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Original Research

Evaluation of Onion (Allium cepa L.) Varieties for Growth, Yield, Quality, and Economic Performance under Irrigated Conditions in Mulo District, North Shewa, Ethiopia

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Abstract

Onion (*Allium cepa* L.) is an economically important vegetable crop in Ethiopia. However, there is no information about how improved onion varieties perform when grown with irrigation in Mulo District. Therefore, a field experiment was carried out in the 2024-2025 off-season to examine the growth, yield, the parts that make up the yield, and some quality characteristics of four onion varieties in Mulo District, Ethiopia. A Randomized Block Design with three replications was used. Varieties studied were Adama Red, Nafis, Bombay Red and Melkam. The data were analyzed with the General Linear Model method of SAS version 9.4 and compared using Duncan's Multiple Range Test at a 5% significance level. Most of the characteristics differed among the onion varieties. Adama Red had plant height (63.45 cm), the number of leaves per plant (10.83), the longest leaves (48.72 cm), the widest bulb diameter (8.24 cm), the longest bulbs (6.87 cm) and the highest average bulb weight (118.65 g). Adama Red produced the highest yield ($p < 0.05$) with marketable yield (42.85 t ha^{-1}), total yield (45.01 t ha^{-1}) and dry matter content (14.86 %). But Bombay Red had longest maturity (115.67 days). Bombay Red usually showed lower growth and yield results. Economic analysis indicated that Adama Red produced the highest benefit (ETB 1,096,950 ha^{-1}) when using the assumed price and cost data. Overall, Adama Red had better quality and economic returns. Therefore, Adama Red is recommended for irrigated onion production in Mulo District and similar agro-ecologies. Further studies, in locations and seasons, are recommended to confirm that Adama Red remains stable and adaptable.

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INTRODUCTION

Onion (*Allium cepa* L.) is one of the significant vegetable crops grown completely over the world. It is grown in subtropical and temperate regions because it can adapt to many different places. It is also grown because people want it for food and because it has uses in cooking (Brewster, 2008). Onion bulbs have a lot of things in them, like carbs, fiber, vitamin C, potassium, calcium, and special compounds that help the body (Block, 2010). The crop helps people have food and also gives money and jobs to many farming families. Globally, onion is one of the major vegetable crops in terms of production and economic value. Every year, more than 100 million metric tons of onions are produced, and the average productivity is about 19–20 tons per hectare (FAOSTAT, 2024).

In Ethiopia, onion is an important crop for marketing and for improving household food security. It is grown by farmers under both rain-fed and irrigated production systems. The crop contributes to household income, employment, market supply, and the provision of vegetables to consumers, hotels, restaurants, and food processing industries (CSA, 2024). Ethiopia has great potential for onion production because of its diverse agro-ecologies and expanding irrigation resources. However, onion productivity remains below its potential because of poor seed quality, pests and diseases, inadequate crop management practices, declining soil fertility, and climate variability (EIAR, 2022; MoA, 2023).

The performance of different onion varieties in the field depends largely on their genetic makeup and the environment in which they are grown. Factors such as temperature, day length, soil condition, water availability, planting time, and crop management practices all influence growth and yield (Brewster, 2008). Consequently, an onion variety that performs well in one location may not produce similar results in another. Studies conducted in Ethiopia have demonstrated significant variation among onion varieties in growth, bulb size, yield, bulb quality, and marketability, highlighting the importance of evaluating varieties under the target production environment (EIAR, 2022). Besides total yield, characteristics such as maturity period, bulb size, marketable yield, and dry matter content are important criteria for selecting suitable varieties for farmers and commercial producers (Brewster, 2008).

Mulo District in the North Shewa Zone is a place with potential for irrigated onion production. The highland agro-ecology gives Mulo District cool conditions that are good for onion cultivation, and the water, from irrigation lets farmers grow onions even in the dry season. Irrigated off-season production gives farmers a chance to grow high-value vegetables and earn money when rainfall is not enough (FAO, 2023).

Despite this potential, onion yield in Mulo District remains low. One major reason is the limited availability of locally tested information on the performance of improved onion varieties. Farmers often select varieties based on seed availability or previous experience rather than research-based recommendations. This results in inconsistent yield, poor bulb quality, and inefficient use of irrigation water, ultimately reducing farm productivity and income (EIAR, 2022).

Studies from different parts of Ethiopia have shown that onion varieties respond differently depending on the production environment. Significant differences have been reported among varieties in vegetative growth, bulb development, total yield, and quality attributes. These findings indicate that the interaction between genotype and environment strongly influences onion performance, emphasizing the need for location-specific variety evaluation before making recommendations (Ceccarelli, 1996; EIAR, 2022).

In Mulo District, irrigated onion production is already widely practiced; however, there is little local evidence regarding the performance of improved onion varieties under these specific conditions. Information is lacking on varieties that combine high total yield, marketable yield, desirable bulb size, and acceptable dry matter content traits that are essential for market acceptance and profitability. Without such evidence, farmers cannot make informed variety selection decisions. Therefore, evaluating improved onion varieties under the irrigated off-season conditions of Mulo District is necessary to identify varieties that produce high yield, good bulb quality, and are well adapted to the local environment.

