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Effect of foliar application of nutrients and plant growth regulator formulation on maize yield

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Abstract

Crop productivity must be doubled in another fifty years to feed the ever-growing population, possibly by cultivating high-yielding varieties or best crop management strategies. We hypothesise that foliar application of nutrients and plant growth regulators may be more effective in increasing maize productivity than other crop management options. The objective was to quantify the impacts of foliar application of nutrio-hormonal consortia on the physiological and yield traits of maize. A pot culture experiment was conducted at the Glasshouse, Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore. The experiment was conducted in a factorial randomized block design with four replications. Factor 1 was genotype (G) with two levels (1. Co 6 and Co(M) H8), and factor 2 was foliar sprays with five levels (T_1- Control, T_2- Nutrio-hormonal consortia 1, T_3- Nutrio-hormonal consortia 2, T_4- Maize booster 1, and T_5- Maize booster 2). The primary result of the present experiment was that the foliar application of maize booster I and II increased the F_v/F_m ratio, soluble protein, nitrate reductase, stomatal conductance, photosynthetic rate, and grain yield. Foliar application of formulation containing nitrogen, boron, auxin, and salicylic acid increased the grain yield through increased grain number and grain size, and the increased seed yield may be associated with delayed leaf senescence.

Keywords: Grain yield, maize, nutrients, photosynthesis, plant growth regulators

Introduction

In India, agriculture contributes 18.8% of gross value added, and there is an urgent need to reorient the agri-food system to enhance farm income and minimize effects on the environment and the climate (Anonymous, 2023) [1]. Globally, it is estimated that by 2023, 700 million people will be hungry, and 600 million people will be chronically undernourished, and the above situation was worsened by the increasing global population (FAO, IFAD, UNICEF, WFP and WHO. 2023) [2]. Most of the hungry and undernourished people live in Asia and Sub-Saharan Africa. Across the globe, population growth is driving the food demand, and the current estimate indicates that food production has to be increased by 50% by 2030 (van-Wart *et al.* 2013) [3]. The crop yield increase can be achieved by adopting high-yielding varieties, appropriate crop management practices, expanding the cultivable area over the current cultivable area, or all. In the current situation, the crop yield increase through the expansion of cultivable areas is not possible; however, adopting appropriate crop management can be a solution to increase the crop yield.

Maize, a plant with a C_4 type of photosynthetic pathway, performs better in various environments, *viz.*, tropics, sub-tropics, and temperate regions. Maize requires 1222 L of water to produce one kg of dry matter. Also, maize is a highly nutrient and plant-growth regulator-responsive crop (Gheith *et al.*, 2022; Gong *et al.*, 2021) [4, 5]. Grain yield is a complex trait dependent on environment and plant factors. Nearly half of the yield enhancement in maize was due to the adoption of mechanization, better crop management, and increased plant populations (Duvick, 2001) [6]. There are many ways to improve maize productivity, such as adopting combined crop production technologies, new and high-yielding maize varieties or hybrids, and fertilizer and plant growth regulators (PGRs) responsive varieties to produce more grains (Shah *et al.*, 2021; Gheith *et al.*, 2022) [7, 4]. Hence, it is hypothesized that the grain yield of maize can be improved by foliar application of nutrient and plant growth regulators to modulate the physiological processes associated with grain yield.

Foliar nutrition is advantageous for the crop because the nutrients are absorbed efficiently compared to soil application of nutrients (Sathishkumar *et al.*, 2020) [8]. Photosynthetic rate is an important trait that indirectly explains nitrogen allocation and photosynthetic nitrogen use efficiency (Zhong *et al.*, 2019) [9].

Nitrogen is a constituent of chlorophyll and enzyme content, and studies have shown that nitrogen application rate had a strong positive relationship with photosynthetic rate (Liu *et al.*, 2019) [10]. Iron is a micronutrient involved in the chlorophyll synthesis, RuBisCo, and electron transport process of photosynthesis (Wang *et al.*, 2017; Yong *et al.*, 2012) [11, 12].

