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Research Article

Demonstration of Onion Seed Production Technologies Under Irrigated Condition of Upper and Middle Awash Areas of Ethiopia

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Abstract

The onion (Allium cepa L.) is a biennial vegetable crop of the Alliaceae family, demanding high-quality seeds for successful cultivation. The Ethiopian Institute of Agricultural Research (EIAR) has prioritized onion as one of the key crops for research and development, aiming to improve yield and quality through the distribution of improved varieties and production technologies. In Ethiopia, the informal sector plays a crucial role in seed supply, meeting the demand largely through unorganized local markets or informal imports. This study aimed to demonstrate the seed production potential of two onion varieties, Nafis and Nafid, using a participatory approach in small-scale irrigation settings across two kebeles in Fentale and Amibara districts during the 2021/22 cropping season. A participatory research group (PRG) approach was employed, connecting agro-pastoralists who received training on onion seed production techniques. The field experiment was applied on systematically selected agro-pastoralists' plots of 10m × 10m, with transplant done 45-55 days after sowing. Data on seed yield and yield-related traits, including the number of stalks per plant, stalk diameter, length of the primary stalk, and number of umbels per plant, were collected and analyzed using an independent two-sample t-test in SAS software (version 9.0). Results showed a significant yield difference between the two varieties, with Nafis producing a regular seed yield of 10.72 q/ha, compared to 9.17 q/ha for Nafid, showcasing a yield advantage of 1.55 q/ha. This superiority of the Nafis variety was consistent across all experimental sites. The study concluded that the Nafis variety is more suitable for seed production in the tested regions, and suggests its potential to enhance seed yield for agro-pastoralists. The participatory approach and training provided to stakeholders were essential in improving knowledge, productivity, and the adoption of improved agricultural practices.

Keywords

Informal Seed Sector, Agro Pastorals, Nafis, Nafid, PRG, KOPIA

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1. Introduction

The bulb onion (Allium cepa L.), belonging to the Alliaceae family, originated in the region comprising Afghanistan, Iran, and the southern part of the former Soviet Union. It is believed that the onion ancestor, likely from Central Asia, migrated to the Near East and eventually to regions surrounding the Mediterranean, which are considered secondary centers of development [1]. In Ethiopia, the majority of onion germplasm introduced and developed has origins in countries such as India, Brazil, Sudan, and Italy. The Allium genus is highly diverse, containing over 600 species, including edible ones like A. fistulosum (bunching onion), A. sativum (garlic), A. ampeloprasum (leek), A. schoenoprasum (chives), and A. tuberosum (Chinese chives). Among these, Allium cepa is the most widely cultivated species. Despite having been cultivated for over 5000 years, onions do not exist in the wild, with A. galanthum and A. vavilovii being the closest wild relatives found in its regions of origin [2].

Onions play a crucial role in human diets, valued for their distinct pungency and widespread use as a key ingredient in various culinary dishes, sauces, and snacks. It is also an economically significant crop, both for local consumption and export earnings, creating employment opportunities due to its labor-intensive cultivation. Dry onions, an indispensable kitchen vegetable, are utilized in many dishes and salads globally. Scientific studies have indicated that onions and their relatives offer numerous health benefits, potentially treating or preventing ailments like cardiovascular disease, diabetes, and cancer [3]. The compounds allicin and alliin in onions are known to enhance appetite, facilitate digestion, and have regulatory effects on the intestines, while the vegetable is rich in essential vitamins, minerals, and anti-bacterial properties [4].

Ethiopia's diverse agro-ecological conditions favor the cultivation of a wide range of vegetable crops, including onions. Vegetables, such as onions, are vital in providing essential vitamins and minerals necessary for a balanced diet, while also contributing to the prevention of serious diseases. Additionally, onion production offers significant economic opportunities, particularly for women, youth, and small-scale farmers due to its labor-intensive nature and high market value. In Ethiopia, onions rank third in terms of area coverage among vegetable crops, with production increasing steadily over recent years [5]. In 2018, approximately 880,638 smallholder farmers produced 293,888 tons of onions from 31,673 hectares of land. Furthermore, Ethiopia generates over 2.6 million USD annually from the export of fresh and chilled onions and shallot products.

Despite the increase in onion cultivation and production, the national average yield remains low compared to the yield potential of released varieties and global standards. Ethiopia continues to import fresh onion bulbs from neighboring Sudan to meet local demand, underscoring the need for improved production practices. Low productivity can be attributed to several factors, including the limited availability of quality seeds and the use of suboptimal production technologies [6]. Moreover, the productivity of onion seed in Ethiopia remains below that of other African countries, with yields ranging from 1000 to 1300 kg ha^{-1}compared to 828 to 1446 kg ha^{-1}in other regions [7]. The Ethiopian Seed Enterprise (ESE) plays a minimal role in supplying onion seeds, with most seed demand being met through informal local markets or imports [8].

