m^{-2} s^{-1}) of tomato.

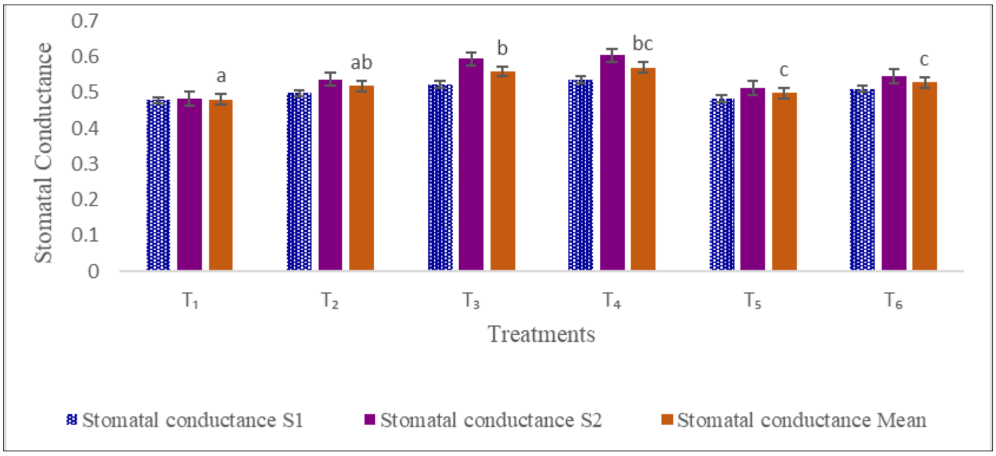

Fig. 3. Effect of Nativo on stomatal conductance (mmol H_2O m^{-2} s^{-1}) of tomato.

on stomatal conductance, the increase in fungicide concentration reduced the conductance of water over the untreated control. Maximum stomatal conductance (0.771) was observed in T_6, followed by T_3 (0.758) and the lowest in T_1 (0.708). Comparing the interaction between the seasons and treatments, a significant difference was observed. S_1T_4 exhibited the peak stomatal conductance (0.793) and the lowest in S_2T_1 (0.687).

The study on the impact of chemical and season revealed that the treatments could significantly reduce transpiration rate, compared to the untreated control (Fig. 4). Comparing the seasons, a significant variation was observed by registering a maximum transpiration rate (12.76) in S_1 and a minimum in S_2 (11.51). Among the concentrations of fungicide, the treatment T_5 was noticed to have the lowest transpiration rate at all crop growth stages. Considering the interaction of seasons along with different levels of fungicide, the difference in transpiration rate was found to be significant. The interaction between S_1 and T_1 recorded the highest transpiration rate (14.18), which was followed by S_1T_2 (13.85) and the lowest rate of transpiration was registered in S_2T_6 (10.58).

Biochemical characters

The application of fungicide at different concentrations and cropping seasons greatly enhanced the chlorophyll content. Considering the cropping seasons, significant variation was observed, with the highest in S_1 (2.314) and the lowest in S_2 (1.477). The chlorophyll content of tomato plants subjected to 2 stages of fungicide applications exhibited a significant difference between the treatments. The treatment, T_4 registered higher chlorophyll content, with a maximum of 2.447 and this was followed by T_3 (2.317) and T_2 (2.24) respectively and the lowest was noticed in T_1 (1.984). The interaction between the seasons and level of fungicide treatments revealed that S_1 coupled with T_4 could record higher chlorophyll content (2.224).

The study revealed that the soluble protein was profoundly influenced by the fungicide treatments, seasons and their combinations (Table 4). Considering the effect of different concentrations of fungicide application, irrespective of the seasons, the increase in fungicide dose significantly increased the soluble protein content. The maximum soluble protein was observed in T_3 (14.34) and the lowest in T_1. The combination of season and fungicide application differed significantly. S_1T_3 registered the highest soluble protein (15.82), whereas the lowest soluble protein of (7.35) was noticed in S_2T_1.

