



Impact of nitrogen and boric acid foliar spray on shelf life of eggplant

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ABSTRACT

A field experiment was conducted at the University of Gondar College of Agriculture Department of Horticulture, Shinta Horticultural Demonstration Site, to evaluate the effects of foliar application of different rates of urea (0, 0.25, 0.5, and 0.75g/l) and boric acid (0, 15, 30, and 45mg/l) on the field under irrigated conditions. Postharvest quality evaluations commenced on May 1st at the University of Gondar's Teda Campus situated in a sub-tropical highland climate characterized by low humidity and mild temperatures (10.5 to 25°C) during the dry season. Laboratory assessments were conducted under controlled room temperature and strict hygienic conditions to ensure accurate results. The combined foliar spray of 0.75g/l urea and 45mg/l boric acid significantly improved fruit firmness (15.5N), sweetness (12.1°Brix), and extended shelf life up to 11.07 days while reducing physiological weight loss (PWL). These findings suggest that foliar application of urea and boric acid is an effective and low-cost treatment for enhancing the postharvest quality and storage longevity of eggplant.

Key words: *Solanum melongena* L., fruit firmness, TSS, PWL, shelf life

INTRODUCTION

Eggplant (*Solanum melongena* L.), a member of the Solanaceae family, is an important vegetable crop widely cultivated in tropical and subtropical regions. It is valued for its nutritional composition, culinary versatility, and contribution to food and nutritional security. Eggplant is among the major vegetable crops cultivated worldwide, following crops such as potato, tomato, and cucumber in importance (Saha *et al.*, 14). Originally domesticated in Southeast Asia, its cultivation subsequently spread to the Mediterranean region, Africa, and the Americas. China and India are the leading eggplant-producing countries, while Bangladesh, Pakistan, and the Philippines are also important producers (Barchi *et al.*, 6). In addition to its nutritional value, eggplant contains bioactive compounds, including phenolics, flavonoids, and antioxidants, which contribute to its potential health-promoting properties. Traditionally, eggplant has also been associated with medicinal benefits, although the therapeutic effects of its consumption require further scientific validation.

Despite its economic and nutritional importance, eggplant production is constrained by several biotic and abiotic factors, including nutrient imbalance, water stress, unsuitable environmental conditions, and inadequate crop management. Eggplant has a relatively high nutrient requirement because of its prolonged growing period, extensive vegetative development, and continuous fruit production. Therefore, balanced nutrient management is essential

for achieving optimum plant growth, fruit yield, and quality. Macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) play important roles in plant development, while micronutrients are required in smaller quantities but are equally essential for various physiological and biochemical processes (Teixeira *et al.*, 17).

Nitrogen is a fundamental component of amino acids, proteins, nucleic acids, chlorophyll, and several enzymes involved in plant metabolism. Adequate nitrogen availability promotes vegetative growth, leaf development, photosynthetic activity, and fruit production. However, excessive or insufficient nitrogen application can adversely affect plant growth, nutrient-use efficiency, and fruit quality. Excessive nitrogen fertilization may also increase production costs and contribute to environmental pollution through nutrient leaching and gaseous losses. Therefore, efficient nitrogen management is necessary to maintain crop productivity while minimizing environmental risks.

Boron (B) is an essential micronutrient involved in cell wall formation, membrane stability, carbohydrate transport, pollen germination, pollen tube growth, and reproductive development (Ali *et al.*, 2). Adequate boron availability is particularly important during flowering and fruit formation because boron deficiency can impair pollen viability, reduce fruit set, and cause abnormal fruit development. Conversely, excessive boron application may result in toxicity and negatively affect plant growth. Thus, the application of boron at an appropriate concentration and growth stage is essential for improving crop performance and fruit

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quality. Previous studies have reported that foliar boron application can enhance fruit yield and quality attributes in eggplant (Ali *et al.*, 2).

Foliar nutrient application is an effective strategy for supplying essential nutrients directly to plant tissues. Compared with conventional soil application, foliar spraying may improve nutrient-use efficiency, facilitate rapid nutrient absorption, and help overcome nutrient deficiencies under conditions where soil nutrient availability is limited. The effectiveness of foliar fertilization depends on several factors, including nutrient concentration, spray timing, environmental conditions, leaf characteristics, and crop growth stage. The combined application of nitrogen and boron may produce complementary effects by improving vegetative growth, photosynthetic activity, reproductive development, and assimilate translocation towards developing fruits.

