frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 16 April 2025
DOI 10.3389/fsufs.2025.1543368

Moringa leaf extract as a natural alternative for the growth, yield, and yield components of onion (*Allium cepa* L.) varieties in central Gondar, North Ethiopia

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RECEIVED 11 December 2024
ACCEPTED 25 March 2025
PUBLISHED 16 April 2025

CITATION
Marie G, Tagele A and Kinfu S (2025) Moringa leaf extract as a natural alternative for the growth, yield, and yield components of onion (*Allium cepa* L.) varieties in central Gondar, North Ethiopia.
Front. Sustain. Food Syst. 9:1543368.
doi: 10.3389/fsufs.2025.1543368

Introduction: Onion (*Allium cepa* L.) is an important bulb crop. These allium species grow in most areas of central Gondar. However, lack of researcher based recommendation of moringa leaf extract (MLE) for onion production and improved varieties of onion are some of the problems.

Methods: Randomized complete block design with 3×5 combinations of three varieties (Nafis, Adama Red and Bombay Red) and four different levels of MLE concentration (0, 2, 4, 6% and one level of kinetin (2mg/l)) with three replications were used.

Results and discussion: Varieties showed significant ($p < 0.05$) variation on most growth, yield and quality parameters except dry matter. The highest leaf number (14.03), bulb diameter (7.06cm), TSS (13.99 °Brix) and late 80% days to maturity (118.02 days) were recorded from Nafis while the lowest was recorded from Bombay Red. Foliar application of MLE (6%) gave the highest leaf number, leaf diameter, bulb diameter, dry matter, TSS and was late to mature compared to control. Nafis variety coupled with spray of MLE (6%) resulted in significantly higher plant height, bulb weight and marketable yield (90 cm, 96.22 g, and 23.13 t ha^{-1}) followed by Nafis variety sprayed with MLE (4%). The partial budget analysis revealed that Nafis variety sprayed with MLE (6%) resulted in yield increment which does not compensate for the increased cost. In addition, MRR observed on Nafis variety sprayed with MLE (4%) was above the acceptable range. Hence, it can be concluded that Nafis variety combined with foliar application MLE (4%) can enhance the growth and productivity of onion.

KEYWORDS
MLE, biostimulant, kinetin, growth, onion yield

1 Introduction

Onion (*Allium cepa* L.) belongs to the family Alliaceous, and it originated in Central Asia, between Turkmenistan and Afghanistan over 5,000 years ago (Bagali et al., 2012; Shultz, 2010). Currently, it is cultivated in tropical and subtropical parts of the world in more than 170 countries (Addai and Anning, 2015). In terms of global production volume, it is the second most important vegetable after tomato (Acharya and Shrestha, 2018) with a global total annual production of 110.6 million tons in 2022 (FAOSTAT, 2023). In addition to being rich in minerals, carbohydrates, proteins, and vitamin C, it is also high in sulfur-containing compounds that are responsible for pungent odors and numerous health benefits (Trivedi and Dhumal, 2013). It contains antioxidants that keep lifestyle-related diseases in check; thus, they are a vital component of a balanced diet (Ouyang et al., 2018). Thus, the achievement of food and nutritional security as well as increased farm revenues for onion farmers depends heavily on the high production and upkeep of high-quality bulb onions (Kiura et al., 2021).

Ethiopia's diversified agro-climatic conditions are suitable for the production of onion (Dessalegn et al., 2006). It is a cool season crop that has some frost tolerance but is best adapted to a temperature range between 13 and 24°C (Limeneh, 2021). However, the best growing altitude for onions under Ethiopian conditions is between 700 and 1800 m above sea level (Dessalegn and Aklilu, 2003). Its area coverage, production, and productivity of onion are estimated at 38,952.58 ha, 3,460,480.88 t, and 88.84 t ha^{-1}, respectively, and this is much lower than the global averages, demanding immediate productivity improvement. The crop production and productivity in the 2020/2021 main cropping season in central Gondar Zone were 14,770.46 t and 10.29 tha^{-1}, respectively, which were also below the country's average (CSA, 2022).

Generally, the production and productivity of onion in the study area and Ethiopia at large is very low. To tackle this problem, the Ethiopia Institution of Agricultural Research (EIAR) did different variety improvement programs and released improved onion varieties, namely, Adama Red, Bombay Red, Nasik Red, and Nafis (Gebregeorgis et al., 2020).

Onion production in Ethiopia is facing numerous problems, which contribute to the low level of production and productivity as compared to its potential (Koye et al., 2022; Tadesse et al., 2021). This is due to use of old varieties, limited quality seed, pest disease, and others (Chandini Kumar et al., 2019). To tackle this problem, the Ethiopia Institution of Agricultural Research (EIAR) did different variety improvement programs and released improved onion varieties, namely, Adama Red, Bombay Red, Nasik Red, and Nafis, and the use of these improved varieties improved the productivity of onion in recent years (Gebregeorgis et al., 2020).