The analysis of data on carbohydrate content (Table 4) in leaves indicated that the treatment and its interaction were found to influence carbohydrate content significantly. Regarding seasonal influence, a significant difference was noticed and the maximum carbohydrate (45.55) was observed in S_1, rather than S_2 (42.48). Considering the fungicide treatments, irrespective of both seasons, the increase in fungicide concentration enhanced the carbohydrate content significantly. T_4 showed higher values of carbohydrate content, when compared with other treatments (46.19) and the lowest was showed by T_1 (41.91). The analysis of carbohydrate in the combination of the treatments showed that the interactions could significantly influence the carbohydrate content. The interaction of

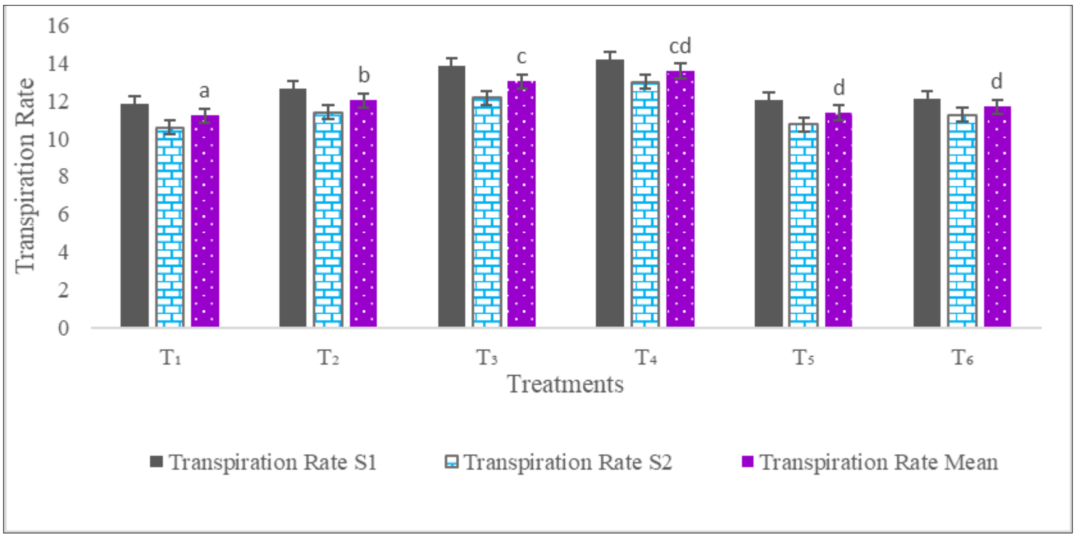

Fig. 4. Effect of Nativo on transpiration rate (mol H_2O m^{-2} s^{-1}) of tomato.

Table 4. Effect of Nativo on biochemical parameters of tomato

Treatment	Total chlorophyll (mg g^{-1} FW)			Soluble protein (mg g^{-1} FW)			Total carbohydrates (mg g^{-1} FW)		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
T_1	1.917	1.793	1.855^d	11.18	8.91	10.05^c	43.35	40.47	41.91^b
T_2	2.138	1.998	2.068^c	14.59	10.75	12.67^{ab}	44.13	42.83	43.48^{ab}
T_3	2.155	2.102	2.129^{ab}	15.82	12.85	14.34^a	45.28	43.57	44.43^{ab}
T_4	2.224	2.133	2.179^a	13.91	13.40	13.66^{ab}	47.72	44.65	46.19^a
T_5	2.016	2.185	2.101^{bc}	13.34	10.51	11.93^{bc}	47.41	41.09	44.25^{ab}
T_6	2.136	2.006	2.071^{bc}	11.57	10.18	10.88^c	45.40	42.29	43.85^{ab}
Mean	2.098	2.036	2.067	13.40	11.10	12.25	45.55	42.48	44.02
	T	**S**	**T x S**	**T**	**S**	**T x S**	**T**	**S**	**T x S**
SEd	0.011	0.006	0.015	0.070	0.040	0.099	0.479	0.277	0.678
CD (p = 0.05)	0.022	0.013	NS	0.143	0.082	0.202	0.976	0.563	1.380

S_1 with T_4 recorded the highest carbohydrate (47.72), followed by S_1T_5 (47.41)

Yield and its components

The response of tomato, in terms of yield and yield attributes, to a given chemical or season was observed. Application of fungicide or cropping seasons or their interactions at 2 different stages could significantly influence the yield components such as the number of flowers, fruits and fruit yield (Table 5). The findings of the experiment are furnished below.