This study aims to evaluate four improved onion varieties, Adama Red, Nafis, Bombay Red, and Melkam during the 2024-2025 off-season in Mulo District. The evaluation focuses on their growth, yield, yield components, and selected quality traits. The findings will provide scientific evidence for identifying superior onion varieties suitable for Mulo District and similar agro-ecologies, thereby supporting farmers, extension workers, researchers, and other stakeholders in improving onion production and productivity.

MATERIALS AND METHODS

Description of the Study Area

The experiment was carried out during the 2024–2025 off-season. It took place under irrigated conditions in Mulo District, which's part of the North Shewa Zone in the Oromia Regional State of Ethiopia. The study site is 34 kilometers north of Addis Ababa. Geographically, Mulo District lies in the highlands of Ethiopia. The region has a cool climate. This kind of climate is well suited for growing cool-season vegetables, including onion. The elevation of the district ranges from about 2,200 meters to 2,600 meters above sea level. The area gets an annual rainfall between 900 and 1,200 millimeters. The average temperature each year varies from around 10 degrees Celsius to 25 degrees Celsius. Onion farming in this area happens under both rain-fed and irrigated conditions; however, irrigation provides an opportunity for off-season production when rainfall is insufficient. The experimental field was supplied with irrigation water from locally available water sources, including river diversion and groundwater sources. The soil resources of Mulo District include Vertisols and Nitisols, which are among the important agricultural soils of the Ethiopian highlands and are used for crop production, including vegetable production where irrigation is available. The distribution and agricultural importance of these soil groups in Ethiopia have been documented in national soil and land-resource assessments (FAO, 2015; EIAR, 2018). Figure 1shows a geographical map showing the location of Ethiopia, Oromia Regional State, North Shewa Zone, Mulo District.

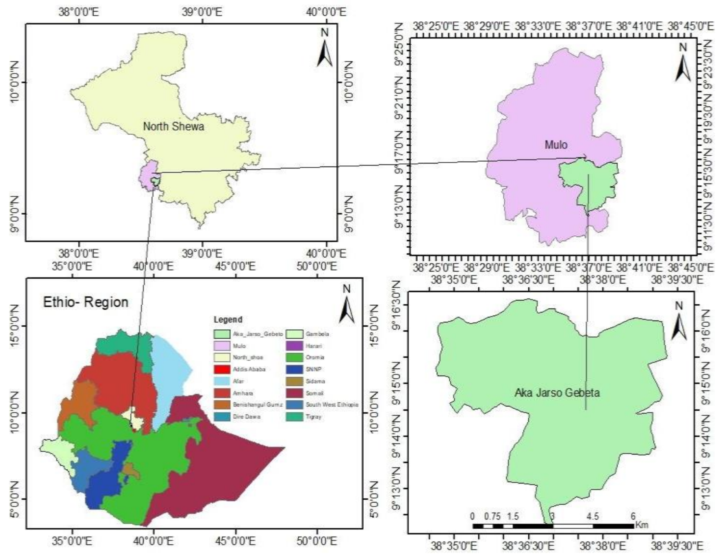

Figure 1. Map of the study area, Mulo District, Ethiopia

Soil Sampling and Analysis

Before moving plants, soil samples were taken from the test field to find out the chemical features of the soil and check how fertile it is. Multiple soil samples were taken from parts of the test area using a soil auger at the depth where onions grow best (0-30 cm). The samples were mixed well to make one combined sample, and a small part of that was used for testing in the lab. The soil samples were left to dry in the air, broken into pieces, and then passed through a sieve that is 2 mm in size before testing. The method the soil feels was found out using the hydrometer method. The pH of the soil was checked by mixing soil with water and using a meter. The amount of material was found using the Walkley and Black wet oxidation method. The total amount of nitrogen was measured using the Kjeldahl method. The amount of phosphorus that plants can use was found by using the way to take it out of the soil based on the type of soil and following the usual lab steps. The levels of bases that can be swapped in the soil and the ability of the soil to hold these bases were checked using soil testing methods. The data from the soil testing was used to describe how good the soil is for growing plants and to help explain the differences between the types of onions, in how they grow how much they produce and the quality of the onions.

Experimental Materials and Description of Varieties

Four onions varieties Adama Red, Adama Red Nafis, Bombay Red and Bombay Red and Melkam, were evaluated under irrigated conditions. The varieties were selected based on their availability, production potential, and relevance to onion production in Ethiopia. Planting materials were obtained from the Debre Zeit Agricultural Research Center. Healthy and uniform onion seedlings were raised in a nursery using recommended nursery management practices and transplanted to the field at the seedling stage. Information on the identity, source, status, and relevant characteristics of the tested varieties is presented in Table 1. Accurate documentation of variety identity and sources is important for ensuring the reproducibility and interpretation of evaluation experiments.

Table 1. Source and status of onion varieties evaluated in the experiment.

Variety	Source	Type/Status	Remarks
Adama Red	DZARC	Improved/released variety	Evaluated under irrigated conditions
Nafis	DZARC	Improved/released variety	Evaluated under irrigated conditions
Bombay Red	DZARC	Improved/released variety	Evaluated under irrigated conditions
Melkam	DZARC	Improved/released variety	Evaluated under irrigated conditions

Note: The pedigree or breeding history of each variety should be included only when verified from the official source. It is preferable to report the confirmed source and varietal status rather than provide unverified pedigree information.