Given the significance of onion cultivation for Ethiopia's economy and food security, the Ethiopian Institute of Agricultural Research (EIAR) has prioritized onion research to improve yield and quality. Through years of research, improved onion varieties and production technologies have been developed, contributing to the growth of onion cultivation in the country. However, challenges remain in increasing productivity, particularly in the area of seed production. Therefore, this research aims to demonstrate improved onion seed production technologies in small-scale irrigation systems in the Upper and Middle Awash areas of Ethiopia, with the goal of enhancing onion seed yield and addressing the challenges faced by small-scale producers.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted during the 2021 cropping season at four sites: Beadamo and Bonta in the Amibara district of the Afar region, and Sareweba and Gare-dima in the Fentale district of the Oromia region, Ethiopia. Beadamo and Bonta are situated in the Afar National Regional State, Zone-3, Amibara district, approximately 280 km northeast of Addis Ababa, at coordinates 9 °60' N latitude and 40 °9' E longitude, with an altitude of 740 meters above sea level (m.a.s.l.). The area experiences a mean annual temperature of 34 °C, with an annual rainfall of 560 mm and an evapotranspiration rate of 2600 mm, characterized by long hot and dry seasons and erratic rainfall.

Sareweba and Gare-dima are located in the Fentale district of the Oromia National Regional State, East Shewa Zone, approximately 198 km east of Addis Ababa in the Great Rift Valley, between 8 °54' N latitude and 36 °23' to 39 °54' E longitude. This area has an average annual rainfall of 486 mm, with maximum yearly temperatures ranging from 32 °C to 42 °C and minimum temperatures between 10 °C and 22 °C.