Considering the seasonal influence, a significant variation was observed and among the seasons, the maximum number of flowers was found in S_1 (70.24), when compared to S_2 (65.05). Analysing the impact of fungicide concentrations, an appreciable increase in flower number was recorded and the highest number of flowers (75.09) was observed in T_4. Among the interactions, S_1 coupled with T_4 could record a higher number of flowers (76.74) and S_2T_1 registered a lower number of flowers (58.26).

The analysis of data on the number of fruits followed a similar trend to the number of flowers. The cropping seasons, fungicide concentrations and their interactions could significantly influence the number of fruits. Comparing the seasons, a higher number of fruits was observed in S_1 (41.37), while S_2 recorded 32.63 fruits. Among the concentrations of fungicide spray, T_4 could register the maximum number of fruits (44.99), compared to T_1 (31.05). Considering the interaction, the maximum number of fruits was noticed in S_1 along with T_4 (49.59) and the minimum in S_2T_1 (27.22).

The analysis of data on fruit yield revealed appreciable variation between the seasons, fungicide concentrations and their interaction. Considering the seasons, S_1 could favour maximum fruit yield (87.1) when compared to S_2 (75.3) and among the fungicide concentrations, higher fruit yield was registered in T_4 (89.8), followed by T_3 (83.0), T_6 (79.6) and the lowest yield was observed in T_1 (76.1). The interaction of season with fungicide had a significant influence and the combination of S_1 along with T_4 could record a maximum fruit yield of 98.9, while S_2T_1 recorded 71.7.

Discussion

Tomato, an important tropical fruit, plays a major role in the food requirements of a vast population worldwide. However, the productivity of the crop is limited due to various biotic factors. A thorough knowledge of the physiology of these crops is essential to step up the productivity. Nativo, a new fungicide, seems to play a role in altering the physiology of different crops. With this background, a detailed investigation was made to assess the impact of Nativo on the photosynthetic efficiency of tomato and the consequent effects on the productivity of the crop. The photosynthetic efficiency of tomato is determined by photosynthetic rate, stomatal conductance, transpiration rate, chlorophyll content in the leaf, chlorophyll fluorescence, soluble protein content and leaf carbohydrate content in tomato.

LAI is the principal factor influencing net photosynthesis, which is related to yield. LAI was reduced significantly by the combination of trifloxystrobin and tebuconazole in tomato, with a record of 8.65 % against the untreated control. The reduced LAI observed in the present study might be due to a significant reduction in leaf area in response to the combination of strobilurin and triazole fungicide, Nativo (6). The reduction is due to the detrimental effect of the fungicide, preventing the expansion of the leaf; however, it increases the leaf thickness (10).

Chlorophyll meter provides a simple, quick and non-destructive method for estimating the N concentration on a dry weight basis. Chlorophyll index (SPAD) is in proportion to the chlorophyll content per unit area for leaves. A significant increase in chlorophyll index was observed in the present study due to the application of trifloxystrobin coupled with tebuconazole, with a maximum of 18.08 % in tomato. This value shows the high greenness effect due to the application of Nativo (Fig. 5). This was in

Table 5. Effect of Nativo on the yield and its components of tomato

Treatment	No. of flowers plant^{-1}			No. of fruits plant^{-1}			Yield (t ha^{-1})		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
T_1	62.51	58.26	60.38^c	34.87	27.22	31.05^c	80.4	71.7	76.1^b
T_2	72.25	63.46	67.85^b	43.81	31.21	37.51^b	87.4	75.9	81.7^{ab}
T_3	68.81	69.61	69.21^{ab}	39.48	35.58	37.53^b	89.6	76.3	83.0^{ab}
T_4	76.74	73.44	75.09^a	49.59	40.39	44.99^a	98.9	80.6	89.8^a
T_5	74.82	64.03	69.42^{ab}	42.10	30.70	36.40^b	81.9	72.6	77.3^b
T_6	66.30	61.51	63.91^c	38.37	30.66	34.51^{bc}	84.4	74.7	79.6^b
Mean	70.24	65.05	67.64	41.37	32.63	37.00	87.1	75.3	81.2
	T	**S**	**T x S**	**T**	**S**	**T x S**	**T**	**S**	**T x S**
SEd	0.616	0.355	0.871	0.403	0.233	0.570	0.768	0.443	1.086
CD (p = 0.05)	1.253	0.723	1.772	0.821	0.474	1.161	1.563	0.902	2.210