Experimental Design, Treatments and Field Layout

The experiment was carried out using a Complete Block Design (RCBD) with three replications. Four onion varieties, Adama Red, Nafis, Bombay Red, and Melkam, were used as treatments. The treatments were placed at random within each block to reduce the influence of field variability. Each experimental plot measured 3.0 m by 2.4 m. giving a plot area of 7.2 m². Each plot had six rows with a spacing of 40 cm between rows and 10 cm between plants within a row. A gap of 0.5 m was kept between plots and a gap of 1.0 m was kept between blocks to make field work easier, and to reduce interference among units. Border rows and border plants were not included in the data to reduce edge effects. Data were taken from the designated sampling area inside each plot. The net plot area used for yield estimation was taken into account when converting plot yield to tons per hectare. All experimental plots received agronomic care throughout the growing season. Land preparation, fertilizer application, irrigation, weeding, pest, and disease management and other cultural practices were kept as consistent as possible across all treatments. Thus, variety was the experimental factor, while all other production factors were kept the same. The placement of varieties in plots was done by randomization within each block. The block arrangement was used to handle differences in soil fertility, slope, moisture, or other field characteristics. The rules used to form the blocks, and the actual randomization steps should be explained clearly in the manuscript.

The experiment involved four varieties and three replications, resulting in 12 experimental units. Under the RCBD statistical model, the residual error degrees of freedom were six. This relatively small error degree of freedom should be recognized when interpreting statistical significance because it may reduce the precision and statistical power of the experiment. Three replications provide a basic level of replication for a field varietal evaluation; however, the results primarily represent varietal performance under the specific location, season, and management conditions of the experiment. Consequently, the findings should not be interpreted as definitive evidence of varietal stability across different environments. To improve the reliability and generalizability of varietal recommendations, future studies should consider additional replications, repeated evaluations across production seasons, and testing at multiple locations. Such approaches would provide stronger evidence concerning varietal stability, adaptability, and potential genotype × environment interaction.

Experimental Procedures and Crop Management

The experimental field was prepared by tillage to create a fine-level seedbed that is suitable for onion production. Onion seedlings were raised in a nursery using recommended nursery management practices. Healthy, uniform, and vigorous seedlings were chosen and then transplanted into the experimental plots at the right transplanting stage. Fertilizers were applied evenly to every plot following the recommended fertilizer rate for onion production in the study area. Irrigation was supplied throughout the growing period according to crop water needs, soil moisture conditions and the prevailing weather. The exact amount and frequency of irrigation should be reported based on the real field records from the experiment. Manual weeding was performed whenever needed to reduce competition between onion plants and weeds. Pest and disease control measures were applied uniformly across all plots whenever infestation reached a level that required action. Other agronomic practices, such as land preparation, transplanting, fertilizer application, irrigation, weeding and crop protection, were kept uniform as possible among all treatments. The uniform management of all plots was designed to reduce environmental and management variation so that differences, in growth, yield and quality could mainly be linked to varietal differences.

Data Collection and Measurement Procedures

Data were collected from representative plants and bulbs within the designated net sampling area of each experimental plot. Border plants and border rows were excluded from sampling to minimize edge effects. Standardized measurement procedures and appropriate measuring instruments were used throughout the experiment to reduce sampling and measurement errors.

Days to 50% Physiological Maturity: Days to 50% physiological maturity was determined as the number of days from transplanting until approximately half of the plants within each experimental plot reached physiological maturity. Maturity was identified based on characteristic visual indicators, including neck softening and bending or lodging of the leaves toward the ground. The number of days was recorded separately for each experimental plot.

Plant Height: Plant height was measured in centimeters from the soil surface to the tip of the longest fully developed leaf. Representative plants were selected from the net sampling area of each plot, and measurements were taken at the designated vegetative growth stage. The mean plant height was calculated for each experimental plot.

Number of Leaves per Plant: The number of fully developed green leaves was counted on representative plants selected from the net sampling area of each plot. Leaves emerging from the pseudostem were counted individually. The mean number of leaves per plant was calculated for each plot and expressed as leaves plant^{-1}.

Leaf Length: Leaf length was measured in centimeters from the point of leaf emergence at the pseudostem to the tip of the longest fully developed leaf. Measurements were taken from representative plants within the net sampling area, and the mean leaf length was calculated for each experimental plot.

Bulb Diameter: At harvest, bulb diameter was measured across the widest portion of representative bulbs using a digital caliper or other appropriate measuring instrument. Measurements were expressed in centimeters, and the mean bulb diameter was calculated for each experimental plot.

Bulb Length; Bulb length was measured from the basal plate to the upper end of the bulb along its longitudinal axis. Representative bulbs harvested from the net sampling area were measured individually, and the mean bulb length was calculated for each experimental plot and expressed in centimeters.

Average Bulb Weight; After harvesting, bulbs from the net sampling area were cleaned and weighed. Average bulb weight was calculated by dividing the total weight of the sampled bulbs by the corresponding number of bulbs:

Average bulb weight (g bulb^{-1}) = Total weight of sampled bulbs (g) / Number of sampled bulbs

The resulting value was expressed as grams per bulb.

