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Enhancing Oat Yield Through Targeted Ascorbic acid Application: Cost-effective Approaches for Sustainable Agriculture

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ABSTRACT

Oat is considered the second crop in Iraq. It needs to select good varieties and improve its quality to increase its yield. This study evaluates the effect of ascorbic acid (AsA) on the growth and yield of four oat *(Avena sativa L.)* varieties-Kangaroo, Possum, ICARDA Short, and ICARDA Tall-under field conditions in Koya, Erbil, Iraq. The experiment was conducted during the winter season using a split-plot design in a randomized complete block layout with three replicates. Four concentrations of ascorbic acid (0, 100, 200, and 300 ppm) were applied via foliar spray at two critical growth stages: tillering and flowering. The critical parameters of the study such as plant height, number of panicles, grain yield, biological yield and harvest index were assessed at harvest. The ICARDA Short cultivar gave the highest seed and biological yield with ascorbic acid treated plants not showing any significant change. ICARDA Tall and Kangaroo showed a significant increase in yield, especially at the 300-ppm concentration of ascorbic acid. The Possum variety responded minimally to all treatments. It seemed that ICARDA Short can be produced successfully without additional ascorbic acid, making it an economically viable product for growers, but that ICARDA Tall and Kangaroo may require additional ascorbic acid to achieve higher yields. Findings from this research give perspective on how to improve oat products by strategically utilizing of plant growth regulators.

Keywords: Oat varieties, Ascorbic acid, Plant growth.

INTRODUCTION

Oats are highly valued for their rich nutritional composition, including important vitamins, unsaturated fats, proteins, and antioxidants. Particularly, their high fiber content contributes to health benefits like cholesterol reduction and improved glucose regulation[1]. However, oat production in Iraq faces significant challenges. The agricultural soils within the nation are characterized by diminished fertility and elevated salinity levels, whereas the over-application of inorganic fertilizers has resulted in environmental contamination and a deterioration of soil health[2]. Crop yields are limited by these variables, which indicates the pressing need for more sustainable agriculture methods. Ascorbic acid is one natural growth regulator that has been shown in recent research to have the ability to both promote and lessen the negative impacts of environmental stresses on plant growth and development[3].

In plant cells, ascorbic acid is an important antioxidant involved in detoxifying reactive oxygen species ROS, which are produced under stress conditions like drought, salinity, and high temperatures[4]. The accumulation of ROS results in crop losses because it can cause cellular damage, hence preventing further development of the plants. Ascorbic acid decreases ROS and guards the plant tissues against oxidative damage, hence strengthening the plants' general resistance to different stressors[5]. ROS neutralization is an indispensable process for the harmful effects to be mitigated. Other than the reduction of stress levels in the plant body, ascorbic acid also takes part in the maintenance of various physiological functions such as cell division, growth, and differentiation. In appropriate conditions, these functions can also enhance biomass accumulation and yield[6]. In fact, most studies have proved that ascorbic acid works for a better yield of crops. The incidence of salinity stress regulated the physiological responses of wheat varieties for improved growth and yield parameters with respect to chlorophyll content and water-use efficiency[7]. In the related study, under conditions of ozone stress, the application of ascorbic acid led to improvements in seed yield, harvest index, and gas exchange parameters across various varieties of mung bean[8]. Moreover, one of the prominent studies investigates the influence of different concentrations of exogenous ascorbic acid on rice varieties grown in saline soils. Indeed, higher values of ascorbic acid at 1500 mg/L have been found to increase yields more significantly; therefore, optimization of the ascorbic acid concentration may prove to be one of the important factors to get optimum productivity under unfavorable conditions[9]. Such findings from the research pinpoint the prioritized determination of the optimal concentration of ascorbic acid to enhance agricultural productivity in Iraq for different oat cultivars. In this regard, it is found in lettuce that an identical concentration of ascorbic acid at 400 mg/L favored better growth and productivity under salinity stress; otherwise, lower concentrations are less effective[10]. This points to an exact change in ascorbic acid concentration for optimum response in many species.