The use of plant growth regulators (PGRs) is also one of the easiest methods to enhance onion productivity (Chaurasiy et al., 2014). These compounds occur naturally in plants, and when applied externally in small quantities, they promote, inhibit, or modify the physiological processes of crops (Yasmeen et al., 2012). Moringa leaf extricate (MLE) may be one of the plant extracts that is considered an ecologically inviting and secure biostimulant since it contains numerous useful bioactive compounds, macro- and micronutrients, minerals, plant hormones vital amino acids, and vitamins (Ahmad El-Sohaimy et al., 2015; Yaseen and Takácsné Hájos, 2020). Fresh Moringa leaf juice contains natural zeatin, one of the cytokinin group's active plant hormone components (Mohammed et al., 2014). MLE is also considered an alternative to inorganic fertilizer and an effective biostimulant to reduce plant stress (drought and salinity) of many crops (Lucini et al., 2015; Rassizadeh et al., 2021).

Moringa trees are present in ample amounts without being used for the enhancement of crop production. The recent attention given to moringa leaf extract can be attributed to its use as a cheap and organic alternative to cytokinin (Mona, 2013). It has been utilized as organic fertilizer for different crops including tomatoes (Culver et al., 2017), peppers (Matthew, 2017), lettuce (El-saady et al., 2020), garlic (Hegazi et al., 2016), and onion (H. Rehman and Basra, 2010). However, there is very limited information in the study area on the use of Moringa leaf extract as an organic fertilizer and its interaction with onion varieties. The aim of this research was to study the effects of different concentrations of moringa leaf extracts (MLEs) on the growth, yield, and yield components of onion varieties.

2 Materials and methods

2.1 Description of the study area

The experiment was conducted at the Shinta Horticultural Research and Demonstration site, College of Agriculture and Environmental Science, University of Gondar, central Gondar zone, Ethiopia. The experimental field is located at 12′0 36′ 0"N latitude, 37′0 28′0″E longitude, and an altitude of 2,133 m.a.s.l. The soil of the experimental field is clay loam with a pH of 6.1 (Tamiru, 2019; Tegegne et al., 2020). The experimental area has a unimodal rainfall distribution pattern with the main rainy season with a total mean annual rainfall of 1240 mm (Gebregeorgis et al., 2020).

2.2 Description of the experimental materials

The onion varieties used in this experiment were Bombay red, Adama red, and Nafis, which were collected from the Melkasa Agricultural Research Center. These varieties differ in their skin color (dark red, medium red, and highest red), bulb size (60–100 g), leaf arrangement (erect and medium erect), and days of maturity (90–130 days). The agronomic and quality characteristics of these three onion varieties are described in Table 1.

2.3 Treatments and experimental design

The treatments consist of the combination of three onion varieties (Bombay Red, Adama Red, and Nafis) and three different concentration levels of moringa leaf extract (MLE) (2, 4, and 6%), kinetin (2 mg/L) as positive control (Basra and Lovatt, 2016), and tap water. This field experiment was carried out in a randomized complete block design (RCBD) with three replications.

2.4 Preparation of moringa leaf extract

Matured *Moringa oleifera* leaves were collected from the Metema area, North West Ethiopia, and their chemical composition is indicated in Table 2. The preparation of MLE was based on the method explained by Vongsak et al. (2013). In brief, moringa leaves were air-dried under shade for 2 weeks, then ground into a powder. Next, maceration was performed by mixing 1 kg moringa powder with 2 liters of ethyl alcohol (80% aq.) for 72 h at room temperature. After that, the extract was purified by filtering twice through the Whatman filter paper. After purification, the crude extract was prepared by evaporating the alcohol from the extract using a rotary evaporator. The concentrations were prepared by diluting 20 g, 40 g, and 60 g of the crude extract in 980 mL, 960 mL, and 940 mL of distilled water, respectively, to achieve final concentrations of 2, 4, and 6%, respectively.

TABLE 1 Features of improved onion varieties.

Onion cultivar	Maturity (days)	Bulb color	Bulb shape	Bulb size (g)	Bulb yield (Q ha^{-1})
Adama Red	120–130	Dark red	Flat glob	65–80	350
Bombay Red	90–110	Light red	Flat glob	85–90	300–400
Nafis	100–115	Red	Glob	85–100	380

Source: HARC (Humera Agricultural Research center) (2018).

TABLE 2 Chemical composition of moringa leaf powder.

Chemical composition in 10 g dry weight	Amount
Crude protein (g)	2.38
Carbohydrate (g)	3.63
Nitrogen (%)	38.1
Potassium (ppm)	3169.51
Phosphorus (ppm)	1601.3
PH	6.03
Electrical conductivity (mS/cm)	11.83

2.5 Application of moringa leaf extracts

Moringa leaf extract (MLE) with concentrations of 2, 4, and 6%, kinetin (2 mg/L), and tap water for the control plots were prepared. The solutions were directly sprayed by using a hand sprayer on the plant four times, at 2-week intervals starting from 2 weeks after transplanting. The spraying of MLE and kinetin was done late in the afternoon. During each spraying session, calibration of the amount of solution required was done using water. The first and second spraying sessions used 6 liters of water per plot, the third spraying session used 7 liters of water per plot, and the last spraying session used 8 liters of water per plot.