Marketable Bulb Yield: Marketable bulbs were separated from the harvested bulbs according to predetermined commercial quality criteria. Bulbs considered marketable were sound, adequately developed, reasonably uniform, and free from serious mechanical damage, disease, rotting, cracking, and other defects that would substantially reduce their market value. Marketable bulbs harvested from the net sampling area of each plot were weighed separately. The recorded weight was converted to tones per hectare using the net plot area:

Marketable bulb yield (t ha^{-1}) = Marketable bulb weight (kg plot^{-1}) × 10,000 / [Net plot area (m²) × 1,000]

The criteria used to classify bulbs as marketable should be clearly stated in the final manuscript and applied consistently to all varieties.

Unmarketable Bulb Yield: Unmarketable bulbs were identified based on predefined quality criteria and included bulbs that were excessively small, diseased, rotten, cracked, physically damaged, or otherwise unsuitable for commercial sale.

Unmarketable bulbs harvested from each net plot were weighed separately, and the recorded weight was converted to tones per hectare using the corresponding net plot area.

Total Bulb Yield: Total bulb yield was calculated as the sum of marketable and unmarketable bulb yields obtained from each experimental plot:

Total bulb yield (t ha^{-1}) = Marketable bulb yield + Unmarketable bulb yield

The resulting value was expressed in tons per hectare.

Bulb Dry Matter Content: Representative bulbs were collected from each experimental plot at harvest. The bulbs were cleaned, and representative portions were prepared for dry matter determination. The fresh samples were weighed and then dried in a forced-air oven at the temperature specified by the laboratory until a constant weight was obtained. After drying, the samples were cooled and weighed to determine their dry weight. Bulb dry matter content was calculated using the following equation:

Dry matter content (%) = [Dry weight of sample / Fresh weight of sample] × 100

The resulting value was expressed as a percentage.

For reproducibility, the final manuscript should report the sample size, oven-drying temperature, drying duration or constant-weight criterion, and laboratory used, based on the actual procedure followed during the experiment.

Statistical Analysis

The data collected for all measured parameters were subjected to analysis of variance using the General Linear Model (GLM) procedure of SAS statistical software version 9.4. Since the experiment was conducted using a Complete Block Design the statistical model was: $Y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij}$

where:

Y_{ij} = observed value of the ith variety in the jth block;

μ = overall experimental mean;

τ_i = effect of the ith onion variety;

β_j = effect of the jth block or replication; and

ε_{ij} = random experimental error.

The analysis of variance was performed at the 5% probability level. When significant differences among variety means were detected, means were separated using Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$. The coefficient of variation (CV) was calculated to assess the magnitude of experimental variability for each measured trait. The residual error degrees of freedom were determined according to the RCBD structure. Were considered when interpreting statistical significance. Because the experiment involved a number of treatments and replications and was conducted at a single location during one production season, statistical results were interpreted primarily in relation to the experimental conditions. Consequently, significant differences among varieties indicate differences under the conditions of the experiment and should not by themselves be interpreted as evidence of stable varietal superiority across different environments.

Economic Analysis

The economic analysis was conducted using the partial budget methodology described by CIMMYT (1988). Current market prices of inputs and outputs prevailing during the experimental period were used, and all costs and benefits were calculated in Ethiopian Birr (ETB) on a hectare basis. The analysis considered the adjusted marketable bulb yield, gross field benefit, total variable cost, and net benefit of each onion variety. The marketable bulb yield was adjusted downward by 10% to account for the expected difference between experimental and farmers' field conditions. Adjusted marketable bulb yield (AMBY) was calculated as: AMBY (t ha^{-1}) = Marketable bulb yield × 0.90. The gross field benefit (GFB) was calculated by multiplying the adjusted marketable bulb yield by the prevailing farm-gate price of onion: GFB (ETB ha^{-1}) = AMBY (t ha^{-1}) × 1,000 × farm-gate price (ETB kg^{-1}). Total variable costs (TVC) included costs that varied among the treatments, particularly labor and other production inputs where applicable. The prevailing local prices during the experimental period were used to estimate the variable costs. The net benefit (NB) was calculated by subtracting total variable costs from gross field benefit: NB (ETB ha^{-1}) = GFB – TVC. The onion varieties were ranked according to their net benefits. Where treatment-specific variable costs differed, a dominance analysis was conducted by arranging treatments in ascending order of variable cost and eliminating any treatment having a net benefit equal to or lower than that of a treatment with a lower variable cost. For non-dominated treatments, the marginal rate of return (MRR) was calculated as: MRR (%) = (Change in net benefit/ Change in total variable cost) × 100.The MRR was used to determine the additional return obtained from an additional unit of variable cost. The economically preferable variety was identified based on its net benefit and acceptable marginal rate of return under the prevailing production and market conditions.

RESULTS AND DISCUSSION

Phenological and Growth Parameters

Days to 50% Physiological Maturity

Significant differences were found among onion varieties in days to 50% maturity (Table 2). Bombay Red reached maturity the earliest, needing 115.67 days, while Nafis took 121.33 days. Adama Red and Melkam reached maturity at 118.67 and 119.67 days. The 5.66-day difference between the earliest and latest onion varieties shows that maturity duration varied enough among the tested cultivars in Mulo. This variation matters to farmers because the time to maturity influences when to harvest, when to bring onions to market, how much irrigation is needed, and how much risk farmers face from late-season weather.