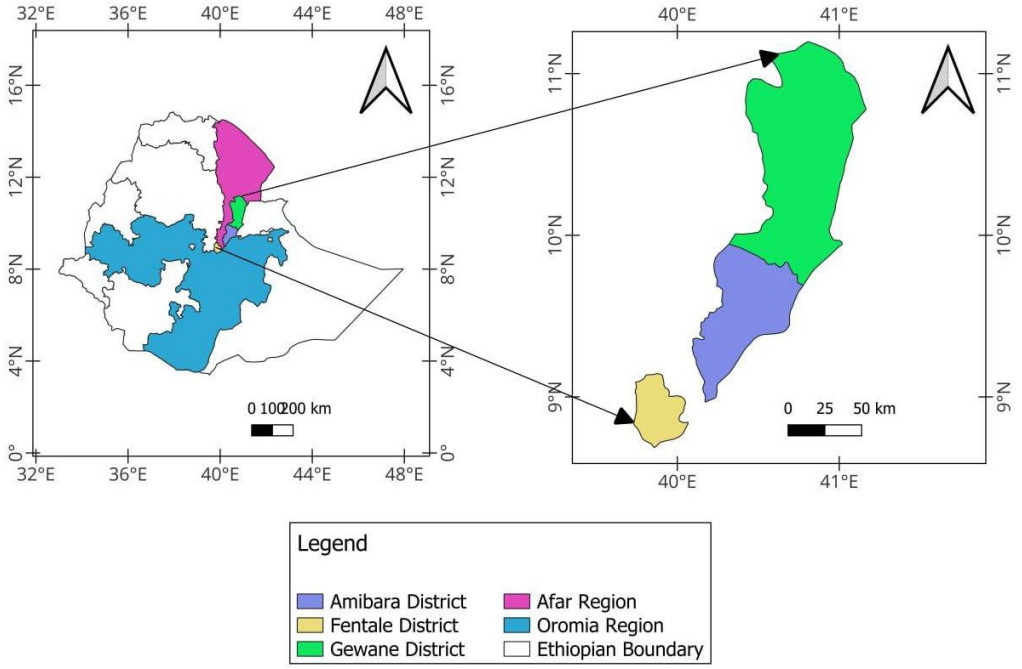

Figure 1. *Location map of the study area.*

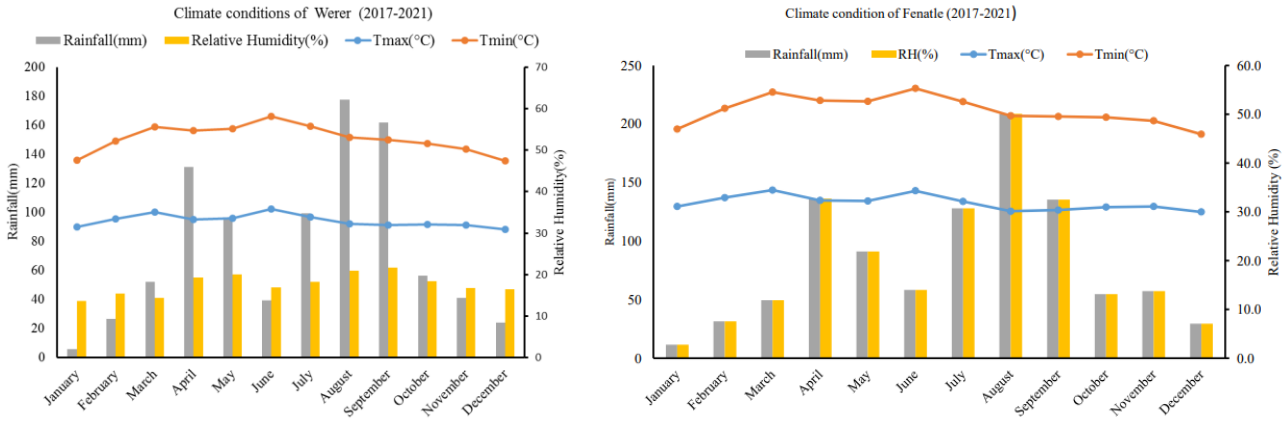

Figure 2. *Climate condition of the study area.*

2.2. Participatory Research Group (PRG) Setup

A Participatory Research Group (PRG) was established at each study site, consisting of approximately ten agro-pastoralists, including both men and women. The PRGs were formed in collaboration with local development agents and agricultural experts, selecting innovative and willing participants from the community. Training sessions were conducted for PRG members, development agents, and agricultural experts on onion seed production techniques. All management practices were implemented according to research recommendations provided during the training. The PRG members, alongside researchers and development agents, were involved in seed collection, evaluation, and drawing conclusions on the outcomes of the demonstration trials.

2.3. Field Experiment

The field experiment was arranged in a single plot design, each measuring 10 meters by 10 meters (100 m^2). Two released onion varieties, Nafis and Nafid, were used in the study. Seeds of each variety were sown on nursery beds for seed bulb production. After 45 to 55 days, the seedlings were transplanted to the main field in double rows with a spacing of 40 cm between rows, 20 cm between plants within rows, and 5 cm between double rows.

Harvested bulbs were stored for one month before being replanted for breeder seed production in October at the Werer Agricultural Research Center. Only healthy, true-to-type, and uniform bulbs with a diameter of approximately 5 cm, free from mechanical and physiological defects, were selected for

seed production. These bulbs were planted in double rows with a spacing of 50 cm between rows, 30 cm between plants, and 20 cm between double rows, using off-season irrigation. The experimental field was divided into blocks of 10 m width and 10 m length, with 1.5 m spacing between blocks.

2.4. Fertilizer Application and Irrigation

NPS (Nitrogen, Phosphorus, and Sulfur) fertilizer was applied at a rate of 242 kg ha^{-1}before transplanting. Urea was applied at a rate of 100 kg ha^{-1}in two split applications: 50% at 21 days after transplanting and the remaining 50% one and a half months after transplanting. Irrigation was administered every 5 days for the first 4 weeks, followed by irrigation every 7 days for the remainder of the growing period [9]. All standard cultural practices, including disease and pest management, were carried out as recommended for onion seed production in Ethiopia.

2.5. Harvesting and Post-Harvest Handling

Harvesting was carried out manually when the umbels began to show exposed black seeds, but before shattering occurred. After harvesting, the umbels were dried on canvas under a ventilated shed or in the sun according to standard onion seed harvesting procedures.

2.6. Data Collection

Data were collected on various yield and yield-related traits, including planting date, seed yield per plot and per hectare, number of stalks per plant, stalk diameter (cm), length of the main stalk (cm), and number of umbels per plant.

2.7. Statistical Analysis

The collected data were analyzed using the independent two-sample t-test with SAS software, version 9.0 [10]. Mean comparisons were performed to evaluate the statistical significance of differences between the two onion varieties at a 95% confidence interval.

3. Result and Discussion

3.1. Seed Yield and Yield-Related Parameters

Seed Yield Performance

The yield performance of the demonstrated onion varieties Nafis and Nafid was analyzed using an independent-samples t-test to compare their average seed yields across the Amibara and Fentale districts. The results showed a statistically significant difference between the two varieties in terms of average seed yield, with Nafis variety outperforming Nafid. Specifically, the mean seed yield for Nafis was 10.72 q ha^{-1} (SD = 0.78), while the mean yield for Nafid was 9.17 q ha^{-1} (SD = 0.59), with a t-value of -5 and a p-value below 0.05, indicating a significant difference in yield (Table 1). This suggests that agro-pastoralists cultivating the Nafis variety can expect a higher seed yield than those cultivating Nafid.

The higher yield of Nafis may be attributed to genetic differences between the two varieties. The results align with previous research, such as that of Ahmed et al. (2020), where significant variation in seed yield was observed between two onion varieties. In that study, the variety Kalash Nagari produced a significantly higher yield (630 kg ha^{-1}) compared to Taherpuri (270 kg ha^{-1}), indicating that genetic traits play a crucial role in seed yield performance.