2.6 Nursery and field management

The seedlings of each onion variety were prepared on a 1 m × 10 m well-prepared seed bed as per the procedure described by Ketema et al. (2013). The seedlings were managed in a nursery until they became ready for transplanting to the main experimental area. Before transplanting, 45 plots having a size of 2 m × 1.2 m in double rows of 40 cm × 20 × 10 between ridges, rows on the ridge, and plants in rows, respectively, were prepared. Transplanting of onion seedlings to the field was done 45 days after sowing following the recommended method of Dessalegn and Aklilu (2003). Irrigation water was applied after transplanting regularly using the furrow irrigation method at 5-day intervals in the early stages and extended to 7 days in the later growth stages until 15 days prior to harvest.

2.7 Data collection and measurements

Data on some growth parameters were recorded without lifting the plants which means that before the leaf became yellow, dry, and collapse or shrink at the neck region, the measurement of growth parameters was performed, while for other parameters that need destructive sampling, previously tagged plants were lifted and the necessary data were recorded.

Plant height (PH) was measured by straightening all the leaves upward in a bunch and measuring the height from the soil level to the green tip of the longest leaf randomly from 10 plants as indicated in the study by Nourbakhsh and Cramer (2022).

Number of leaves per plant was counted as living leaves with more than half of their area having green tissue from ten randomly sampled plants as indicated in the study by Nourbakhsh and Cramer (2022).

Days to maturity (DM) was calculated by counting the number of days from seed emergence to the time when 80% of plants' foliage collapsed and became yellow as well as shrunk at the neck region (Wassie et al., 2022).

Bulb weight (g) was recorded from ten randomly selected plants from the net plot after harvesting as indicated in the study by Dessalegn and Aklilu (2003).

Bulb diameter (cm) at harvest was computed by measuring the diameters in the middle of ten randomly selected bulbs in each plot using a caliper (Dessalegn and Aklilu, 2003).

Marketable bulb yield was calculated following the description of Dessalegn and Aklilu (2003) by discarding physiologically disordered, rotten, and small-sized (<20 g) bulbs.

Bulb dry matter content (%): Mature bulbs were chopped and from which 200 g of sample was dried in an oven at 70°C to a constant weight and the DMC (%) was calculated by using the formula as described in the study by Derajew et al. (2017):

$$\text{DMC}(\%) = \frac{\text{Sample oven dry weight}(\text{g})}{\text{Sample fresh weight}(\text{g})} \times 100$$

Total soluble solid content (TSS) was determined at harvesting time from 12 randomly selected bulbs using the procedures described by Waskar et al. (1999). The juice of the onion bulb was extracted, and TSS was determined by using a hand refractometer (Erma Japan) in the 0 to 32 percent range, and the values were expressed as °Brix.

Data were subjected to the analysis of variance (ANOVA) by using SAS 9.4 (SAS Institute Inc, 2013) computer software. Two-way analysis of variance (ANOVA) was performed using a generalized linear model to determine the effects of MLE concentrations on the growth, yield, and fruit quality of onion varieties. Treatment means were separated by the least significant difference (LSD) method at a 5% level of significance.

2.8 Partial budget analysis

The partial budget analysis was performed using CIMMYT methodology (CIMMYT, 1988). The cost of MLE and kinetin hormone, labor cost for foliar application of MLE, and marketable onion market price were used for the cost–benefit analysis.

3 Results and discussion

3.1 Plant height

The interaction between onion varieties and moringa leaf extract (MLE) concentrations had a significant ($p < 0.05$) effect on plant height of onion (Figure 1). The result showed that plants of Nafis variety treated with MLE (6%), which was statistically at par with Nafis variety treated with MLE (4%) and kinetin (2 mg/L) as well as Adama Red variety treated with MLE (6 and 4%) and kinetin (2 mg/L), recorded the tallest plant (90.00 cm). Similarly, the shortest plant (39.34 cm) was recorded on Nafis variety with sprays of tap water followed by Bombay Red and Adama Red varieties sprayed with tap water. The result tends to show an increment in plant height of each variety with an increase in the concentrations of MLE sprayed on plants.