Postharvest quality is another important factor determining the marketability, consumer acceptance, and economic value of eggplant. Eggplant fruits are highly perishable and susceptible to moisture loss, surface dullness, softening, browning, and decay during storage. These changes reduce firmness, visual quality, and consumer acceptability, thereby limiting the storage and marketing period. Eggplant is also sensitive to chilling injury when stored at temperatures below the recommended range, which can accelerate surface pitting, browning, and tissue deterioration. Therefore, improving fruit quality at the preharvest stage through appropriate nutrient management may contribute to better postharvest performance.

Nutritional management can influence several characteristics associated with postharvest quality, including fruit firmness, dry matter accumulation, soluble solids content, tissue mineral composition, and physiological stability. Adequate nitrogen availability supports biomass production and fruit development, whereas boron may contribute to cell wall integrity and tissue strength. Consequently, the combined application of nitrogen and boron through foliar spraying may improve fruit quality and delay postharvest deterioration. However, the response to these nutrients depends on their concentration, interaction, application timing, and prevailing environmental conditions.

Although the effects of nitrogen and boron on crop growth and yield have been investigated, limited information is available regarding their combined influence on the postharvest quality and storage life of irrigated eggplant under the agroecological conditions of Central Gondar, Ethiopia. Developing a simple, affordable, and efficient nutrient-management

strategy could help farmers improve fruit quality, reduce postharvest losses, and extend the marketing period of eggplant.

Therefore, the present study was conducted to evaluate the effects of foliar applications of different concentrations of urea and boric acid on the postharvest quality and shelf life of eggplant grown under irrigated conditions in Central Gondar, Ethiopia.

MATERIALS AND METHODS

The experiment was conducted during the 2023/2024 dry season at the Shinta Horticultural Research Site, University of Gondar, Ethiopia (12°36'N, 37°28'; 2133 m.a.s.l.), on clay loam soil with a pH of 6.1, average temperatures ranging from 12.6°C -26.1°C, and an annual rainfall of 912 mm (Fig 1). The heirloom plant variety 'Black Beauty' recognized for its early maturity, spineless stems, and large purple fruits, was utilized. A factorial randomized complete block design with three replications tested 16 treatments combining four nitrogen levels, 0, 0.25, 0.5, and 0.75g/l, and four boric acid levels, 0, 15, 30 and 45mg/l (Al-Tufailli *et al.*, 3) on 5.6 m² plots spaced 70 cm × 40 cm. Seedlings were transplanted at the 3-5 leaf stage 10-15 cm tall, (Al-Tufailli *et al.*, 3). Foliar sprays of nitrogen and boric acid were applied three times at 30, 40, and 50 days, and 31, 41, and 51 days after transplanting, respectively, with 0.5mL Tween-20 per 100mL solution to improve adherence. Phosphorus fertilizer (300kg/ha TSP) was applied ten days post-transplant. Standard irrigation, weeding, and pest control were followed. Postharvest quality evaluations commenced on May 1st at the University of Gondar's Teda Campus, located in Gondar's subtropical highland climate. This period corresponds to the dry season, characterized by low humidity and mild temperatures ranging

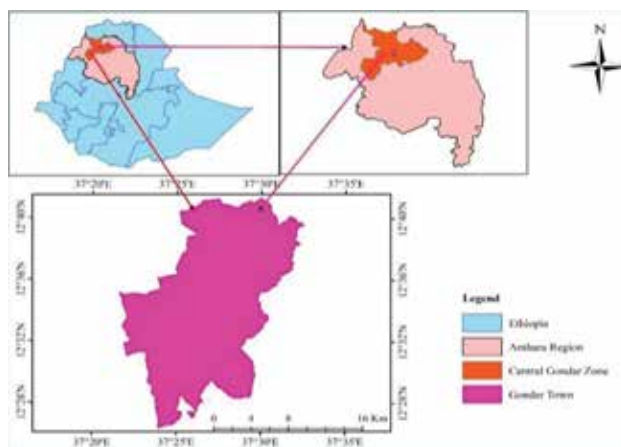


Fig. 1. Location map of the study area.

from 10.5 to 25°C. Laboratory assessments were conducted under controlled room temperature and strict hygienic conditions to ensure reliable and accurate results. Data were subjected to analysis of variance (ANOVA) using SAS Statistical Software (version 9.4), and significant treatment means were separated by Duncan's multiple range test (DMRT) at 5% level of significance (Gomez and Gomez, 8).