The present study evaluates the effect of ascorbic acid on the growth and yield of four oat cultivars-Kangaroo, Possum, ICARDA Short, and ICARDA Tall-each with distinct agronomic traits:

- **Kangaroo:** A mid to late-season, tall oat variety known for its high grain yield potential, good foliar disease resistance, and moderate tolerance to nematodes. It is best suited to high rainfall regions and is recognized for its late maturity and robust growth, though it requires careful management for hay quality due to higher fiber content and lower water-soluble carbohydrates[11].
- **Possum:** An early to mid-season variety with good early vigor, moderate plant height, and strong standing ability. It is valued for its relatively high feed value and digestibility, making it suitable for both grain and hay production, though its yield potential is generally moderate compared to Kangaroo and ICARDA Tall[12].
- **ICARDA Short:** A short-statured cultivar that matures earlier than the tall types. It is generally selected for environments where early maturity is advantageous, though its yield potential for both grain and forage is typically lower than the taller cultivars[13].
- **ICARDA Tall:** Characterized by its tall stature and late maturity, ICARDA Tall is notable for its superior dry forage yield and strong general combining ability for biological yield. It is often preferred for forage production due to its high biomass output and has shown positive effects on plant height, maturity, and growth rate[14].

This study was to evaluate the effect of ascorbic acid on the growth and yield of four oat cultivars: Kangaroo, Possum, ICARDA short, and ICARDA long, in light of the environmental issues in Iraq and the importance of sustainable agriculture. The main objectives are to determine if ascorbic acid may increase yields in this cultivar, establish the appropriate concentration for each cultivar, and find cost-effective sustainable farming methods. This study will reveal how oat cultivars react to ascorbic acid, which might improve oat yield in hostile locations like Iraq.

Methodology

A field experiment was conducted in winter in the fields of the Agricultural Research Station in Koya, Erbil, located at an altitude of 570 meters above sea level. The aim of the study was to evaluate the effect of different concentrations of ascorbic acid on the growth and yield of four oat species namely Kangaroo, Possums (Australian Varieties), ICARDA Short, and ICARDA Tall.

Experimental Design and Treatments

The design followed the experience of arranging plots using a completely randomized design (R.C.B.D.), with three replications for each treatment. The paper flow with ascorbic beads is divided into four different tracks: 0 parts per million, 100 parts per million, 200 parts per million, and 300 parts per million. Rush is applied until the plants are completely covered, but ensures even stirring.

Rationale for Stage Selection

Ascorbic acid was applied as a treatment during two critical stages of oat growth:

Tillering Stage

The tillering stage is a key phase in plant development, during which multiple shoots (tillers) are formed, and nutrient uptake becomes essential for subsequent growth. The application of ascorbic acid at this stage was anticipated to enhance stress tolerance and promote shoot growth by supporting antioxidative processes in young tissues.

Flowering Stage

The second application occurred at the flowering stage, a crucial period marking the transition to reproductive growth. Ascorbic acid was applied at this stage due to its role in enhancing pollen viability and seed setting, especially under environmental stress conditions.

Environmental Conditions

Temperatures varied from 11.8°C to 33.6°C during the study, and the season of growing was recorded an average rainfall of 516.85 mm. These circumstances fit the region's typical winter climate, which is marked by cool temperatures and moderate rainfall and is ideal for oat farming. The pH of the sandy loam soil at the research site was 7.6, and it was moderately fertile. It is important to note that during the study, no significant epidemics of disease or pests were seen in the field.

Sampling and Measurements

At harvest, key growth and yield parameters were measured for each treatment, including:

1. **Plant Height (cm):** Measured from the soil surface to the base of the panicle.
2. **Number of Panicles per Meter:** Effective spikes were counted along a meter-long row.
3. **Grain Weight (g/panicle):** Measured using precise laboratory balances.
4. **Grain Yield (tons/hectare):** Calculated by threshing grains from a one-meter harvested row and converting to tons/hectare.
5. **Biological Yield (tons/hectare):** Harvested plant material was weighed and converted to biological yield.

Biological yield was measured as the total above-ground dry biomass per unit area. At harvest, all plant material (stems, leaves, grains) was cut at ground level, weighed fresh, then oven-dried at 70°C until constant weight to determine dry biomass. The dry weight was then converted to tons per hectare based on plot size. This method is standard in agronomic research for accurate biomass estimation[15].

6. **Straw Yield (tons/hectare):** Calculated by subtracting the grain yield from the biological yield.
7. **Harvest Index (HI%):** Calculated as (Grain Yield/Biological Yield)×100.