Bombay Red's maturity in this study matches its known early maturity traits. Still, these maturity times for onion varieties cannot be applied straightaway to places because temperature, daylight length, planting date, soil fertility, moisture, and the interaction between onion variety genetics and the environment can change how onions develop. Alemu *et al*. (2022) also found variation in maturity among onion varieties in western Ethiopia and their study showed that plant spacing also affected the relative maturity period of onion varieties. This local observation says that Bombay Red can be a good choice when farmers want an early harvest, while Nafis may need a longer growing period in Mulo. Yet early maturity by itself does not mean overall production because the onion variety that matured first in this experiment did not give the highest bulb yield.

Plant Height

Significant differences were found among onion varieties in plant height (Table 2). Adama Red had the tallest plants at 63.45 cm, followed by Nafis at 61.28 cm, while Bombay Red had the shortest at 58.92 cm. Melkam was in the middle at 60.15 cm. The taller plant height of Adama Red shows vegetative growth for this onion variety under irrigated conditions in Mulo. Plant height alone does not decide bulb yield. Strong vegetative growth can help increase photosynthesis if the onion variety also has good leaf development and efficient transfer of energy to the bulb.

The 63.45 cm height of Adama Red is higher than what some Ethiopian onion variety trials have reported. For instance, Alemu *et al.* (2022) Saw heights of about 59–60 cm depending on plant spacing in western Ethiopia. These differences may come from variations in conditions, planting dates, soil fertility, irrigation, plant density and how the experiment was managed. This finding indicates that Adama Red showed vegetative adaptation in Mulo. Importantly the taller plant height of this onion variety came with leaves and longer leaves meaning the advantage was not just longer stems or leaves but a wider vegetative growth response.

Number of Leaves per Plant

The number of leaves per plant varied significantly among onion varieties (Table 2). Adama Red had the most leaves, 10.83 per plant, followed by Nafis with 10.17 per plant. Bombay Red had the fewest, 9.33 per plant and Melkam had 9.83 per plant. The higher leaf count of Adama Red is important because leaves are the photosynthetic organs that produce energy which is then stored in the bulb of this onion variety. More leaves, plus longer leaves mean a photosynthetic area for this onion variety, which may help explain why Adama Red produced bigger bulbs, and higher bulb yield. These results match Ethiopian studies that found significant differences among onion varieties in leaf development. Alemu *et al.* (2022) Reported varietal effects on leaf number and plant height in western Ethiopia. Alemu *et al*. (2022) Also found effects of onion variety and spacing on growth traits.

Yet, the size and ranking of the onion varieties varied across studies. This matters because it shows that onion variety performance is not the same. The interaction between the onion variety's genes and the environment can affect how the plant grows. So, the higher leaf production of Adama Red in Mulo shows adaptation to this particular site but it does not guarantee that Adama Red will always make more leaves than Nafis or other onion varieties in different places.

Leaf Length

Significant differences were found among onion varieties for leaf length (Table 2). Adama Red had the longest leaves at 48.72 cm, followed by Nafis at 46.85 cm. Bombay Red had the leaves at 43.64 cm and Melkam was in the middle at 45.76 cm. The longer leaves of Adama Red along with leaves mean that this onion variety had a larger photosynthetic canopy than the others. A larger canopy can capture light and produce more energy, which can help the bulb grow when resources are not limited. This matches Ethiopian studies that found onion varieties differ in vegetative growth. This study adds that the order of the onion varieties in traits matched the order in bulb size and yield. Adama Red was first in plant height, leaf number and leaf length. Also, first in bulb diameter, bulb length, average bulb weight, marketable yield, total yield and dry matter content. The consistent advantage across both reproductive traits gives stronger proof of adaptation than looking at plant height or leaf number by themselves.

Table 2. Effect of onion varieties on phenological and growth parameters under irrigated conditions of Mulo District, North Shewa, Ethiopia

Variety	Days to 50% physiological maturity	Plant height (cm)	Number of leaves plant^{-1}	Leaf length (cm)
Adama Red	118.67^{cd}	63.45^{a}	10.83^{a}	48.72^{a}
Nafis	121.33^{a}	61.28^{ab}	10.17^{ab}	46.85^{ab}
Bombay Red	115.67^{fg}	58.92^{c}	9.33^{fg}	43.64^{cd}
Melkam	119.67^{bc}	60.15^{cd}	9.83^{cd}	45.76^{bc}
LSD (5%)	**2.41**	**2.18**	**0.74**	**2.56**
CV (%)	**1.12**	**2.34**	**4.21**	**3.18**

Note: Means followed by different superscript letters within the same column are significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% probability level. LSD = Least Significant Difference; CV = Coefficient of Variation.