Among all the micronutrients, zinc, boron, and manganese play a major role in increasing the productivity of maize by increasing the 100-seed weight (Tahir *et al.* (2016) [13]. (Ehsanullah *et al.*, 2015) [14] reported that foliar application of zinc during the reproductive stage increased the cob length, cob diameter, and 100-grain weight over the control. Foliar application of boron at the grain-filling stage increased the grains per plant by 54% than the control plants (Haghi, 2016) [15]. Similar to nutrients, PGRs are involved in the regulation of crop growth (Zeng *et al.*, 2012) [16]. Studies showed that the foliar application of PGRs during the peak vegetative stage significantly decreased plant height, increased stem diameter, and enhanced lodging resistance in maize (Ahmad *et al.*, 2018; Zhang *et al.*, 2014) [17, 18]. Similarly, foliar application of ethephon to maize increased the aerial roots and reduced plant height and lodging (Zhang *et al.*, 2022) [19]. Hence, foliar application of nutrients and plant growth regulators may be more effective in increasing maize productivity than other crop management options. The objective was to quantify the impacts of foliar application of nutrio-hormonal consortia on the physiological and yield traits of maize.

Materials and Methods

A pot culture experiment was conducted at the Glasshouse, Department of Crop Physiology, Tamil Nadu Agricultural University, and Coimbatore. The experiment was conducted in a factorial randomized block design with four replications. Factor 1 was genotype (G) with two levels (1. Co 6 and Co(M) H8), and factor 2 was foliar sprays with five levels (T_1- Control, T_2- Nutrio-hormonal consortia 1, T_3- Nutrio-hormonal consortia 2, T_4- Maize booster 1, and T_5- Maize booster 2).

Crop husbandry

The released maize variety Co 6 and hybrid Co(M)H 8 seeds were collected from the Department of Millets, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India. The maize seeds were treated with insecticide imidacloprid at 2 mL per kg of seed and shade dried. The treated seeds (3 numbers per pot) were sown in pots at a depth of 3 cm and irrigated. Each genotype was sown in 25 pots. The crop was irrigated on alternate days based on the soil moisture. Thinning and gap filling were carried out on the 5th day after sowing. The seedlings were thinned on the 10th day of seedling emergence, and one plant per pot was maintained till harvest. Each pot was fertilized with 10 grams of urea, 5 grams of single super phosphate, and 5 grams of muriate of potash at the time of sowing. After the 10th day of sowing, each pot was fertilized with 2g of urea and 1 gram of single super phosphate. The plant in the pot do not show any nutrient deficiency symptoms from sowing to harvest. The plant was maintained from sowing to the start of tasselling, and then the treatments were imposed. At the start of tasselling stage, the following foliar treatments were imposed on the variety and hybrid: T_1 - Control (Water spray), T_2 – 1% Nutrio-hormonal consortia I, T_3 – 1% Nutrio-hormonal consortia II, T_4 – 1% Maize booster I, and T_5 – 1% Maize booster II. The I foliar spray was carried out at the start of the tasselling stage, and the II spray was given 15 days after the I spray, i.e., during the seed development stage. The foliar spray was carried out in the evening.

Traits recorded

The following traits were recorded in each replication on the 10th day after the I and II sprays. The physiological traits from each replication were recorded in the top fully expanded leaf between 9.00 a.m. and 12.30 p.m.

Maximum Quantum Yield of Photosystem (PS) II (Fv/Fm ratio) and gas exchange

The maximum quantum yield of PS II (Fv/Fm) was measured using a modulated fluorometer (OS5p+, Opti Sciences, Hudson, NH) by the dark adaptation method, as explained by Djanaguiraman *et al.* (2014) [20]. LICOR 6400XT portable photosynthesis system (LI-COR, Lincoln, NE, USA) was used to measure the leaf gas exchange parameters [photosynthetic rate (µmol $m^{-2}s^{-1}$), transpiration rate (m mol m^{-2} s^{-1}), and stomatal conductance (mol m^{-2} s^{-1})]. Gas exchange measurements were taken at daytime growth temperature and ambient CO_2 conditions (410 ppm). The quantum flux of the LICOR 6400XT was set at 1600 µmol m^{-2} s^{-1} to provide uniform illumination. (Djanaguiraman *et al.*, 2018) [21].