RESULTS AND DISCUSSION

Average fruit length (cm), the analysis of variance revealed that the interaction between foliar-applied boric acid and nitrogen had a highly significant effect on the average fruit length of eggplant (Table 1). The maximum fruit length (14.10 cm) was recorded in plants treated with 0.75g/l nitrogen and 45mg/L boric acid, whereas the minimum fruit length (7.17 cm) was observed in the untreated control group (Table 1). Increased fruit size with higher levels of boron and nitrogen application (Bana *et al.*, 4; Ali *et al.*, 2). The enhancement in fruit length can be attributed to the role of boron in promoting nutrient translocation and cellular development during fruit growth (Saini *et al.*, 14). The contribution of nitrogen to the accumulation of assimilates within developing fruits (Acedo and Benitez, 1). The average fruit width (cm), the analysis of variance revealed that the average fruit width of eggplant was highly significantly influenced by the interaction between foliar-applied boric acid and nitrogen (Table 1). The greatest fruit width (18.60 cm) was obtained from plants treated with 45mg/l boric

acid and 0.75g/l nitrogen, whereas the narrowest fruits (ranging from 7.74 to 9.18 cm) were observed at lower application rates or in the absence of foliar treatments (Table 1). These results are consistent with those of (Bana *et al.*, 4; Haider *et al.*, 8), who reported increased fruit diameter in response to boron application, and with the findings of (Ali *et al.*, 2), who observed similar effects with nitrogen supplementation. The enhancement in fruit width may be attributed to improved photosynthetic efficiency and carbohydrate accumulation (Sun *et al.*, 15), enhanced nutrient mobilization supporting rapid cell expansion, and the fundamental role of nitrogen in protein synthesis and chloroplast development, all of which contribute to fruit enlargement (Fathi *et al.*, 7).

Fruit Firmness, the analysis of variance indicated that the fruit firmness of eggplant was highly significantly influenced by the interaction between foliar-applied boric acid and nitrogen (Table 2). The highest fruit firmness (15.58 N) was observed in plants treated with 45mg/l boric acid and 0.75g/l nitrogen, while the lowest firmness (7.41 N) was recorded in untreated control plants (Table 2). This treatment combination resulted in a 110.26% increase in fruit firmness compared to the control, suggesting a synergistic effect of boron and nitrogen on nutrient uptake and utilization. Increased firmness with elevated nitrogen levels (Ali *et al.*, 2). Boron enhances fruit firmness by supporting cell wall and membrane integrity, promoting cell division, facilitating carbohydrate metabolism, and

Table 1: Interaction effects of foliar application of urea and boric acid on eggplant fruit length and width.

Urea (g/l)	Boric acid (mg/l)	0 mg/l	15 mg/l	30 mg/l	45 mg/l
Average fruit length (cm)					
0.00		10.01 ^c	8.80 ^c	8.93 ^c	15.80 ^b
0.25		8.90 ^c	9.25 ^c	8.32 ^c	9.71 ^c
0.50		7.74 ^c	9.05 ^c	8.19 ^c	9.18 ^c
0.75		15.98 ^b	8.90 ^c	9.14 ^c	18.60 ^a
LSD (0.05)					1.09 ^{***}
CV (%)					9.59
Average fruit width (cm)					
0.00		10.01 ^c	8.80 ^c	8.93 ^c	15.80 ^b
0.25		8.90 ^c	9.25 ^c	8.32 ^c	9.71 ^c
0.50		7.74 ^c	9.05 ^c	8.19 ^c	9.18 ^c
0.75		15.98 ^b	8.90 ^c	9.14 ^c	18.60 ^a
LSD (0.05)					1.63 ^{***}
CV (%)					3.73

Where: NS = non-significant; * = Significant (P < 0.05); ** = highly significant (P < 0.01); means followed by the same letter(s) in a column are not significantly different at P < 0.05 (DMRT).