Yield Components

Bulb Diameter

Significant differences ($P < 0.05$) were found among onion varieties for bulb diameter as shown in Table 3. Adama Red had the largest bulb diameter at 8.24 cm. This was followed by Nafis, which had a bulb diameter of 7.86 cm. Bombay Red produced bulbs measuring just 6.95 cm. Melkam had a bulb diameter of 7.43 cm. The difference between Adama Red and Bombay Red was 18.6 percent, showing a variety-based difference in bulb size under the conditions of this study.

Larger bulb diameter is important in terms. Bulb size and consistency affect what customers prefer, how onions are classified in the market, and how much they sell for. The larger bulb diameter of Adama Red likely comes from its vegetative growth. This variety grew taller, produced leaves, and had longer leaves, all of which suggest it had a stronger capacity to carry out photosynthesis during bulb development. As a result, more nutrients and energy were likely moved to the bulbs, leading to larger bulbs. These results match the trend seen in recent Ethiopian studies, though the exact rankings and sizes differ depending on location. For example, a study in Dambi Dollo also found differences among onion varieties in bulb traits. In that area, Nafis performed well in terms of marketable and total yield. The difference between that result and the current study is not a contradiction. Instead, it highlights that variety × environment interactions are at play. This means that results may vary depending on where the onions grown. Therefore, variety recommendations should be made based on conditions.

Bulb Length

Bulb length was significantly affected by onion variety ($P < 0.05$) as shown in Table 3. Adama Red had bulbs at 6.87 cm. Nafis followed with 6.54 cm. Bombay Red had the bulbs at 5.72 cm. Melkam measured 6.18 cm. The longer bulbs of Adama Red, combined with its diameter, show that this variety had a greater ability to develop bulbs under the Mulo environment. This is important because bulb shape and size directly affect how the onion looks to consumers and how well it sells in the market.

Alemu *et al*. (2022) found that onion variety and planting spacing had effects on bulb traits in western Ethiopia. This current study adds to that knowledge by showing that in the Mulo irrigated area, Adama Red consistently showed the largest bulb dimensions among the four varieties tested.

Average Bulb Weight

Significant differences ($P < 0.05$) were observed among varieties for bulb weight (Table 2). Adama Red had the average bulb weight at 118.65 grams. Nafis followed with 110.42 grams. Bombay Red had the lowest at 91.38 grams. Melkam weighed 102.76 grams on average. The difference between Adama Red and Bombay Red was 30 percent. This shows a difference in bulb mass between the two varieties. The higher bulb weight of Adama Red matches its diameter and length. This means that its higher yield came partly from producing heavier bulbs. This is important when looking at yield data. It shows that Adama Red did not get its yield just by making more small bulbs. Instead, it made larger and heavier bulbs, with a high amount of marketable yield. Recent studies in Ethiopia have also found that variety has an effect on bulb weight and yield traits. A 2025 study in Ethiopia found major differences among onion cultivars in yield and quality, showing that choosing the right variety is key to improving productivity.

Bulb Yield

The results showed $P < 0.05$ differences among onion varieties for marketable bulb yield, unmarketable bulb yield, total bulb yield, and dry matter content (Table 3). Adama Red had the highet values for marketable yield, total yield, and dry matter content. Bombay Red had the marketable and total yields and the highest unmarketable yield. These yield results provide evidence of differences in variety performance under Mulo conditions. Importantly, the ranking of varieties by yield matched their ranking for vegetative growth and bulb size traits. Adama Red ranked first in plant height, number of leaves, leaf length, bulb diameter, bulb length, average bulb weight, marketable yield, total yield, and dry matter content.

This consistent pattern suggests that Adama Red's high yield came from its strong performance across many important traits. It did not just excel in one area. Instead, it performed well across traits that together contributed to higher yield. This makes it a reliable choice for farmers in the Mulo area.

Table 3. Effect of onion varieties on yield components under irrigated conditions of Mulo District, North Shewa, Ethiopia

Variety	Bulb diameter (cm)	Bulb length (cm)	Average bulb weight (g)
Adama Red	8.24^{a}	6.87^{a}	118.65^{a}
Nafis	7.86^{ab}	6.54^{ab}	110.42^{ab}
Bombay Red	6.95^{c}	5.72^{c}	91.38^{c}
Melkam	7.43^{bc}	6.18^{bc}	102.76^{bc}
LSD (5%)	**0.48**	**0.39**	**8.72**
CV (%)	**4.16**	**3.84**	**5.21**

Note: Means followed by different superscript letters within the same column are significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% probability level. LSD = Least Significant Difference; CV = Coefficient of Variation.

Marketable Bulb Yield

Marketable bulb yield varied significantly ($P < 0.05$) among the onion varieties tested in this study (Table 4). Adama Red had the highest marketable bulb yield at 42.85 t ha^{-1}. This was followed by Nafis with 39.72 t ha^{-1}. Bombay Red had the marketable yield at 32.64 t ha^{-1}. Melkam produced 36.85 t ha^{-1}. Adama Red outperformed Bombay Red by about 10.21 t ha^{-1}, which is roughly a 31.3% increase in marketable yield. This difference is important because marketable yield, not biological yield alone reflects how much of the onion crop can actually be sold. That means it directly affects how much income farmers can expect.