Soluble protein and nitrate reductase enzyme activity

Soluble protein was estimated as per Bradford (1976) [32]. Briefly, 250 mg of leaf sample was weighed and macerated with 10 ml of phosphate buffer. The content was transferred to a centrifuge tube and centrifuged at 3000 rpm for 15 min. A 30 µl of aliquot was taken from the supernatant, to which 1.5 ml of Bradford dye reagent (Sigma Aldrich, Bangalore, India) was added. The contents were mixed thoroughly, and the optical density was measured at 595 nm after 10 min. The soluble protein content of the leaf was expressed as mg g^{-1}. The procedure explained by Nicholas *et al.* (1979) was followed to quantify the nitrate reductase enzyme activity in leaves. In short, 500 mg of leaf sample was weighed, cut into small bits, and transferred to a test tube containing 10 ml of assay medium containing potassium nitrate. The test tube containing the solution and leaf sample was desiccated to extract the enzyme from the leaf to the solution. After desiccation, the test tube was dark adapted for one hour. A 2 ml of aliquot was taken in a test tube, and l ml of zinc acetate and 2 ml of ethanol were added to the aliquot. The formed precipitate was filtered, and l ml of sulpha nil amide and l ml of NEDD were added. The absorbance of the pink color end product was measured at 540 nm using a spectrophotometer.

Yield and yield components

The cob was harvested from each plant at physiological maturity and the harvested cobs were dried in the oven maintained at 50 ºC for 72 h. After that, the cob was hand thrashed, and the seeds were counted and expressed as the number of grains cob^{-1}. One hundred randomly selected seeds from each replication were weighed to arrive at a 100-grain weight and expressed as grams. The oven-dried seeds from a single cob were weighed and expressed as g $plant^{-1}$.

Data analysis

The experiment was conducted in a factorial randomized block design with four replications. The first factor was the genotype, and the second factor was foliar spray. The data were analyzed using the PROC GLM procedure of SAS.

Means of various variables were separated for significance by the least significant difference test or Tukey-Kramer adjustment at a probability level of 0.05.

Results

Physiological traits: Normalized difference vegetation index, leaf soluble protein content, and nitrate reductase activity

The data on leaf soluble protein content (mg g^{-1}), nitrate reductase enzyme activity (μg NO_2 g^{-1} h^{-1}), and NDVI (no units) after II spray were presented in Table 3. There was a significant ($p<0.05$) effect of formulation on leaf soluble protein, nitrate reductase enzyme activity, and NDVI (Table 3). The impact of genotype was significant ($P<0.05$) for nitrate reductase enzyme activity (Table 3). Like the I spray, the maize booster II increased the leaf soluble protein (44%), nitrate reductase enzyme activity (10%), and NDVI (6%) over water spray. Between the genotypes, a significant ($p<0.05$) increase in the nitrate reductase enzyme activity was observed in the variety Co 6 (6%) than the hybrid, CoHM 8.

Gas exchange traits: Photosynthetic rate, stomatal conductance, and transpiration rate

The data on genotype, formulation, and their interaction on photosynthetic rate (μmol m^{-2} s^{-1}), stomatal conductance (mol m^{-2} s^{-1}), and transpiration rate (mmol m^{-2} s^{-1}) after II spray was presented in Table 2. The effect of formulation was significant ($P<0.01$) for photosynthetic rate, stomatal conductance, and transpiration rate (Table 2). Among the treatments, foliar application of maize booster II increased the photosynthetic rate (20%), stomatal conductance (48%), and transpiration rate (19%) compared to water spray (Table 2).

Yield and yield components: Number of grains cob^{-1}, 100-grain weight, and yield $plant^{-1}$

The data on the number of grains cob^{-1}, 100-grain weight (g), and yield $plant^{-1}$ (g) was presented in Table 3. The effect of genotype was significant ($P<0.05$) for the number of grains cob^{-1}, 100-grain weight (g), and yield $plant^{-1}$ (g). Among the foliar spray treatment, applying maize booster II increased the numbers of grains cob^{-1}, 100-grain weight (31%), and yield $plant^{-1}$ (38%) compared to water spray treatment. Between the genotypes, the hybrid CoMH 8 had a higher grain yield (6%) than the variety Co 6.