Table 2: Interaction effect of nitrogen and boric on fruit firmness (N).

Urea (g/l)	0 mg/l	15 mg/l	30 mg/l	45 mg/l	LSD (0.05)
0	7.41 ^d	8.15 ^{dc}	8.71 ^c	10.73 ^b	
0.25	8.22 ^{dc}	8.95 ^c	8.93 ^c	8.53 ^c	
0.5	8.05 ^{dc}	8.68 ^c	8.64 ^c	8.61 ^c	
0.75	11.36 ^b	8.63 ^c	8.53 ^c	15.58 ^a	1.46 ^{***}
CV (%)	11.27				5.71

Where: NS = Non-significant; * = Significant ($P < 0.05$); ** = highly significant ($P < 0.01$); means followed by the same letter(s) in a column are not significantly different at $P < 0.05$ (DMRT).

aiding in sugar transport. It also forms structural complexes with calcium in the cell wall, contributing to mechanical strength. Additionally, nitrogen increases the water content of the protoplasm, which further contributes to fruit firmness (Ali *et al.*, 2).

Total soluble solids (TSS) ($^{\circ}$ Brix), the analysis of variance revealed that total soluble solids (TSS) in eggplant fruits were highly significantly affected by the interaction of foliar-applied boric acid and nitrogen (Table 3). The highest TSS value (12.10 $^{\circ}$ Brix) was obtained from plants treated with 45 mg/l boric acid combined with 0.75g/l nitrogen, whereas the lowest TSS (5.02 $^{\circ}$ Brix) was recorded in untreated plants (Table 3), indicating a 141.04% increase. Increased TSS following boron foliar applications (Bana *et al.*, 4) and enhanced fruit quality in strawberries treated with boric acid. Additionally, elevated nitrogen levels were associated with increased TSS (Ali *et al.*, 2). The observed enhancement in TSS is attributed to boron's role in facilitating the translocation of sugars and carbohydrates from leaves to fruits, thereby promoting sugar accumulation (Haleema *et al.*, 9), a mechanism supported by similar findings in tomatoes (Khatri *et al.*, 10).

Shelf life and physiological weight loss (%), the interaction between foliar applications of boric acid

Table 3: Interaction effect of nitrogen and boric acid on total soluble solids ($^{\circ}$ Brix).

Urea (g/l)	0 mg/l	15 mg/l	30 mg/l	45 mg/l	LSD (0.05)
0	5.02 ^e	6.60 ^{cd}	6.82 ^{dc}	9.72 ^b	
0.25	6.70 ^{cd}	6.04 ^{de}	6.48 ^{cd}	7.54 ^c	
0.5	5.85 ^{de}	6.76 ^{cd}	6.52 ^{dc}	6.14 ^d	
0.75	8.79 ^b	6.45 ^{cd}	6.64 ^{dc}	12.10 ^a	0.79 ^{***}
CV (%)					9.79

Where: NS = Non-significant; * = Significant ($P < 0.05$); ** = highly significant ($P < 0.01$); means followed by the same letter(s) in a column are not significantly different at $P < 0.05$ (DMRT).

and nitrogen significantly affected the physiological weight loss of eggplant fruits during storage. The effect was highly significant on the 4th and 12th days and significant ($P < 0.05$) on the 8th day (Table 4). 4th Day of Storage, on the fourth day, the maximum physiological weight loss (10.70%) was recorded in fruits from untreated plants. In contrast, the minimum weight loss (ranging from 6.01% to 6.59%) was observed in fruits treated with a combination of 45mg/l boric acid and 0.75g/l nitrogen (Table 4). This indicates that early postharvest weight loss can be significantly reduced through combined foliar nutrient application. 8th Day of Storage, on the eighth day, a similar trend continued, with untreated fruits showing greater weight loss (16.87%). The lowest weight loss (9.2%) was recorded in fruits treated with 45mg/l boric acid and 0.75g/l nitrogen (Table 4), demonstrating the persistent benefit of the combined treatment in slowing moisture loss during intermediate storage. 12th Day of Storage, by the twelfth day, physiological weight loss peaked in untreated fruits, reaching 56.40%. In contrast, fruits that received combined applications of boric acid and urea exhibited substantially lower

Table 4: Physiological weight loss (%) of eggplant at different storage days as affected by foliar application of nitrogen and boric acid.