Data Analysis

The data were analyzed using IBM® SPSS Software V. 26.0. A one-way ANOVA was conducted to assess the statistical significance of differences between treatments, and Duncan's Multiple Range Test ($p<0.05$) was used to compare means. Statistical results are represented in tables, where letters indicate the significance of differences.

RESULT AND DISCUSSION

Effect of Ascorbic Acid on Plant Height

The application of ascorbic acid significantly impacted the height of oat varieties, with the Kangaroo variety exhibiting the highest plant height at 300 ppm (94.017 cm), significantly greater than ICARDA Tall (89.750 cm) and ICARDA Short (82.750 cm) (Table 1). This effect can be attributed to the role of ascorbic acid in mitigating oxidative stress, allowing plants to utilize more resources for growth. Plants with higher ascorbic acid content tend to better tolerate environmental stresses such as salt and cold, which might explain the increased height in Kangaroo at 300 ppm. However, ICARDA Short did not show a significant increase in height across treatments, which may indicate a genetic predisposition to maintain its height regardless of external treatments. Liu *et al.,* found that AsA helps reduce oxidative stress by enhancing antioxidant activity in plants under cold stress[16], while Elkelish *et al.,* observed similar benefits in tomato plants under chilling conditions, with AsA improving growth and ion uptake[17]. Additionally, another study reported that AsA increased barley growth under salinity stress by boosting antioxidant defenses[18], and Farooq *et al.,* (2020) showed that AsA-treated safflower plants exhibited enhanced height and biomass under water stress[19]. These findings suggest that the increased height of the Kangaroo variety can be attributed to AsA's ability to improve stress tolerance and resource allocation for growth. The varied responses to ascorbic acid may also relate to each oat variety's environmental adaptation and genetic traits. Kangaroo, suited to Australian conditions, exhibits heat and drought tolerance, which could enhance its utilization of ascorbic acid's antioxidant benefits (cite relevant seed company data if available). ICARDA Tall's improved response may stem from its genetic potential for higher growth when oxidative stress is mitigated. ICARDA Short, conversely, might have inherent stress resistance, lessening its dependence on external ascorbic acid. These interactions between variety characteristics and ascorbic acid response offer insights for optimizing oat cultivation, in line with recent findings on nutrient allocation in cereals[20] and antioxidant capacity in stress tolerance[21].

Table 1: Effect of Ascorbic Acid Concentrations on Height of Oat Varieties (cm)

Varieties	Ascorbic acid concentrations (ppm) on height of Oat varieties (cm)			
	0	100	200	300
ICARDA Short	84.750 bc	78.333 c	83.37 bc	82.750 bc
Kangaroo	83.500 bc	80.250 c	82.625 c	94.017 a
ICARDA Tall	80.958 c	78.000 c	83.375 bc	89.750 ab
Possum	54.375 de	48.500 e	49.250 e	56.125 d

The results showed by Mean. The same letter marks in this table represent non-significant differences at $p \leq 0.05$ according to Duncan's Multiple Range test and vice versa

Effect of Ascorbic acid Concentrations on Panicles Number of Oat Varieties (Panicle/m)

Ascorbic acid treatment had varied effects on panicle number and grain weight across different varieties, as shown in Table 2. ICARDA Tall exhibited the highest increase in panicle number at 300 ppm (98.5 panicles/m), compared to Possum (96.75 panicles/m) and Kangaroo (82.25 panicles/m). This increase in panicle number can be attributed to ascorbic acid's role in regulating key plant hormones, such as gibberellins and cytokinins, which promote panicle initiation and development[22]. However, ICARDA Short did not show significant changes in panicle number, likely due to its inherent oxidative stress resistance and naturally high endogenous antioxidant levels, which may render additional ascorbic acid applications less effective[23].

Despite the increased panicle number in the Possum variety, grain weight decreased at higher panicle numbers, as illustrated in (Table 3). This suggests a resource allocation issue, where nutrients are distributed too thinly across more panicles. Similar phenomena have been observed in other cereals, such as rice, where the relationship between panicle number and grain weight is affected by nutrient allocation and sink-source dynamics. For instance, a study by Yabe et al. introduced the concept of an "allocation index" to evaluate how resources are distributed in rice panicles, showing a trade-off between panicle number and grain filling stability[24]. Additionally, Barus *et al.,* reported that while ascorbic acid treatment improved panicle numbers and grain filling under stress conditions, it did not consistently lead to increased grain weight[9]. In contrast, the Kangaroo variety in my study managed to maintain both high panicle number and grain weight at 300 ppm ascorbic acid, likely due to a more efficient nutrient allocation system, similar to findings in transgenic rice varieties[25]. These findings suggest that nutrient allocation mechanisms play a critical role in balancing panicle number and grain weight.