This increment of plant height with higher concentrations of MLE could be attributed to the presence of higher concentrations of macro- and micronutrients such as calcium, magnesium, potassium, zinc, manganese, and different antioxidants as well as plant hormones such as gibberellic acid, IAA, and zeatin, which can improve the vegetative growth and production of the plant (Rady et al., 2013; Rehman et al., 2017; Yasmeen et al., 2012). The current result is in line with the finding of Abebe and Biniam (2018) who reported the tallest onion plant (89.18 cm) with combined foliar sprays of 4% concentration of MLE and 4% alfalfa. Mohamed et al. (2022) also reported taller plants with higher concentrations of moringa compared to lower concentration and the control. Furthermore, Muhammed et al. (2013) reported the highest effect on onion plant height from MLE at a concentration of 50% (1:2) with twice application. Ali et al. (2024) also observed taller plants with applications of 6% MLE on okra.

3.2 Number of leaves per plant

The number of leaves per plant of onion was significantly ($p < 0.05$) affected by MLE concentration levels, whereas the main effect of varieties and the interaction of MLE and varieties did not have a significant ($p > 0.05$) effect (Table 3). Generally, the number of leaves per plant increased with increment of MLE concentrations. The result showed that onion plants sprayed with MLE (6%) had a significantly higher number of leaves than kinetin (2 mg/L), MLE (4 and 2%), and the control. Moreover, all treatments showed a statistically higher number of leaves than the control. The highest leaf number (17.45) was recorded on plants sprayed with MLE (6%) followed by plants sprayed with kinetin (2 mg/L) and MLE (4%), whereas the lowest number of leaf per plant (7.33) was obtained from the control followed by spray of MLE (2%).

The increase in the number of leaves with higher concentrations of MLE might be due to the fact moringa is the source of protein, stimulating hormone, and macro- and micronutrients, all of which are responsible for growth, cell division, and metabolism of the plant (Mazrou, 2019; Mehmood et al., 2021). Moringa is one the most nutritious plants which is rich in macronutrients and micronutrients such as potassium, calcium, magnesium, iron, copper, total phenols, and proteins in the leaves (Hekmat et al., 2015). It is also an excellent source of phytonutrients such as carotenoids, tocopherols, and ascorbic acid (Saini et al., 2014). The findings of the current results are in accordance with Muhammed et al. (2013) who reported that the highest number of leaves per plant of onion at 5, 7, and 9 weeks after transplanting with foliar application of MLE (50%) and twice supplying at a 3-week interval, whereas the lowest number of leaf per plant recorded from untreated plots (control).

3.3 Days to maturity

The analysis of variance indicated that the day to maturity of onion was significantly ($p < 0.05$) influenced by the main effect of moringa leaf extract concentration level (Table 3). The study showed that days to maturity increased with increment in MLE concentrations. Spraying of MLE (6%), MLE (4%), and kinetin (2 mg/L) had statistically similar effect on days to maturity and resulted in statistically longer days to maturity than MLE (2%) and the control. Moreover, onion plants sprayed with MLE (2%) showed statistically longer maturity than the control. The earliest maturity (92.73 days) was recorded from control plants, while late maturity

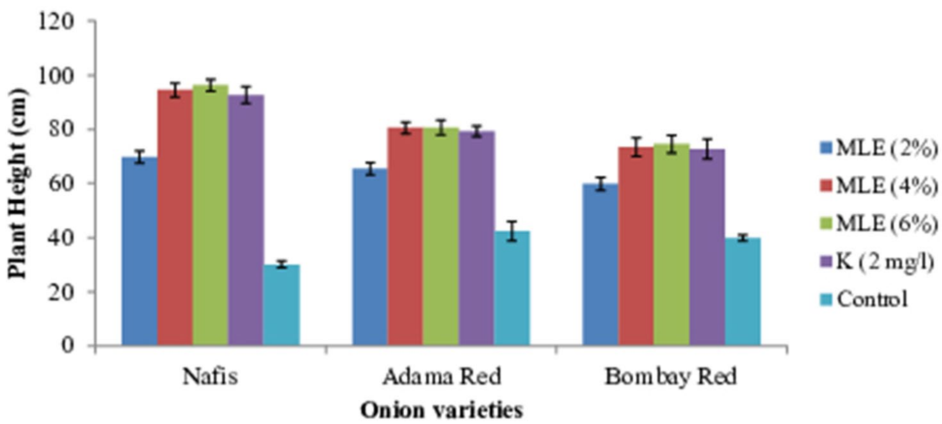

FIGURE 1
Interaction effects of moringa leaf extract concentration and variety on the plant height (cm) of onion.

TABLE 3 Effects of moringa leaf extract (MLE) concentration and variety on leaf number per plant and days to maturity of onion.

Treatments	Leaf number per plant	Days to maturity
MLE conc.		
MLE (2%)	11.13 ± 0.55[c]	107.33 ± 2.82[b]
MLE (4%)	16.20 ± 0.73[b]	121.78 ± 1.83[a]
MLE (6%)	17.45 ± 0.69[a]	122.38 ± 1.81[a]
K (2 mg/L)	16.28 ± 0.71[b]	121.38 ± 1.73[a]
Control	7.33 ± 0.35[d]	92.73 ± 0.52[c]
LSD (0.05)	0.86	3.81
Varieties		
Nafis	14.03 ± 1.15	118.02 ± 3.72a
Adama Red	13.76 ± 1.14	111.25 ± 3.07[b]
Bombay Red	13.24 ± 1.09	110.09 ± 3.06[b]
LSD (0.05)	NS	2.95
CV (%)	6.53	3.49
MLE conc.	***	***
Variety	NS	***
MLE conc. X variety	NS	NS

Means followed by the same letter(s) in columns are not significantly different at 5% level of significance; NS, non significant; ***, significant at $p \leq 0.001$; K, kinetin; LSD, least significant difference; CV, coefficient of variation.