Urea (g/l)	Boric acid (mg/l)	4 th Day	8 th Day	12 th Day
0.00	0	10.70 ^a	16.87 ^a	56.40 ^a
	15	7.50 ^b	14.00 ^{bc}	39.10 ^b
	30	6.82 ^{bc}	13.11 ^{bc}	40.70 ^b
	45	6.42 ^{bc}	12.70 ^{bc}	31.30 ^d
0.25	0	6.92 ^{bc}	12.20 ^{bc}	36.60 ^{bc}
	15	7.43 ^b	14.70 ^{ab}	37.10 ^{bc}
	30	7.01 ^{bc}	12.30 ^{bc}	38.70 ^b
	45	6.89 ^{bc}	12.10 ^{bc}	37.90 ^{bc}
0.50	0	6.92 ^{bc}	12.64 ^{bc}	40.40 ^b
	15	6.82 ^{bc}	12.80 ^{bc}	37.50 ^{bc}
	30	7.42 ^b	11.60 ^c	38.80 ^b
	45	7.09 ^{bc}	12.70 ^{bc}	9.24 ^b
0.75	0	6.59 ^{bc}	13.70 ^{bc}	37.90 ^{bc}
	15	7.40 ^b	11.90 ^{bc}	39.03 ^b
	30	7.13 ^{bc}	13.20 ^{bc}	36.31 ^{bc}
	45	6.01 ^c	9.20 ^d	31.00 ^d

LSD (5%): *

CV (%): 4th Day, 8.9%, 8th Day, 11.6%, and 12th Day, 12.7%

Note: Means followed by the same letter(s) in a column are not significantly different at $P < 0.05$ according to DMRT. Significant at $P < 0.05$; ** = highly significant at $P < 0.01$; NS = Not Significant.

losses (between 31.00% and 31.60%) (Table 4). These results strongly suggest that the treatments played a critical role in preserving fruit quality over extended storage periods. Overall, the combined foliar application of boric acid and nitrogen was effective in minimizing physiological weight loss in eggplant fruits throughout the storage period. Boron application reduced spoilage and improved skin firmness in eggplants (Zhao *et al.*, 18). Extended shelf life in tomatoes following boron treatment (Xu *et al.*, 17). The observed benefits are likely due to boron's role in maintaining cell wall structure through pectin cross-linking (Ankita *et al.*, 3) and enhancing membrane stability. In addition, boron is known to promote calcium uptake and increase vitamin C content, both of which strengthen membrane integrity and reduce respiration rates-factors that collectively contribute to prolonged shelf life (Milagres *et al.*, 12).

The study demonstrated that foliar application of urea and boric acid, particularly at concentrations of 0.75mg/l and 45mg/l, respectively, significantly enhances the postharvest quality and shelf life of eggplant. This treatment improved fruit firmness, increased total soluble solids, and reduced postharvest weight loss. Therefore, it can be recommended as an effective strategy to extend the marketability and storage duration of eggplant in Gondar and similar agro-ecological regions. However, further research across different locations and seasons is necessary to confirm the consistency and broader applicability of these findings. As a researcher, we would say that while higher concentrations of boric acid (40mg/l) and urea (0.75g/l) can promote healthier eggplant growth, leading to stronger plants and better fruit quality, there's a threshold where too much could be harmful. Excessive amounts could lead to toxicity or disrupt nutrient balance, which would ultimately reduce growth and quality. The key takeaway is that it is crucial to find a balanced approach-optimizing these nutrients can improve both plant performance and shelf life, but careful monitoring is necessary to avoid negative impacts.

AUTHOR'S CONTRIBUTION

Data collection and analysis, designing the research methods, managing software tools, and drafting the initial manuscript (GM); Methodology, analyzing the data, applying relevant software, and overseeing parts of the research process. AT also contributed to writing and revising the manuscript (AT); Data collection and method development, supervising the process, validating results, and contributing to both the writing and editing of the paper (SK).

DECLARATION

We, the authors, confirm that we have no competing financial or personal interests that could have influenced the findings or conclusions presented in this work

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