Table 2: Effect of Ascorbic acid Concentrations on Panicles Number of Oat Varieties (panicle/m)

Varieties	Ascorbic acid concentrations(ppm) on panicles number of Oat varieties (panicle/m)			
	0	100	200	300
ICARDA Short	90.083 bc	72.250 df	91.000 bc	90.750 bc
Kangaroo	59.583 f	75.500 de	69.500 df	82.250 cd
ICARDA Tall	83.167 cd	66.500 ef	70.250 df	98.500 ab
Possum	82.500 cd	66.250 ef	88.750 a	96.750 ac

The results showed by Mean. The same letter marks in this table represent non-significant differences at $p \leq 0.05$ according to Duncan's Multiple Range test and vice versa

Effect of Ascorbic acid Concentrations on Panicle Grain Weight of Oat Varieties (g/panicle)

The weight and the number of panicles show a direct relationship between them, with an increase in the number of panicles (panicle/m). The Panicle weights of Oat varieties significantly increased (g/panicle) under the influence of 300ppm Ascorbic Acid concentration when compared with the control group, except for Possum, with increasing panicle number, panicle weight significantly decreased. The increasing number of panicles leads to an increase in the total weight of panicles produced by the plant. This is because more panicles usually mean more sites for grain or seed formation[26].

The weight of ICARDA Short did not increase under the influence of Ascorbic Acid concentrations compared to the control group and other Oat varieties. There is a negative correlation between panicle number and individual panicle weights. As the number of panicles increases, the weight of each panicle may decrease as the plant resources (nutrients, water, energy) are distributed to more panicles[27].

Table 3: Effect of Ascorbic Acid Concentrations on Panicle Grain Weight of Oat Varieties (g/Panicle)

Varieties	Ascorbic acid concentrations (ppm) on panicle grain weight of Oat varieties (g/panicle)			
	0	100	200	300
ICARDA Short	1.066 a-c	0.786 f-h	0.943 c-e	1.069 a-c
Kangaroo	1.129 ab	0.732 h	0.889 e-g	1.151 a
ICARDA Tall	0.895 ef	0.758 gh	0.924 de	1.071 a-c
Possum	1.129 ab	0.749 h	0.662 h	0.998 a-e

The results showed by Mean. The same letter marks in this table represent non-significant differences at $p \leq 0.05$ according to Duncan's Multiple Range test and vice versa

Effect of Ascorbic acid Concentrations on Grain Yield of Oat Varieties

Ascorbic acid had a significant impact on seed yield across the studied varieties, with the highest yields recorded at 300 ppm. ICARDA Tall exhibited the best performance, yielding 5.240 tons/hectare at this concentration, while ICARDA Short and Possum showed no significant yield improvement compared to the control. In contrast, lower concentrations, such as 100 ppm, led to a significant yield reduction in Possum (2.090 tons/hectare) (Table 4). This highlights the necessity of optimizing AsA concentrations, as suboptimal levels may reduce seed yield rather than enhance it.

The notable increase in seed yield for ICARDA Tall at 300 ppm AsA in this study aligns with findings from recent research. For example, Barus *et al.,* reported that higher concentrations of AsA significantly improved yield in rice under saline conditions, with the best results at 1,500 mg/L, reinforcing the idea that optimal AsA levels can boost yields in stress environments[9]. Similarly, Miladinov *et al.,* observed a 9.67% increase in soybean seed yield following foliar application of AsA under favorable conditions[28]. They also found that lower AsA concentrations negatively affected yield, which parallels the yield reduction in Possum at 100 ppm in my study. These studies collectively emphasize that determining the proper AsA concentration is crucial for maximizing seed yield potential.