(122.38 days) was recorded from foliar application of MLE (6%). Compared to the control, onion plants sprayed with MLE (6%), MLE (4%), and kinetin (2 mg/L) delayed the maturity by approximately 29 days, 28 days, and 29 days, respectively.

The increment in days to maturity at higher concentrations of MLE might be due to the presence of considerable amount of growth enhancer hormones such as zeatin, which lead to delayed leaf senescence of onion (Anwar et al., 2007; Rehman and Basra, 2010). The current result is consistent with Abebe and Biniam (2018) who reported that the earliest days to mature (110.3 days) were recorded from control which was significantly different from other treatments, whereas late days to mature (126 days) were recorded from the interaction concentration level on 3% alfalfa leaf extract concentration with 4% moringa leaf extract concentration.

The analysis of variance indicated that day to 80% maturity was significantly ($p < 0.05$) influenced by the main effect of variety; however, it was not significantly ($p > 0.05$) affected by the interaction of moringa leaf extract concentration level and variety (Table 3). Bombay Red variety was the earliest (110.09 days) variety to mature, whereas Nafis variety, which was statistically at par with Adama Red variety, took the longest days (118.02 days) to mature. Bombay Red variety matured approximately 8 days and 7 days earlier than Nafis and Adama Red varieties, respectively.

The variation in maturity among onion varieties might be due to the variation in the response to their surroundings (Kahsay et al., 2014; Ketema et al., 2013). The findings of this study are in line with Alemu et al. (2022) who reported variation in maturity date among onion varieties, in which Nafis variety took longer days to mature with wider spacing. Similarly, Tesfalgn and Wassu (2015) reported that Bombay Red reached maturity far earlier than Adama Red.

3.4 Bulb weight

The analysis of variance showed that the interaction effect of moringa leaf extract concentration and variety was significant ($p < 0.05$) on bulb weight of onion (Figure 2). Application of MLE resulted in significantly higher bulb weight of onion than the untreated control in the three varieties. Adama Red and Bombay Red varieties without MLE application had significantly heavier bulbs than Nafis variety without MLE application. Nafis variety combined with MLE (6 and 4%) and kinetin (2 mg/L) had a similar effect and resulted in statistically heavier bulbs than the other treatment combinations. The heaviest bulb (96.22 g) was recorded from Nafis onion variety combined with MLE (6%) followed by Nafis combined with MLE (4%) and kinetin (2 mg/L), while the lightest bulb (30.06 g) was recorded on Nafis onion variety without MLE application.

The increase in bulb weight with higher concentrations of MLE and kinetin on Nafis variety could probably be due to the higher nutrient absorption and photosynthesis efficiency as well as increased production of assimilate and translocation to the bulb (Nasir et al., 2016). This finding is in line with the study of Yaseen and Takácsné Hájos (2020) who reported the highest bulb weight from a combination of foliar application of 4% with large onion set size followed by 6 and 2% foliar application of MLE with large onion set size. Hegazi et al. (2016) also observed the heaviest bulb of garlic with a higher rate of MLE compared to lower rates and without MLE application.

3.5 Marketable bulb yield

The interaction between moringa leaf extract concentrations and variety had a significant ($p < 0.05$) effect on marketable bulb yield of onion (Table 4). The result showed that the marketable bulb yield ranged between 23.13 t ha^{-1} on Nafis variety sprayed with MLE (6%) and 4.13 t ha^{-1} on Nafis variety without MLE spray. Generally, regardless of the variety, all MLE and kinetin spray treatments showed significantly higher marketable bulb yield than the control. Nafis variety sprayed with MLE (6%), MLE (4%), and kinetin (2 mg/L) resulted in statistically similar bulb yields, and they had significantly higher marketable yields than the other treatments and the control. In addition, Nafis Adama Red and Bombay Red varieties showed similarity in marketable bulb yield without MLE spray treatments. The highest marketable bulb yield (23.13 t/ha) was recorded from Nafis variety combined with MLE (6%), while the lowest marketable bulb yield (4.13 t/ha) was recorded from Nafis variety without spray.