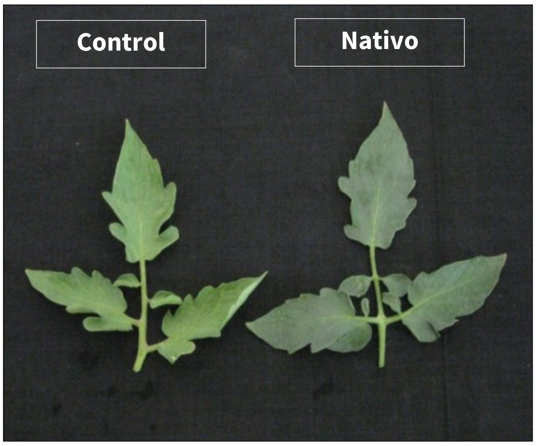

Fig. 5. Greening effect in tomato leaves on 80 DAT.

correlation with the increase in relative chlorophyll content measured by SPAD meter, observed due to triazole applications in barley (11).

Light energy, absorbed by chlorophyll molecules in a leaf, can undergo 3 important fates: it can be used to drive photosynthesis, excess energy can be dissipated as heat, or it can be reemitted as light-chlorophyll fluorescence. The chlorophyll fluorescence ratio (F_v/F_m) is directly correlated to the efficiency of leaf photosynthesis. A previous study reported that the plants treated with paclobutrazol were found to have 11–13 % more photosynthetic efficiency under stress conditions and despite low temperature stress, paclobutrazol increased the fluorescence ratio (13). However, there was no significant difference in the ratio due to the combined effect of trifloxystrobin and tebuconazole in tomato.

Leaf gas exchange is considered one of the indicators to evaluate the plant's ability to produce a better yield. Photosynthesis is an important component of the plant's capacity for the utilisation of atmospheric CO_2 and is correlated with leaf greenness. Application of fungicide, Nativo, in tomato significantly increased the photosynthetic rate, irrespective of the seasons, with a 20.49 % increase over the control. However, the reduction in transpiration rate (17.5) and stomatal conductance (8.17) was observed over the control in tomato. The increased photosynthetic rate with a reduction in leaf area index was due to the improvement in leaf thickness, especially the mesophyll region, which ultimately improves the photosynthetic rate (7). The increased rate of photosynthesis due to the triazole fungicide could have resulted in increased intercellular CO_2 concentration. Triazoles like paclobutrazol and triadimefon have been reported to increase chlorophyll content, activity of ribulose 1,5-bisphosphate-carboxylase and photosynthetic rates in peanut and foxtail millet (12). The increase in photosynthetic pigments due to the application of triazoles might have contributed to more stimulation of stomatal regulation (13). The reduction in transpiration rate and stomatal conductance with the application of fungicide is due to the increased level of abscisic acid in guard cells. The mechanism, which is involved in the diffusion of CO_2 into the mesophyll cells and water vapour to the atmosphere, is mainly driven by the complex system of stomatal aperture. Triazole treatment decreased stomatal conductance by reducing the transpiration rate and improved the CO_2 metabolism (14) .

Irrespective of the seasons, the chlorophyll content of tomato was significantly improved by 23.3 % with the application of a fungicide. This enhancement in chlorophyll due to strobilurin, coupled with triazole application, leads to the retardation of chlorophyll breakdown and delayed senescence (15). In general, triazole compounds such as triadimefon and uniconazole have a cytokinin-like activity with anti-senescence properties (16) and increased levels of cytokinin were observed on application of the fungicide. The increase in chlorophyll reflects increased PS II photochemistry, photosynthate production and dry matter accumulation. Such an increase may be attributed to the inhibition of chlorophyllase enzyme activity, which is known to be responsible for the destruction of chlorophyll in plant tissue (17).