Table 4: Effect of Ascorbic Acid Concentrations on Grain Yield of Oat Varieties (tons/hectare)

Varieties	Ascorbic acid concentrations (ppm) on yield of Oat varieties (tons/hectare)			
	0	100	200	300
ICARDA Short	4.764 ab	2.899 df	4.155 bc	4.798 ab
Kangaroo	2.911 df	2.868 df	3.149 de	4.686 ab
ICARDA Tall	3.709 cd	2.486 ef	3.282 de	5.240 a
Possum	4.959 ab	2.090 f	3.588 cd	4.903 ab

The results showed by Mean. The same letter marks in this table represent non-significant differences at $p \leq 0.05$ according to Duncan's Multiple Range test and vice versa.

Effect of Ascorbic acid Concentrations on Straw Yield of Oat Varieties (tons/hectare)

The Kangaroo variety demonstrated the highest straw yield (6.439 tons/hectare) at 300 ppm (Table 5), reflecting a strong positive response to higher concentrations of AsA. In contrast, ICARDA Tall showed the lowest straw yield at 200 ppm (1.785 tons/hectare) but exhibited significant recovery at 300 ppm, suggesting a possible inhibitory effect at moderate concentrations. These findings underscore the variety-dependent nature of AsA's influence on straw yield, with some varieties, such as Kangaroo, benefiting more from higher concentrations.

The strong response of the Kangaroo variety to 300 ppm AsA in this study mirrors findings in other crops. Kandil *et al.,* observed that higher AsA concentrations significantly boosted both biological and straw yields in soybean, particularly under drip irrigation, where the most favorable results were achieved at higher concentrations[29]. Similarly, Shahzadi et al. reported that AsA treatment enhanced yield and mineral uptake in mung beans, though the effectiveness varied between genotypes, highlighting a concentration-dependent and variety-specific response[8]. This explains the recovery observed in ICARDA Tall at 300 ppm after a reduction at 200 ppm, as certain varieties may exhibit sensitivity to specific AsA concentrations. These results emphasize the importance of tailoring AsA applications to individual crop varieties for optimal straw yield outcomes.

Table 5: Effect of Ascorbic Acid Concentrations on Straw Yield of Oat Varieties (ton/he.)

Varieties	Ascorbic acid concentrations (ppm) on Straw yield of Oat varieties (ton/he.)			
	0	100	200	300
ICARDA Short	4.299 cd	2.643 gh	3.970 c-f	4.765 bc
Kangaroo	3.756 d-f	3.945 c-f	4.101 c-f	6.439 a
ICARDA Tall	3.374 e-g	2.264 hi	1.785 i	5.135 b
Possum	4.229 c-e	3.219 fg	3.288 fg	4.098 c-f

The results showed by Mean. The same letter marks in this table represent non-significant differences at $p \leq 0.05$ according to Duncan's Multiple Range test and vice versa.

Effect of Ascorbic Acid Concentrations on Biological Yield of Oat Varieties (tons/hectare)

The results presented in (Table 6) highlight the effects of varying concentrations of ascorbic acid on the biological yield of different Oat varieties, measured in tons per hectare. The biological yield of the Kangaroo variety was highest at 300 ppm (11.125 tons/hectare), outperforming other varieties. Both ICARDA Tall and Possum also exhibited significant increases in biological yield at 300 ppm, whereas ICARDA Short showed a more moderate response. This indicates that while all varieties benefited from ascorbic acid (AsA) application, the magnitude of the effect varied, likely due to differences in their metabolic responses to stress[30].

The Kangaroo variety's highest biological yield at 300 ppm in this study aligns with findings from other research emphasizing the role of AsA in enhancing stress tolerance and yield. For instance, Gaafar et al. reported that AsA application improved growth and yield in common beans by alleviating water stress and enhancing antioxidant activity, particularly at higher concentrations[31]. Similarly, Hamidi *et al.,* showed that AsA application, in combination with biological fertilizers, significantly increased biological yield in basil under drought stress, reinforcing the idea that the effectiveness of AsA varies by variety and environmental conditions[32]. These findings confirm that while all varieties in this study benefited from AsA, the extent of the response is influenced by each variety's specific metabolic mechanisms for coping with stress.