The higher marketable bulb yields with application of MLE and kinetin hormone and Nafis variety might be due to the presence of higher protein and carbohydrate contents in moringa leaf extracts (Muhammed et al., 2013) as well as genetic variation among onion varieties. The increased number of leaves that resulted from using MLE might be related to the photosynthetic apparatus efficiency, which increased the number of bulbs that are produced (Muhammed et al., 2013). The current result is in line with Abebe and Biniam (2018) who reported the maximum marketable bulbs from the combined application of 4% concentration level of alfalfa leaf extract with 4% concentration level of moringa leaf extract, which was significantly different from the untreated onion. Alemu et al. (2022) also observed variation in the marketable bulb yield of onion among varieties, the highest being recorded from Nafis variety.

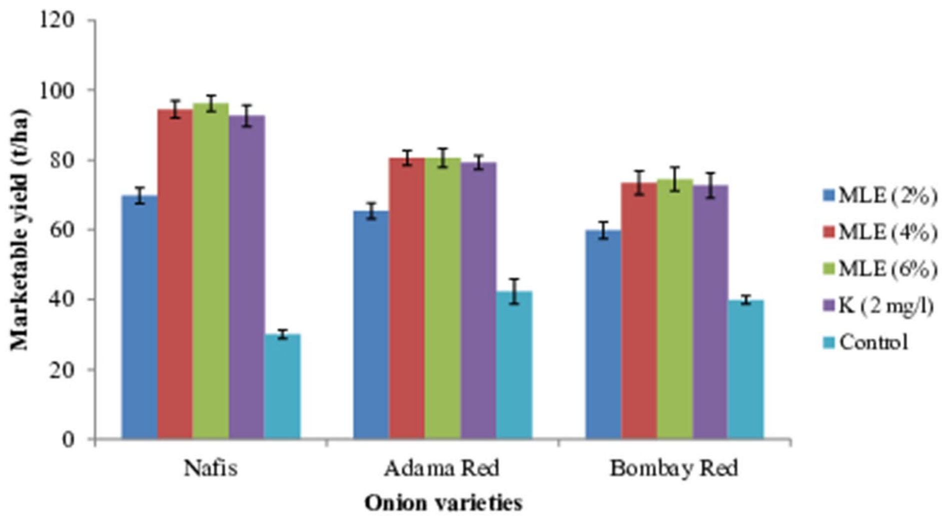

FIGURE 2
Interaction effects of moringa leaf extract (MLE) concentration and variety on the bulb weight (g) of onion.

TABLE 4 Interaction effects of moringa leaf extract (MLE) concentration and variety on the marketable bulb yield (t ha^{-1}) of onion.

Treatments	Variety		
MLE conc.	Nafis	Adama Red	Bombay Red
MLE (2%)	13.95 ± 0.39^{e}	13.08 ± 0.25^{ef}	11.10 ± 0.41^{f}
MLE (4%)	22.67 ± 0.50^{a}	18.16 ± 0.58^{bc}	16. 53 ± 0.40^{cd}
MLE (6%)	23.13 ± 0.58^{a}	19.07 ± 0.49^{b}	16. 83 ± 0.42^{cd}
K (2 mg/L)	22.20 ± 0.47^{a}	17.68 ± 0.31^{bcd}	16.22 ± 0.13^{d}
Control	4.13 ± 0.05^{g}	5.82 ± 0.17^{g}	5.49 ± 0.33^{g}
LSD (0.05)	1.70		
CV (%)	6.72		
MLE conc.	***		
Variety	***		
MLE conc. X variety	**		

Means followed by the same letter(s) in columns are not significantly different at 5% level of significance; NS, Non significant; **, ***, significant at $p \leq 0.01$ and $p \leq 0.001$, respectively; K, kinetin; LSD, least significant difference; CV, coefficient of variation.

3.6 Bulb diameter

The results of the analysis of variance indicated that the main effects of the application of moringa leaf extract concentrations on bulb diameter were significant ($p < 0.05$) (Table 5). Application of MLE (6%), which was statistically similar to MLE (4%) and kinetin (2 mg/L), produced larger-sized onion bulbs than MLE (2%) and the untreated control. Similarly, the application of MLE (2%) resulted in larger onion bulbs than the untreated control. The largest bulb (7.95 cm) was recorded from MLE (6%), whereas the smallest bulb (3.63 cm) was recorded from the control. Bulb diameter significantly increased as the level of MLE increased from 2% to 4–6%. However, the values did not increase as the concentration of MLE was raised from 4 to 6%. Foliar application of moringa leaf extract might have increased the amount of phosphorus, potassium, nitrogen, and other useful nutrients that can contribute to the growth of bulbs (Biel et al., 2017). This result is in line with the finding of Yaseen and Takácsné Hájos (2020) who reported that the maximum bulb diameter from onion treated with 4% followed by 6 and 2% whereas the minimum onion bulb diameter was recorded from the control.

Onion variety had a significant ($p < 0.05$) effect on the bulb diameter, whereas the interaction between moringa leaf extract concentrations and variety did not have a significant ($p > 0.05$) effect (Table 5). Nafis onion variety recorded a significantly higher bulb

TABLE 5 The main effects of moringa leaf extract (MLE) concentration and varieties on the bulb diameter (cm), bulb dry matter content (BDMC) (%) and total soluble solids (TSS) (°Brix) of onion.