When comparing the yield differences across the two districts, the t-test results indicated no statistically significant difference in seed yield between Amibara and Fentale. The average seed yield in Amibara was 9.79 q ha^{-1}(SD = 0.99), while in Fentale it was 10.11 q ha^{-1}(SD = 1.12), with a t-value of -0.67 and a p-value of 0.51 (Table 2). These findings suggest that despite potential environmental differences between the two locations, these factors did not significantly affect the seed yield of either onion variety. The similarity in seed yield across the two districts could be attributed to the comparable agro-ecological conditions in Amibara and Fentale, or it may reflect the adaptability of the Nafis and Nafid varieties to a broad range of environmental conditions. Similar results have been reported in previous studies, which found that certain crop varieties can perform consistently across different regions due to their inherent genetic robustness and environmental adaptability [11, 12].

The findings suggest that the Nafis variety is better suited for higher seed production compared to Nafid, regardless of the location. Nafis consistently demonstrated superior seed yield, indicating its potential to enhance onion seed production for agro-pastoralists in similar agro-ecological settings. The absence of a significant seed yield difference between Amibara and Fentale further underscores the robustness and adaptability of the Nafis variety. Its stable performance across different locations suggests that Nafis can effectively respond to a variety of environmental conditions, making it a promising choice for broader adoption by onion producers [13, 14].

In summary, while both varieties perform well across different regions, Nafis consistently produces higher seed yields, providing a clear advantage to producers seeking to maximize seed production. This consistency across locations is critical for scalability, allowing seed producers from various regions with similar agro-climatic conditions to adopt the variety with confidence. Future research could focus on identifying the specific genetic traits that contribute to Nafis's superior performance, as well as evaluating its adaptability to a broader range of climatic conditions [15-18].

Table 1. *T-test of yield difference among the varieties.*

t-test of variety difference				
Statistics				
Variety	**N**	**Mean (q ha^{-1})**	**SD**	**SE**
Nafid	10	9.17	0.59	0.19
Nafis	10	10.72	0.78	0.25
Equality of Variance				
F value		Sig		
1.76		0.41		

t-test for equality of Means							
Method	**t**	**Df**	**Sig (2 tailed)**	**Mean Diff (q ha^{-1})**	**SE Diff**	**95% CI of Diff**	
						Lower	**Upper**
Pooled	-5	18	< 0.0001	-1.55	0.3	-2.2	-0.9
Satterthwaite	-5	16.7	0.0001				

Table 2. *T-test of yield difference among the locations.*

t-test of location difference				
Statistics				
Districts	**N**	**Mean (q ha^{-1})**	**SD**	**SE**
Amibara	10	9.79	0.99	0.32
Fentale	10	10.11	1.12	0.35
Equality of Variance				
F value		Sig		
1.26		0.74		

t-test for equality of Means						
t	**Df**	**Sig (2 tailed)**	**Mean Diff (q ha^{-1})**	**SE Diff**	**95% CI of Diff**	
					Lower	**Upper**
-0.67	18	0.51	-0.32	0.47	-1.31	0.68
-0.67	17.8	0.51				

Yield Related Parameters

The analysis of yield-related parameters in onion seed production highlights several important traits that influence the performance of the Nafis and Nafid onion varieties (Table 3). These traits, including the number of stalks per plant, stalk length, number of umbels, umbel diameter, and seed yield per umbel and per plant, all contribute to overall seed productivity and reflect the genetic and environmental factors that influence onion cultivation.

Number of Stalks per Plant

The number of stalks per plant plays a critical role in onion seed production, as each stalk bears umbels that eventually produce seeds. In this study, the independent sample t-test results revealed a significant difference between the two varieties in terms of stalk production. The Nafis variety exhibited an average of 5.1 stalks per plant, while the Nafid variety averaged 4.2 stalks per plant, with an overall mean of 4.6 stalks. This finding is consistent with previous research, such as [11], which indicated that larger bulbs tend to produce more flowering stalks. The increased number of stalks in the Nafis variety likely contributes to its higher seed yield, as more stalks provide a greater potential for flower and seed production.

Length of Main Stalk

The length of the main stalk is another crucial parameter. In this study, Nafis variety exhibited significantly longer stalks (64 cm) compared to Nafid (45 cm), with an overall mean stalk length of 59.65 cm. longer stalks can support larger umbels and facilitate better access to sunlight, which enhances photosynthesis and supports the development of seeds. This result aligns with findings by [19-21], which reported a similar range of plant heights in onion seed production. The superior stalk length in Nafis provides a physiological advantage for seed production by enabling more robust flower development.

Number of Umbels per Plant

Umbel number is directly linked to seed yield, as each umbel contains multiple flowers that can develop into seeds. The study found significant differences between the varieties, with Nafid showing a higher maximum number of umbels per plant (13) compared to Nafis (11). However, Nafis had a higher overall average number of umbels per plant (7.2) compared to Nafid (3). This result is in line with the research of [22-25], which indicated that larger bulbs produce more umbels due to higher food reserves. The higher number of umbels in Nafis likely supports its superior seed production capacity.