Discussion

The primary result of the present experiment was that the foliar application of maize booster I and II increased the F_v/F_m ratio, soluble protein, nitrate reductase, stomatal conductance, photosynthetic rate, and grain yield (Tables 1, 2, and 3). The present study showed that foliar application of formulation containing nitrogen, auxin, and salicylic acid increased the F_v/F_m ratio compared to water spray. Nitrogen is an essential nutrient for reproductive tissue growth and yield (Lawlor, 2002) [22]. The F_v/F_m ratio of a leaf reflects the ability of chloroplast to produce adenosine triphosphate (ATP) or nicotinamide adenine diphosphate (NADPH) (Baker *et al.*, 1983; Shen and Li, 2011) [23, 24]. Similar to the present study, Ma *et al.* (2010) [25] observed an increased F_v/F_m ratio under nitrogen application in winter wheat. The increased F_v/F_m ratio in maize booster II sprayed plants was due to decreased F_o value and not with F_m value. The changes in the F_v/F_m ratio caused by the foliar application of maize boosters I and II may be a direct response to the chlorophyll content of their leaves.

Similar to the F_vF_m ratio, foliar application of maize boosters I and II increased the photosynthetic rate through increased stomatal conductance. Photosynthesis is influenced by nitrogen level and studies showed a positive linear relationship between leaf nitrogen level and the photosynthetic rate (Lin *et al.*, 2013) [26]. In general, the grain yield can be improved by increasing the photosynthetic rate and translocation of photosynthates from source to sink (Simkin *et al.*, 2019) [27]. The primary mechanism by which nitrogen increases the photosynthetic rate is delaying the leaf senescence (Hu *et al.*, 2008) [28] and increasing the concentration of CO_2 around ribulose 1-5- bisphosphate through increased stomatal conductance (Xu, 1998 and Zhu *et al.*, 2010) [29, 30].

In the present study, the variation between the genotypes is associated with their differences in genetic makeup (variety vs. hybrid). Between the genotypes, hybrid (CoMH 8) had increased seed yield than variety (Co 6), and it was due to the phenomenon of hybrid vigor (Baranwal *et al.*, 2012) [31]. Foliar application of maize booster II increased the maize grain yield, and the increase in grain yield is primarily from the increase in the grain numbers cob^{-1}, followed by individual grain weight, and this was confirmed by the chemical composition of maize booster II, as it contained boron.

Table 1: Interaction of genotypes (G) and foliar application of maize booster formulation (T) on normalized difference vegetation index (NDVI; no units), soluble protein content (mg g^{-1}), and nitrate reductase enzyme activity (μg NO_2 g^{-1} h^{-1}) of maize after II spray (seed development stage). Means are separated by Tukey's test and the values with same alphabet in a column are not statistically different at $p<0.05$.

Treatments (T)	Genotypes (G)								
	Quantum efficiency of photosystem II (F_v/F_m ratio; no units)			Soluble protein (mg g^{-1})			Nitrate reductase activity (μg NO_2 g^{-1} h^{-1})		
	CoMH 8	Co 6	Mean	CoMH 8	Co 6	Mean	CoMH 8	Co 6	Mean
T_1 – Water	0.72^{a}	0.72^{a}	0.72^{c}	15.60^{a}	15.55^{a}	15.58^{d}	291.4^{b}	339.0^{ab}	315.2^{b}
T_2 - Nutrio-hormonal consortia - I	0.74^{a}	0.74^{a}	0.74^{c}	17.90^{a}	17.57^{a}	17.73^{bc}	330.6^{ab}	328.9^{ab}	329.8^{b}
T_3 - Nutrio-hormonal consortia - II	0.76^{a}	0.76^{a}	0.76^{b}	18.17^{a}	16.96^{a}	17.56^{cd}	332.3^{ab}	337.6^{ab}	334.9^{ab}
T_4 - Maize booster I	0.76^{a}	0.76^{a}	0.76^{b}	19.90^{a}	19.34^{a}	19.62^{b}	324.6^{ab}	365.7^{a}	344.8^{ab}
T_5 - Maize booster II	0.78^{a}	0.78^{a}	0.78^{a}	22.72^{a}	22.33^{a}	22.52^{a}	355.0^{a}	368.4^{a}	361.7^{a}
Mean	0.75^{a}	0.75^{a}		18.86^{a}	18.35^{a}		326.8^{b}	347.9^{a}	
CD ($p<0.05$)	G = NS						G = 13.52**		
	T = 0.01**						T = 30.50*		
	G x T =NS						G x T = NS		

Table 2: Interaction of genotypes (G) and foliar application of maize booster formulation (T) on photosynthetic rate (μmol m^{-2} s^{-1}), stomatal conductance (mmol m^{-2} s^{-1}), and transpiration rate (mol m^{-2} s^{-1}) of maize after II spray (seed development stage). Means are separated by Tukey's test and the values with same alphabet in a column are not statistically different at $p<0.05$.