Treatments	Bulb diameter	BDMC	TSS
MLE conc.			
MLE (2%)	4.42 ± 0.33^{b}	15.03 ± 0.57^{b}	11.67 ± 0.64^{b}
MLE (4%)	7.78 ± 0.31^{a}	17.35 ± 0.29^{a}	14.04 ± 1.14^{a}
MLE (6%)	7.95 ± 0.32^{a}	17.51 ± 0.49^{a}	15.86 ± 0.56^{a}
K (2 mg/L)	7.61 ± 0.31^{a}	17.03 ± 0.34^{a}	14.68 ± 0.74^{a}
Control	3.63 ± 0.09^{c}	12.36 ± 0.50^{c}	7.50 ± 0.52^{c}
LSD (0.05)	0.57	1.27	0.60
Varieties			
Nafis	7.06 ± 0.58^{a}	16.00 ± 0.66	13.99 ± 0.89^{a}
Adama Red	6.04 ± 0.52^{b}	15.83 ± 0.62	13.67 ± 0.83^{a}
Bombay Red	5.74 ± 0.46^{b}	15.80 ± 0.61	10.59 ± 0.96^{b}
LSD (0.05)	0.44	NS	0.47
CV (%)	9.46	7.35	4.53
MLE conc.	***	***	***
Variety	***	NS	***
MLE conc. X Variety	NS	NS	NS

Means followed by the same letter(s) in columns are not significantly different at 5% level of significance; NS, non significant; ***, significant at $p \leq 0.001$; K, kinetin; LSD, least significant difference; CV, coefficient of variation.

diameter (7.06 cm) than the other two onion varieties. Adama Red and Bombay Red varieties had statistically similar bulb diameters. This might be due to the higher vegetative growth of Nafis variety, which might have resulted in higher photosynthetic production and translocation to bulbs (Kabe, 2021; Sirba et al., 2022). Bulb diameter is a significant predictor of an onion variety's yielding potential, which is influenced by the variety's genetic composition and the growing environment (Yeshiwas et al., 2023). Similar to the present findings, Jilani et al. (2010) and Ijoyah et al. (2008) have noted differences in bulb diameter across several onion types.

3.7 Bulb dry matter content

The analysis of variance indicated that the application of moringa leaf extract concentration had a significant ($p < 0.05$) effect on the dry matter content of onion (Table 5). The results showed that dry matter content tends to increase with an increment in the concentration of MLE. Application of MLE (6%), MLE (4%), and kinetin (2 mg/L) had similar effects on dry matter content and they resulted in statistically higher bulb dry matter content than MLE (2%) and the control. Moreover, application of MLE (2%) resulted in higher dry matter content than the control. The highest number of dry matter content (17.51%) was recorded from plants sprayed with MLE (6%), while the lowest number of dry matter content (12.36%) was recorded on the control. Application of MLE (6%), MLE (4%), and kinetin (2 mg/L) increased the bulb dry matter content by 41.67, 40.37, and 37.78%, respectively, as compared to the control. The increment in dry matter content could be attributed to the presence of bioactive compounds in moringa leaf extract that can promote plant growth and development (Bari et al., 2024). The findings of the present study are in line with the reports of Mohamed et al. (2022), who observed that 5 g/L and 10 g/L of moringa extract resulted in higher dry matter production of lettuce than the control.

3.8 Total soluble solid content

The results of the analysis of variance indicated that the moringa leaf concentration significantly ($p < 0.05$) affected the TSS content of onion (Table 5). The TSS contents of onion tend to increase as the concentration of MLE is increased. All levels of MLE showed significantly higher TSS of onion bulbs than the control. Onion plants sprayed with MLE (6%), MLE (4%), and kinetin (2 mg/L) had similar effect, and they showed significantly higher TSS than MLE (2%) and the control. Similarly, the application of MLE (2%) resulted in statistically higher TSS than the control. The highest TSS content (15.04 ^{0}brix) was observed at MLE (6%) followed by MLE (4%) (14.86 ^{0}brix) and kinetin (2 mg/L) (14.68 ^{0}brix), whereas the lowest TSS content (7.50 ^{0}brix) was observed on the control. The TSS increased with increasing the concentration of MLE from 2% to 4 and 6%, and this might be due to the high levels of protein and carbohydrates found in moringa leaves, which contributes to the rise in TSS (Muhammed et al., 2013). The findings of this study are in line with the finding of Thanaa et al. (2017) who reported maximum TSS content in Hollywood plum with foliar application of 6% leaf of moringa aqueous extract while the lowest TSS content was observed in control. Similar results have been reported by Weerasinghaand and Harris (2020) in Chili, in which the highest TSS content was obtained at 10% foliar application of MLE whereas the lowest TSS content was from control treatment. Ngcobo and Bertling (2021) also reported higher sugar content of cherry tomato with applications of MLE compared to the control. In line with this, Mahmoud et al. (2024) reported higher sugar-soluble solid production in apple with the application of 6% MLE combined with mannitol.