The high marketable yield of Adama Red was linked to its larger bulb diameter, bulbs, heavier average bulb weight, and lower unmarketable yield. This shows that Adama Red had both quantity and better quality of bulbs. Comparing this result to the Dambi Dollo study by Alemu *et al*. (2022), we sees a picture. In that study Nafis had the marketable yield at 34.44 t ha^{-1} while Adama Red had much lower yield. In this study Adama Red was the top-performing variety in Mulo. This contrast is one of the findings. It shows that the performance of an onion variety can vary a lot depending on the environment. Factors like temperature, altitude, soil, water availability, planting time, and plant density likely played a role.

So, it would be too simple to say Adama Red is the onion variety.

Unmarketable Bulb Yield

There were significant differences ($P < 0.05$) among onion varieties in bulb yield (Table 4). Bombay Red recorded an unmarketable yield of 3.71 t ha^{-1}, while Adama Red had the lowest unmarketable yield (2.16 t ha^{-1}). Nafis and Melkam recorded unmarketable yields of 2.84 and 3.12 t ha^{-1}, respectively. The relatively low unmarketable yield of Adama Red indicates that a greater proportion of its harvested bulbs met the marketability criteria compared with the other varieties. In contrast, the relatively higher unmarketable yield recorded for Bombay Red may have reduced its marketable yield, and consequently its economic value. The proportion of unmarketable bulbs can be influenced by bulb size distribution, disease incidence, physical damage, physiological disorders, and the adaptability of a variety to the prevailing environmental and management conditions. Since all varieties were evaluated under the same field conditions, the observed differences in unmarketable yield may partly reflect varietal differences in adaptation and response to the growing environment. Differences in susceptibility to diseases, physiological disorders, and other factors affecting bulb quality may also contribute to variation in unmarketable yield. Recent studies conducted in Ethiopia have reported significant differences among onion varieties in bulb yield, yield components, marketable yield, and quality characteristics, demonstrating the importance of varietal selection under specific production environments (Beji & Mulugeta, 2025; Olana & Abata, 2025). Similarly, recent research has shown that production practices and varietal characteristics can influence the proportion of marketable and unmarketable bulbs. Therefore, evaluating onion varieties based only on total bulb yield may not provide sufficient information for farmers and producers; both total yield and marketable yield should be considered when identifying promising varieties for production.

Total Bulb Yield

Total bulb yield also differed significantly ($P < 0.05$) among the onion varieties (Table 4). Adama Red had the total bulb yield at 45.01 t ha^{-1}.

Nafis followed with 42.56 t ha⁻¹. Bombay Red had the lowest at 36.35 t ha⁻¹. Melkam produced 39.97 t ha⁻¹. Adama Red exceeded Bombay Red by 8.66 t ha⁻¹.which is about a 23.8% higher total yield. This difference shows a production advantage under the conditions of this experiment. The high total yield of Adama Red was linked to its growth and yield components. This variety had the plants the most leaves, the longest leaves, the largest bulb diameter, the longest bulb, and the highest average bulb weight. These traits suggest a growth pattern where vigorous leaf development supported more photosynthesis, which then led to larger bulb formation and higher yield. However, the total yields observed in this study are much higher than the average in Ethiopia. The average onion productivity reported for Ethiopia is considerably lower than the global average, indicating a substantial gap between national productivity and the attainable yield potential of the crop (FAOSTAT, 2024). However, these production averages should not be directly compared with yields obtained under well-managed experimental conditions. Experimental trials are generally conducted using relatively uniform and timely management practices, including appropriate planting density, irrigation, fertilizer application, weed management, and pest and disease control. Therefore, the 45.01 t ha⁻¹ yield recorded by Adama Red in the present study represents the production potential of the variety under the specific environmental and management conditions of the experimental site rather than a yield that can necessarily be achieved by farmers under all production conditions.

The yield obtained from Adama Red was higher than the 35.40 t ha⁻¹ total bulb yield reported for Nafis at Dambi Dollo, Western Ethiopia (Alemu *et al*., 2022). The difference in yield may be associated with variation in variety, agro-ecological conditions, soil characteristics, irrigation management, planting density, and other crop management practices. This result suggests that Adama Red performed well under the conditions of Mulo District. However, superior performance at a single location and during a single season is not sufficient to establish broad adaptability or yield stability. Therefore, multi-location and multi-season evaluation is required to confirm the consistency, stability, and adaptability of Adama Red across different onion-growing environments in Ethiopia. Recent research has similarly demonstrated that onion variety and agronomic management can significantly influence bulb yield and yield components under Ethiopian conditions (Beji & Mulugeta, 2025).

Dry Matter Content

There were differences ($P < 0.05$) among the varieties in dry matter content (Table 4). Adama Red had the highest dry matter content at 14.86%. Nafis had 13.74%. Bombay Red had the lowest at 11.92%. Melkam had 12.85%. Dry matter content means more solid material in the bulb. This includes sugars, proteins and fibers. It is a quality trait because it affects how firm the bulb is, how it behaves during processing, and how well it stores. So, the high dry matter in Adama Red means it not only produces more but also produces a bulb that may be better for processing and longer storage. This finding matches recent research in Ethiopia. Studies in Ethiopia have shown that different onion cultivars vary in yield and quality. A 2025 study in Central Gondar also found differences among varieties in both yield and quality traits.