Number of Flowers per Umbel

The number of flowers per umbel is a crucial determinant of seed yield, as each flower has the potential to develop into seeds. In this study, the Nafis variety significantly outperformed Nafid in this parameter, with an average of 395.8 flowers per umbel, compared to 285.8 flowers per umbel in Nafid. This substantial difference suggests that Nafis has a greater capacity for seed production at the floral level. The increased number of flowers in Nafis provides more opportunities for pollination and seed set, which contributes to its higher overall seed yield. This finding is consistent with prior research indicating that varieties with more flowers per umbel generally exhibit superior seed productivity [26-28].

Umbel Diameter

Umbel diameter is an important characteristic that reflects the size of the umbel and its capacity to support a greater number of flowers, thereby influencing seed yield. In this study, the Nafis variety exhibited a significantly larger mean umbel diameter of 3.04 cm compared to 2.52 cm for Nafid. This finding aligns with established trends in onion seed production, which indicate that larger umbels are generally associated with higher seed yields [22, 29, 30]. The increased umbel diameter in Nafis likely contributes to its superior performance by providing a larger surface area for flower development, thereby enhancing pollination opportunities and seed set.

Number of Seeds per Umbel

The number of seeds per umbel serves as a direct measure of the reproductive success of onion plants. In this study, the Nafis variety produced significantly more seeds per umbel, with a range of 182 to 280 seeds, compared to Nafid, which yielded between 100 and 222 seeds per umbel. This finding aligns with previous research by [31-34], which noted that high temperatures during the flowering stage could lead to flower abortion and, consequently, reduced seed set. Despite the challenges posed by environmental conditions, Nafis demonstrated a clear advantage in seed production, establishing itself as a more reliable variety for maximizing seed yield.

Seed Yield per Umbel

The yield per umbel is a critical parameter for assessing the efficiency of seed production in onions. The current study demonstrated that the Nafis variety had a significantly higher seed yield per umbel, ranging from 1.25 g to 2.99 g, while the Nafid variety yielded between 0.67 g and 3.38 g per umbel. Although Nafid achieved a higher maximum yield in some instances, the consistent performance of Nafis across various umbels emphasizes its reliability as a high-yielding variety. This finding is consistent with previous research indicating that reliable yield performance is essential for producers looking to maximize their output and adapt to market demands [35]. Consequently, the selection of the Nafis variety could be advantageous for optimizing seed production efficiency in onion cultivation.

Seed Yield per Plant

Seed yield per plant is perhaps the most important parameter for evaluating the overall performance of onion varieties in seed production. Nafis demonstrated a higher average seed yield per plant (ranging from 7.80 g to 11.62 g) compared to Nafid (5.08 g to 15.18 g), with an overall average of 9.08 g for Nafis. These results suggest that Nafis provides a more consistent and reliable seed yield per plant, making it a superior choice for agro-pastoralists aiming to maximize seed produc-

tion. The findings are consistent with [11], who also reported higher seed yields from larger bulbs and optimized spacing.

In conclusion, the analysis of yield-related parameters strongly supports the selection of the Nafis variety for onion seed production. The Nafis variety consistently outperformed Nafid across critical metrics such as the number of stalks per plant, number of flowers per umbel, umbel diameter, and seed yield per plant. These differences are primarily attributed to genetic factors and the superior adaptability of Nafis to the agro-ecological conditions of the study areas. Research indicates that environmental factors, particularly temperature during the flowering period, significantly influence seed production, which is evident in the observed variation of seed yield per umbel [27, 36]. Therefore, selecting appropriate planting and flowering times is essential for optimizing seed production outcomes.

The overall superior performance of Nafis in terms of yield-related parameters underscores its potential for widespread adoption in similar agro-ecological regions, providing producers with a more reliable and productive option for onion seed production. This aligns with findings by [37], who emphasized the importance of selecting high-yielding varieties for sustainable agricultural practices. By promoting the use of the Nafis variety, stakeholders can enhance seed production efficiency and improve the livelihoods of agro-pastoralists in comparable environments.