Table 6: Effect of Ascorbic Acid Concentrations on Biological Yield of Oat Varieties (tons/hectare)

Varieties	Ascorbic acid concentrations (ppm) on Biological yield of Oat varieties (tons/hectare)			
	0	100	200	300
ICARDA Short	9.063 bc	5.542 ef	8.125 cd	9.563 bc
Kangaroo	6.667 de	6.813 de	7.250 d	11.125 a
ICARDA Tall	7.084 de	4.750 fg	6.500 de	10.375 ab
Possum	9.188 bc	3.875 g	6.875 de	9.000 bc

The results showed by Mean. The same letter marks in this table represent non-significant differences at $p \leq 0.05$ according to Duncan's Multiple Range test and vice versa

Effect of Ascorbic acid Concentrations on Harvest Index of Oat Varieties (%)

The harvest index, which is the ratio of grain yield to total biological yield, showed significant variation across the Oat varieties with different levels of ascorbic acid application. Notably, the "Possum" variety exhibited the highest harvest index at 100 ppm (54.458%) and 300 ppm (54.003%), indicating a robust response to ascorbic acid, likely due to enhanced grain filling or efficient resource allocation under these conditions. According to Table (4), the Kangaroo variety showed a marked increase in both grain yield and biological yield at 300 ppm AsA. However, the HI remained relatively low (41–44%) compared to Possum. This suggests that although AsA application at higher concentrations stimulated overall biomass production in Kangaroo, a substantial proportion of this biomass was allocated to vegetative rather than reproductive growth[33]. Table (5) further demonstrates that while grain yield increased significantly at 300 ppm, the increase in biological yield was proportionally greater, resulting in a modest HI. As shown in Tables (6) and (7), ICARDA Tall also exhibited a strong positive response to increasing AsA concentrations, particularly at 300 ppm, with significant increases in both grain and biological yields. However, the HI for ICARDA Tall showed only moderate improvement, rising from approximately 46% in the control to 49% at 300 ppm. This suggests that, similar to Kangaroo, ICARDA Tall benefits from increased biomass production under AsA treatment, but the proportional allocation to grain remains moderate. The data in Table (6) indicate that the increase in biological yield slightly outpaced the increase in grain yield, resulting in only a modest gain in HI. These findings are consistent with previous reports that the effect of AsA on HI is variety-dependent and influenced by the balance between vegetative and reproductive growth[34]. The strong vegetative response in Kangaroo and ICARDA Tall highlights the importance of optimizing AsA concentrations and understanding varietal traits to maximize grain yield and HI in oat breeding and cultivation programs35. The Possum variety's high harvest index in my study is consistent with findings in other crops. For instance, Noreen *et al.,* observed that foliar application of ascorbic acid improved the harvest index in barley under saline conditions by enhancing photosynthetic activity and ion uptake, supporting the idea that ascorbic acid can optimize biomass allocation[36]. Similarly, Ren *et al.,* found that variations in the harvest index could be attributed to changes in biomass accumulation at different growth stages, which might explain why Kangaroo, despite its high biomass production, had a lower harvest index[37]. These studies reinforce the notion that harvest index responses to ascorbic acid are variety-dependent and are influenced by how efficiently each variety allocates biomass to grain production.

Table 7: Effect of Ascorbic Acid Concentrations on Harvest Index of Oat Varieties (%)

Varieties	Ascorbic acid concentrations (ppm) on Harvest index of Oat varieties (%)			
	0	100	200	300
ICARDA Short	52.165 a-c	51.969 a-c	50.787 bc	49.971 c
Kangaroo	44.072 d	41.437 d	42.479 d	41.879 d
ICARDA Tall	52.070 a-c	52.207 a-c	51.704 a-c	50.453 c
Possum	51.312 a-c	54.458 a	51.709 a-c	54.003 ab

The results showed by Mean. The same letter marks in this table represent non-significant differences at $p \leq 0.05$ according to Duncan's Multiple Range test and vice versa

CONCLUSION

This study demonstrates that ascorbic acid application improves the growth and yield of most oat varieties, particularly ICARDA Tall and Kangaroo, when applied at 300 ppm. However, ICARDA Short showed limited yield response to additional ascorbic acid, indicating that it can be effectively cultivated without the need for external ascorbic acid application. This makes ICARDA Short a more cost-efficient choice for farmers, as it eliminates the need for supplementary treatments while still delivering competitive yields. Tailoring ascorbic acid application based on the specific variety could help optimize both productivity and resource use.

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Conflict of interest

The author(s) don't have any conflict of interest.

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