Treatments (T)	**Genotypes (G)**								
	Photosynthetic rate (μmol m^{-2} s^{-1})			**Stomatal conductance (mol m^{-2} s^{-1})**			**Transpiration rate (mmol m^{-2} s^{-1})**		
	CoMH 8	**Co 6**	**Mean**	**CoMH 8**	**Co 6**	**Mean**	**CoMH 8**	**Co 6**	**Mean**
T_1 - Water	32.87^{a}	31.85^{a}	32.36^{b}	0.40^{a}	0.43^{a}	0.41^{b}	1.44^{a}	1.49^{a}	1.47^{bc}
T_2 - Nutrio-hormonal consortia - I	31.55^{a}	31.60^{a}	31.57^{b}	0.39^{a}	0.40^{a}	0.39^{b}	1.56^{a}	1.58^{a}	1.57^{abc}
T_3 - Nutrio-hormonal consortia - II	34.03^{a}	34.25^{a}	34.14^{b}	0.43^{a}	0.43^{a}	0.43^{b}	1.46^{a}	1.42^{a}	1.44^{c}
T_4 - Maize booster I	37.82^{a}	36.47^{a}	37.15^{a}	0.60^{a}	0.56^{a}	0.58^{a}	1.74^{a}	1.70^{a}	1.72^{ab}
T_5 - Maize booster II	39.40^{a}	38.72^{a}	39.06^{a}	0.62^{a}	0.60^{a}	0.61^{a}	1.77^{a}	1.74^{a}	1.75^{a}
Mean	35.13^{a}	34.58^{a}		0.49^{a}	0.48^{a}		1.59^{a}	1.59^{a}	
CD (p<0.05)	G = NS			G = NS			G = NS		
	T = 2.77**			T = 0.06**			T = 0.25**		
	G x T = NS			G x T =NS			G x T =NS		

Table 3: Interaction of genotypes (G) and foliar application of maize booster formulation (T) on number of grains cob^{-1}, 100 grain weight (g) and yield $plant^{-1}$ of maize at maturity stage. Means are separated by Tukey's test and the values with same alphabet in a column are not statistically different at $p<0.05$.

Treatments (T)	**Genotypes (G)**								
	Number of grains cob^{-1}			**100-grain weight (g)**			**Yield $plant^{-1}$ (g)**		
	CoMH 8	**Co 6**	**Mean**	**CoMH 8**	**Co 6**	**Mean**	**CoMH 8**	**Co 6**	**Mean**
T_1 - Water	440.7^{c}	427.7^{a}	434.25^{b}	27.72^{a}	27.17^{a}	27.45^{e}	142.3^{a}	136.3^{a}	139.3^{c}
T_2 - Nutrio-hormonal consortia - I	470.0^{a}	466.5^{a}	468.25^{b}	31.62^{a}	28.50^{a}	30.06^{d}	148.7^{a}	133.0^{a}	150.8^{b}
T_3 - Nutrio-hormonal consortia - II	516.2^{a}	515.2^{a}	515.75^{a}	33.00^{a}	31.02a	32.01^{c}	170.6^{a}	160.0^{a}	165.3^{b}
T_4 - Maize booster I	520.2^{a}	523.5^{a}	521.88^{a}	34.65^{a}	33.57^{a}	34.11^{b}	180.3^{a}	175.9^{a}	178.1^{ab}
T_5 - Maize booster II	538.7^{a}	537.5^{a}	538.13^{a}	36.95^{a}	35.02^{a}	35.98^{a}	199.2^{a}	188.2^{a}	193.7^{a}
Mean	497.2^{a}	494.1^{a}		32.79^{a}	31.06^{b}		168.2^{a}	158.7^{b}	
CD (p<0.05)	G = NS						G = 8.31**		
	T = 41.52**						T = 11.74**		
	G x T = NS						G x T = NS		

Conclusion

Overall, it can be concluded that foliar application of formulation containing nitrogen, boron, auxin, and salicylic acid increased the grain yield through increased grain number and grain size, and the increased seed yield may be associated with delayed leaf senescence.

Conflict of interest: None

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