Table 3. *Mean performance of yield and yield related traits of two varieties over the study area.*

Variety	Location	NSP	SD	LMS	NUP	NFU	UD	NSU	SYU	SYP
Nafid	Amibara	4.20	1.12	55.20	6.60	280.40	2.58	180.80	1.49	8.45
	Fentale	4.00	1.20	57.60	6.80	291.20	2.46	178.20	1.66	8.04
	Mean	4.10	1.16	56.40	6.70	285.80	2.52	179.50	1.58	8.25
	SD	0.99	0.22	6.26	3.27	98.53	0.57	37.40	0.78	2.88
	SE	0.31	0.07	1.98	1.03	31.16	0.18	11.83	0.25	0.91
	Min	3.00	0.90	45.00	3.00	120.00	1.90	100.00	0.67	5.08
	Max	6.00	1.50	64.00	13.00	490.00	3.60	222.00	3.38	15.18
Nafis	Amibara	5.00	1.14	63.40	7.80	389.40	3.14	220.00	2.22	9.86
	Fentale	5.20	1.24	62.40	7.60	402.20	2.94	219.20	2.35	9.98
	Mean	5.10	1.19	62.90	7.70	395.80	3.04	219.60	2.29	9.92
	SD	0.88	0.19	5.86	2.11	53.97	0.51	34.82	0.70	1.11
	SE	0.28	0.06	1.85	0.67	17.07	0.16	11.01	0.22	0.35
	Min	4.00	1.00	56.00	5.00	296.00	2.50	182.00	1.25	7.80
	Max	6.00	1.60	71.00	11.00	475.00	4.20	280.00	2.99	11.62
Overall Mean		4.60	1.18	59.65	7.20	340.80	2.78	199.55	1.93	9.08
Diff (1-2) Mean		-1.00	-0.03	-6.50	-1.00	-110.00	-0.52	-40.10	-0.71	-1.68
N		10	10	10	10	10	10	10	10	10
DF		18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	11.60
t-value		-2.39	-0.32	-2.40	-0.81	-3.10	-2.16	-2.48	-2.15	-1.72
Sig. (2 tail)		0.03	0.75	0.03	0.43	0.01	0.04	0.02	0.05	0.11
F-value		1.29	1.35	1.14	2.40	3.33	1.27	1.15	1.24	6.73
Sig.		0.71	0.66	0.85	0.21	0.09	0.73	0.84	0.76	0.01

SC=Stand Count at harvest, SNP= Number of Stalk plant-1, LMS= Length of main stalk (cm), NUP=Number of umbels plant^{-1}, NFU= Number of flowers umble^{-1}, UD= Umbel diameter (cm), NSU=Number of seed umple^{-1}, SYU= Seed yield umble^{-1} (gm), SYP= Seed yield plant^{-1} (gm), and SD= Stalk diameter (cm)

3.2. Impact of Training on Agro-pastoralists' Knowledge and Productivity

The training of agro-pastoralists and development agents (DAs) on improved onion seed production packages demonstrated significant improvements in participants' knowledge and practical skills (Figures 3, 4, 5 and 6). The training was organized with participants from both Amibara and Fentale districts, comprising 40 agro-pastoralists and 4 DAs. The training covered key stages of onion seed production, including planting, field management, harvesting, seed grading, and treatment, which are crucial for enhancing onion seed productivity and ensuring high-quality seeds.

The training program significantly enhanced the knowledge and practical skills of the agro-pastoralists, particularly those in the Fentale district. Participants from Fentale demonstrated over double the seed production compared to their counterparts in Amibara, illustrating the effectiveness of the training in providing essential seed production techniques. This performance disparity underscores the importance of proper training in agronomic practices, especially in regions where onion seed production is less familiar or perceived as complex [38].

The substantial improvements observed in the Fentale district highlight the necessity for continuous, hands-on training aimed at increasing the productivity and income of small-scale agro-pastoralists. Onion seed production is a critical cash-generating activity for these communities, and enhancing their skills can lead to improved livelihoods and food security [39]. By investing in educational programs that focus on practical applications of agronomic principles, stakeholders can empower local farmers to adopt better practices, ultimately contributing to sustainable agricultural development.

Importance of Timely Planting

The participants underscored the vital importance of timely planting, particularly in early September, to achieve optimal vegetative growth and seed set prior to the onset of high temperatures. This timing is consistent with established agronomic principles that advocate for sufficient growing periods to mitigate temperature-induced stress on onion plants [40]. Early planting enables onion crops to develop a robust vegetative phase, which is crucial for effective seed formation.

Participants noted that delays in planting times could result in diminished seed yields and compromised seed quality, reinforcing the significance of adhering to recommended planting schedules. Previous research supports this observation, indicating that improper planting timing can lead to suboptimal growth conditions, ultimately affecting overall crop performance [41-43]. Ensuring that planting occurs during the ideal window can significantly enhance both the yield and quality of onion seeds, highlighting the need for education and training on optimal planting strategies for agro-pastoralists.

Varietal Selection for Seed Production

The training program emphasized the critical aspect of selecting suitable varieties for onion seed production, highlighting Nafid and Nafis as optimal choices for both the Amibara and Fentale districts. These varieties were identified based on their adaptability to local agro-ecological conditions and their superior yield potential, as supported by previous studies demonstrating their efficacy in similar environments [16, 44]. The inclusion of alternative varieties such as Adama Red and Bombe Red further illustrates the comprehensive approach of the training, equipping producers with knowledge not only about immediate practical skills but also about the strategic importance of variety selection.