The combination of total yield, high marketable yield, large bulbs. and relatively high dry matter makes Adama Red a strong candidate for irrigated onion farming, in Mulo. High dry matter alone does not prove better storage. To know if Adama Red stores better, we need storage experiments. These would test how well it holds up over time, whether it shrinks or rots, and how much weight it loses. Then can we be sure its dry matter contributes to longer shelf life?

Table 4. Effect of onion varieties on marketable bulb yield, unmarketable bulb yield, total bulb yield, and dry matter content under irrigated conditions of Mulo District, North Shewa, Ethiopia

*	Marketable bulb yield (t ha⁻¹)	narketable bulb yield (t ha⁻¹)	Total bulb yield (t ha⁻¹)	Dry matter content (%)
Adama Red	42.85^{a}	2.16^{b}	45.01^{a}	14.86^{a}
Nafis	39.72^{ab}	2.84^{ab}	42.56^{ab}	13.74^{ab}
Bombay Red	32.64^{c}	3.71^{a}	36.35^{c}	11.92^{c}
Melkam	36.85^{bc}	3.12^{ab}	39.97^{bc}	12.85^{bc}
LSD (5%)	**3.24**	**0.86**	**3.68**	**1.08**
CV (%)*	**4.52**	**12.36**	**4.87**	**5.64**

Note: Means followed by the same superscript letter(s) within a column are not significantly different at the 5% probability level according to DMRT. LSD = Least Significant Difference; CV = Coefficient of Variation.

Economic Analysis

The economic analysis followed the CIMMYT (1988) method. the current market prices were used for everything during the test period. All costs and benefits were measured in Ethiopian Birr (ETB) per hectare. The economic analysis looked at each onion variety's marketable bulb yield, gross benefit, and variable production costs. Gross benefit was based on the price of onion with the marketable yield lowered by 10%. From the budget analysis, Adama Red had the highest net benefit of ETB 1,096,950 per hectare then came Nafis (ETB 1,012,440 per hectare), Melkam (ETB 934,950 per hectare), and Bombay Red (ETB 821,280 per hectare) (Table 5). The top economic return from Adama Red came mainly from its adjusted marketable bulb yield of 38.57 t per hectare giving the highest gross field benefit of ETB 1,156,950 per hectare. In contrast, Bombay Red had the adjusted marketable yield of 29.38 t per hectare and thus the lowest net benefit. The varieties were ranked by their benefits after adding the variable production costs. In short, Adama Red is the economically promising onion variety for irrigation in Mulo District because it has the best marketable yield, gross benefit, and net benefit.

Table 5. Partial budget analysis of onion varieties, under irrigated conditions

Variety	MBY (t ha⁻¹)	AMBY (t ha⁻¹)	GFB (ETB ha⁻¹)	TVC (ETB ha⁻¹)	NB (ETB ha⁻¹)	Rank
Adama Red	42.85	38.57	1,156,950	60,000	1,096,950	1
Nafis	39.72	35.75	1,072,440	60,000	1,012,440	2
Melkam	36.85	33.17	994,950	60,000	934,950	3
Bombay Red	32.64	29.38	881,280	60,000	821,280	4

Where**:** MBY = marketable bulb yield; AMBY = adjusted marketable bulb yield; GFB = gross field benefit; TVC = total variable cost; NB = net benefit.

CONCLUSION

This study was carried out to assess the growth, yield, yield components and quality of four onion varieties—Adama Red, Nafis, Bombay Red and Melkam—under irrigated conditions in Mulo District, North Shewa, Ethiopia. The results showed differences ($P < 0.05$) among the varieties, for phenological traits, growth characteristics, yield components, yield and quality indicators. This shows that there is variation in how these varieties perform under the given conditions. Among the four varieties Adama Red performed the best overall. It had plants (63.45 cm) more leaves per plant (10.83) longer leaves (48.72 cm) larger bulb diameter (8.24 cm) longer bulbs (6.87 cm) heavier average bulb weight (118.65

g) highest marketable bulb yield (42.85 t ha⁻¹) highest total bulb yield (45.01 t ha⁻¹) lowest unmarketable yield (2.16 t ha⁻¹), and highest dry matter content (14.86%). Nafis came in second. Bombay Red generally had the highest values for most growth, yield and quality traits, but it reached physiological maturity earlier than the others.

The strong performance of Adama Red was linked to its vegetative growth, larger and heavier bulbs, higher marketable yield, lower unmarketable yield, and greater accumulation of dry matter. The partial budget analysis also showed that Adama Red gave the net benefit (ETB 1,096,950 ha⁻¹) which supports its economic potential in the study area.

Because of its performance in agronomic traits, yield, quality, and economic returns, Adama Red is recommended for irrigated onion farming in Mulo District and similar regions. However, the study was conducted at a location during one season using only four varieties and three replications. Therefore, the results are specific to that location and season. Should not be taken as definitive evidence of wide-ranging superiority. More trials at locations and over several seasons involving a broader range of onion genotypes, with adequate replication, are needed to confirm the stability, adaptability, yield potential, quality, and economic performance of Adama Red before it is promoted more broadly to farmers.

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Conflict of Interest
The author declares that there are no known competing financial or personal interests that could have influenced the work reported in this article.

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