The results of the analysis of variance indicated that varieties showed significant ($p < 0.05$) variation in TSS whereas the interaction effect of varieties and moringa leaf concentration was not significant ($p > 0.05$) on the TSS content of onion (Table 5). The study showed that Nafis and Adama Red varieties recorded statistically similar TSS content and both varieties had higher TSS than Bombay Red variety.

TABLE 6 Partial budget analysis of onion variety and foliar application of moringa leaf extract (MLE) concentrations.

Varieties	MLE conc.	MY (t ha^{-1})	AMY (t ha^{-1})	GB (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)
Bombay Red	0	5.49	4.94	247,000	5,600.00	241,400.00	-
Nafis	0	4.13	3.72	186,000	6,400.00	179,600.00	D
Adama Red	0	5.82	5.24	262,000	6,800.00	255,200.00	1,150
Bombay Red	2%	11.53	10.38	519,000	112,437.60	406,562.40	143.28
Nafis	2%	13.95	12.56	628,000	113,237.60	514,762.40	13,525
Adama Red	2%	13.08	11.77	588,500	113,637.60	474,862.40	D
Bombay Red	4%	16.53	14.88	744,000	219,275.20	524,724.80	9.40
Nafis	4%	22.67	20.40	1,020,000	220,075.20	799,924.80	34,400
Adama Red	4%	18.16	16.54	827,000	220,475.20	606,524.80	D
Bombay Red	6%	16.83	15.15	757,500	326,112.80	431,387.20	D
Nafis	6%	23.13	20.82	1,041,000	326,912.80	714,087.20	D
Adama Red	6%	19.07	17.16	858,000	327,312.80	530,687.20	D
Bombay Red	2 mg/L	16.22	14.60	730,000	470,341.50	259,658.50	D
Nafis	2 mg/L	22.20	19.98	999,000	471,141.50	527,858.50	D
Adama Red	2 mg/L	17.68	15.91	795,500	471,541.50	323,958.50	D

MY, marketable yield; AMY, adjusted marketable yield; GB, gross benefit; TVC, total variable cost; NB, net benefit; MRR, marginal rate of return; D, dominated.

The highest TSS content (13.99 ^{0}brix) was recorded from Nafis onion variety followed by Adama Red variety (13.67 ^{0}brix), whereas the lowest TSS content (10.59 ^{0}birx) was recorded from Bombay Red variety. Even though Nafis onion variety had higher vegetative growth, the absorption and translocation efficiency may not be higher, and this might have led to the lower TSS content, which was in agreement with the study of Meghana et al. (2021). This result is in line with the findings of Kushwah and Sengupta (2012) who reported differences in the TSS contents of onion varieties.

3.9 Partial budget analysis

The market price of onion bulb was taken to be 50 Birr (Ethiopian currency) kg^{-1}. The highest net benefit (799,924.80 Birr ha^{-1}) was recorded from Nafis variety combined with MLE (4%) followed by Bombay Red variety combined with MLE (4%). The marginal rate of return (MRR) showed that Nafis variety combined with MLE (4%) had acceptable MRR, and this implied that for every one Birr invested on the Nafis variety of onion and MLE (4%), the producers can expect to recover the one Birr invested and obtain an additional 344.00 ETB (Table 6). However, the MRR of Bombay Red variety combined with MLE (4%) is below the acceptable MRR of 50–100% (CIMMYT, 1988). The present study indicated that the MRR of Nafis variety of onion and MLE (4%) treatment was greater than 100%. Thus, on the basis of marketable yield, costs incurred for seeds of the onion varieties and preparation of MLE, and net income from the sale of the bulbs and MRR, it can be concluded that production of Nafis variety combined with MLE (4%) is economically feasible and can be recommended for producers/farmers.

4 Conclusion

The results of this study showed that moringa leaf extracts had a significant influence on the growth and yield-related traits of onion. The study showed that the growth and economically feasible bulb yield of onion can be obtained with a combination of Nafis variety and foliar application of MLE (4%). Generally, as one of the natural biostimulants, foliar application of moringa leaf extract can be used as an affordable and environmentally friendly substitute for synthetic chemicals. However, the majority of research focused on the effect of moringa in the form of leaf extract and foliar application. Hence, future research on the effects of moringa on the growth and yield of onion should be conducted using seed extracts and soil application methods.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

GM: Data curation, Formal analysis, Methodology, Software, Writing – original draft, Writing – review & editing, Conceptualization, Funding acquisition, Investigation, Project administration, Resources, Validation, Visualization. AT: Data curation, Formal analysis, Methodology, Software, Supervision, Writing – original draft, Writing – review & editing. SK: Data curation, Methodology, Project administration, Software, Supervision, Validation, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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