Understanding the significance of variety selection in maximizing yields under varying environmental conditions is essential for sustainable agricultural practices. Research indicates that selecting the appropriate variety can significantly influence seed yield and quality, particularly in regions with diverse climatic factors [45]. By educating agro-pastoralists on these aspects, the training program contributes to enhancing productivity and resilience in onion seed production.

Weed Management and Bolting

Weed management emerged as a crucial focus area during the training, where agro-pastoralists learned that hand weeding is more effective for onion seed production than other methods. The training emphasized the importance of avoiding weeding during the bolting stage, which is critical as this is when the onion plant develops flowering stalks. Weeding at this stage could damage the bolting plants, thereby negatively impacting seed production [46, 47].

Effective weed management is vital, as competition from weeds can severely hinder the growth and seed yield of onion plants, which are particularly sensitive to such interference [48-51]. By adopting proper weed management practices, agro-pastoralists can minimize competition, support better plant growth, and ultimately enhance seed yields. This knowledge transfer is essential for improving onion seed production efficiency and ensuring sustainable agricultural practices within the community.

Seed Harvesting, Grading, and Treatment Techniques

For the first time, agro-pastoralists were introduced to modern techniques for harvesting, grading, and treating onion seeds. These techniques included timely harvesting specifically, when the umbel exposes black seeds, which is crucial for maximizing seed quality [21, 52]. The training emphasized the importance of drying the heads in ventilated sheds, which helps to prevent mold and ensures proper seed storage. Additionally, participants learned to employ sieving and water treatment methods to sort and clean the seeds effectively.

One notable technique introduced was the floating of seeds in cold water to separate fertilized seeds from unfertilized ones. This method is particularly valuable, as it ensures that only viable seeds are retained, significantly enhancing seed quality and minimizing post-harvest losses [53]. The practical knowledge instilled in participants ensured that they could

effectively apply these techniques in their own seed production efforts.

The adoption of these modern methods represents a significant improvement over traditional practices, which often involved inefficient harvesting and grading processes, leading to lower seed quality and reduced viability [54]. By implementing these improved techniques, the training empowered agro-pastoralists to enhance the overall quality of their seed output, which is likely to result in better crop performance and increased market value.

3.3. Participant Feedback and Future Recommendations

The training program had a profound impact on the participants, who expressed significant appreciation for the knowledge and skills they gained. Many agro-pastoralists had previously perceived onion seed production as complex and difficult; however, the training helped demystify the process and instilled confidence in their ability to engage in seed production activities [55, 56]. Participants emphasized the importance of more frequent and practical training sessions to further enhance their skills, highlighting a strong demand for ongoing capacity-building efforts in onion seed production. This feedback underscores the necessity of practical, hands-on training that addresses the specific challenges faced by agro-pastoralists in these regions [57].

The positive outcomes from this training program emphasize the critical role that education and hands-on practice play in improving agricultural productivity, particularly in areas where producers have limited experience with specialized practices like onion seed production [58]. The significant improvement in seed yields among agro-pastoralists in Fentale compared to those in Amibara suggests that targeted training can bridge gaps in knowledge and skill, leading to tangible performance improvements.

Moreover, the feedback from participants indicates that training programs should incorporate not only theoretical knowledge but also practical sessions where producers can apply what they have learned [59]. This approach ensures that participants retain the knowledge and are more likely to implement improved techniques in their farming operations. The enthusiasm for future training suggests that agro-pastoralists are eager to adopt new technologies and practices that can enhance their productivity and income.

The training program on improved onion seed production packages significantly impacted the participating agro-pastoralists, particularly in the Fentale district, where seed yields more than doubled. The program effectively addressed critical aspects of onion seed production, including planting time, varietal selection, weed management, and seed harvesting and grading techniques. The participants' positive feedback and requests for additional training indicate the program's success and the need for continued capacity-building efforts to further improve onion seed production in the region. Such programs are essential for empowering small-scale onion seed producers, enhancing their livelihoods, and increasing the overall productivity of the agricultural sector [60, 61].

3.4. Field Performance of Onion Seed Production at Amibara and Fentale Districts

The productivity of onion seed production in the Amibara and Fentale districts reflects the underlying land conditions and the effectiveness of field management practices. Proper field management including optimal land preparation, planting, irrigation, and weeding is essential for achieving good crop growth, seed formation, and successful harvesting [62]. Variations in onion seed performance between these districts highlight the influence of local environmental factors and differences in management practices.

In Fentale district, land preparation faced significant challenges. Producers were often pressured by societal leaders to prioritize irrigated wheat production, which limited their ability to focus on onion seed preparation. Small-scale producers, lacking access to mechanized tools, had to rely on manual labor, making it difficult to prepare seedbeds effectively. This limitation in land preparation likely affected onion seedling establishment and plant growth, resulting in suboptimal yields when compared to districts like Amibara, where such pressures were absent [63].