The improvement in the light reaction of photosynthesis leads to improvement in the C3 cycle. The CO_2 observed by the plants is efficiently translocated into sugars because of the larger amount of energy produced during the light reaction. Thus, an increase of 38.97 % in soluble protein content was observed with the application of Nativo. Soluble protein is an indirect measure of RuBP carboxylase activity in the plants, accounting for more than 50 % of the RUBISCO content and is an index for assessing the photosynthetic efficiency of the crop. RUBISCO is known to degrade extensively and selectively at early stages of senescence in many plants. It was reported that strobilurin inhibited chlorophyll loss and degradation of proteins, slowing down the progression of senescence by reducing the levels of formation of 1-aminocyclopropane-1-carboxylic acid (ACC) and ethylene (17).

Starch and sugars are the dominant storage polysaccharides present in all major organs of higher plants. The total carbohydrates of tomato were significantly increased by 10.21 % with the application of the fungicide, irrespective of the seasons. A high amount of sugar in the source leaf reduces the senescence process, as the leaf was not the thrust of the respiratory burden (5). The enhanced carbohydrate content with the application of fungicide might have delayed the membrane degradation and improved the longevity of the leaves in the present study. Triazole inhibited the gibberellin biosynthesis while increasing the cytokinin. The changes may also be due to the inhibition of gibberellin biosynthesis coupled with increased cytokinin levels. A similar increase in sugar content by the application of trifloxystrobin and tebuconazole was observed in wheat seedlings (17).

Yield and its components in tomato

Crop productivity, in general, depends on the photosynthetic rate and canopy architecture of the crop. The fruit yield in tomato depends on the accumulation of photo-assimilates and their partitioning between the desired storage organs. Application of Nativo in different concentrations could strongly increase the yield. In the present study, Nativo 75 WG at 400g ha^{-1} could significantly increase the economic yield to an extent of 18 % in tomato. This improvement in yield is due to the stabilisation of chlorophyll content, enhanced chlorophyll index and photosynthetic rate by the combined application of strobilurin and triazole fungicide, which promoted the translocation of assimilates from source to sink by extending the greenness in leaves. The increment of these parameters significantly increased the accumulation of dry matter in reproductive parts and promoted the yield in tomato. The increase in yield, by the application of strobilurin, was earlier reported in tomato and in cotton (18).

In line with prior dissipation studies on trifloxystrobin and tebuconazole, the recommended application of Nativo 75WG at 400 g ha^{-1} during 35-40 and 55-60 DAT adheres to established pre-harvest intervals (PHI) and maximum residue limits (MRLs) set by regulatory authorities. These timings ensure that residue levels in harvested tomato fruits remain within safe thresholds for consumer health. Furthermore, the dual-action fungicide was applied in accordance with integrated pest management (IPM) principles, minimizing environmental impact and promoting sustainable crop protection. No adverse effects on non-target organisms or soil health were observed, supporting the responsible use of agrochemicals in open-field tomato cultivation.

Conclusion

This study investigated the physiological effects of Nativo 75WG, a combination of trifloxystrobin and tebuconazole, on tomato under field conditions with low disease pressure. *In vitro* assays confirmed fungicide toxicity against *A. solani*. Foliar application of Nativo at 400 g ha^{-1} enhanced photosynthetic rate, chlorophyll index, soluble protein and carbohydrate accumulation, contributing to improved fruit yield. These physiological benefits occurred despite a reduction in leaf area index, suggesting possible compensatory mechanisms such as increased leaf thickness or pigment density, which warrant further anatomical investigation.

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Authors' contributions

Conceptualisation was done by NR and SV. Methodology was carried out by NR, PJ and JVS. JVS handled the software. Validation was performed by NR, PJ and SV. Formal analysis was conducted by VS and JVS. The investigation was done by NR and resources were provided by PJ and SV. Data curation was carried out by NR and JVS and writing the original draft was done by NR and JVS. Writing review and editing were performed by VS and JVS. Visualisation was done by SV and supervision was provided by PJ. Project administration was managed by VS and PJ. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The Authors do not have any conflicts of interest to declare.

Ethical issues: None

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