Figure 3. *Pastorals and DA training at Amibara districts (Photo by: Tadesse Alemayehu).*

Figure 4. *Pastorals and DA training at Fentale districts (Photo by: Tadesse Alemayehu).*

Figure 5. *Community based onion seed production at Amibara districts (Photo by: Tadesse Alemayehu).*

Figure 6. *Community based onion seed production at Fentale districts (Photo by: Tadesse Alemayehu).*

Crop management practices further impacted onion production in both districts. Poor plant spacing, inadequate irrigation, and improper weeding led to a progressive decline in the onion population over time. Issues such as bulb rotting and damage from weeding, particularly during sensitive growth stages, contributed to yield losses [43, 64]. These findings underscore the need for improved crop management strategies, including better planting practices, irrigation management, and careful weeding, to enhance onion seed production in both Amibara and Fentale districts.

4. Conclusion and Recommendation

4.1. Conclusion

The findings of this study indicate significant differences in yield and associated yield components between the onion varieties Nafis and Nafid. Specifically, the Nafis variety yielded an average of 10.72 q ha^{-} ¦ surpassing the Nafid variety's yield of 9.17 q ha^{-} ¦ resulting in a yield increase of 1.55 q ha^{-} ¦ The enhanced performance of the Nafis variety is evidenced by superior metrics across various yield components, including the number of stalks per plant, length of the main stalk, number of umbels per plant, and seed yield per umbel. These results suggest that Nafis is a more suitable option for onion seed production in agro-pastoralist contexts, particularly within the Amibara and Fentale districts.

Furthermore, the training program for agro-pastoralists and development agents (DAs) on improved onion seed production packages has yielded substantial improvements in knowledge and practical skills, particularly in Fentale, where seed yields more than doubled relative to those in Amibara. Critical elements of the training, such as optimal planting timing, varietal selection, weed management, and advanced harvesting and grading techniques, have been identified as essential for enhancing onion seed productivity and quality. The positive feedback from participants underscores the efficacy of hands-on training in demystifying seed production practices and fostering confidence among agro-pastoralists.

The observed disparities in seed production between districts further emphasize the influence of local environmental factors and management practices, highlighting the necessity for tailored training programs that address specific regional

challenges. Ongoing capacity-building initiatives are crucial for empowering small-scale producers, improving their livelihoods, and bolstering the overall productivity of the agricultural sector. Therefore, it is recommended that the Nafis variety be promoted and adopted across other kebeles, with continued support from district administrations and agricultural experts to enhance the effectiveness of onion seed production practices.

4.2. Recommendation

Community-based seed multiplication programs should be expanded and strengthened as effective platforms for technology transfer, thereby enabling agro-pastoralists to adopt improved seed production practices and diversify their crop portfolios. These initiatives play a crucial role in introducing high-yielding onion varieties, such as Nafis, which has demonstrated superior seed yield performance, making it an ideal choice for onion seed production in similar agro-ecological areas. Encouraging agro-pastoralists to adopt the Nafis variety can significantly enhance productivity. Additionally, district-level agricultural experts must prioritize the dissemination of comprehensive onion crop management strategies, which should encompass optimal planting times, appropriate plant spacing, irrigation techniques, and efficient weeding practices. Such measures are essential for preventing losses due to plant damage and bulb rot, ultimately improving seed yield. While the Ethiopian government emphasizes wheat production for import substitution, it is imperative to maintain a balanced approach that also supports small-scale onion and other crop production. This diversification of agricultural output is vital for ensuring sustainability and enhancing food security. Future research efforts should investigate the genetic factors contributing to the yield advantages of the Nafis variety and assess its performance across various climatic conditions to facilitate broader adoption. By implementing these recommendations, stakeholders can effectively enhance the knowledge and skills of agro-pastoralists, leading to improved productivity, better quality onion seeds, and ultimately greater food security and economic stability within these communities.

Abbreviations

DA	Developmental Argent
EIAR	Ethiopian Institute of Agricultural Research
KOPIA	Korea Program on International Agriculture
PRG	Participatory Research Group
WARC	Werer Agricultural Research Center

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Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Yitages Kuma Beji, a dedicated horticultural researcher at the Ethiopian Institute of Agricultural Research (EIAR), holds a B.Sc. in Plant Sciences from Ambo University (Jun. 24, 2010) and an M.Sc. in Horticulture from Hawassa University (Feb. 20, 2017). With over a decade of experience, he has advanced from Junior Researcher to Researcher-I and Crop Research Process Head at the Werer Agricultural Research Center. Yitages specializes in horticultural crop research, statistical data analysis, and sustainable agricultural practices, contributing significantly to field experimentation, technology demonstration, and participatory research approaches. An accomplished academic, he has authored several publications on crop improvement and demonstrations, reflecting his commitment to enhancing agricultural productivity and resilience in Ethiopia.

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