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Garlic (Allium Sativum L.) Variety Development for the Highland Areas of North Shewa, Amhara Region

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Abstract

Ethiopia has a suitable edaphic condition for garlic production. The crop has a paramount importance for seasoning in many foods and is also thought to have a medicinal value. Production and productivity of garlic in Ethiopia is affected by various biotic and abiotic bottlenecks such as lack of high yielding varieties, non-availability of quality seeds, and prevalence of various diseases. Therefore, the objective of this study was to evaluate and verify the most stable, high yielding and disease tolerant garlic accession for the highlands of North Shewa. Thirteen promising accessions were selected for regional variety trial (RVT) from the regional collection made from North Shewa and North Gondar Zones in Amhara National Regional State. The regional variety trial was conducted in RCBD with three replications for three years and two locations. The study revealed that NG0048/04 accession had outstanding yield performance in almost all test environments, out yielded both the standard "kuriftu" and local check varieties. Moreover, based on AMMI 1, AMMI 2 and AMMI stability analysis the bulb yield of NG0048/04 accession was found more stable as compared to the other accessions and the standard check variety "Kuriftu". Hence, this accession was approved and released by the National variety releasing committee with the varietal name of "Qundi" for cultivation in the mid and high-altitude areas of Ethiopia.

Keywords: AMMI; Bulb yield; Genotype; Qundi garlic variety

Introduction

Garlic (Allium sativum L.) belongs to the genus Allium in the family of Alliaceae It is grown as an edible bulbous crop throughout the world [1] and is one of the most important Allium crops in terms of production and economic value after onion [2]. It has been used since ancient for its' culinary, medicinal, and health benefits.The origin of garlic is thought to be in Central Asia (India, Afghanistan, West China, Russia) and spread to other parts of the world through trade and colonization (Eric, 2010). Today, garlic is grown in temperate and tropical regions all over the world and many varieties have been developed to suit different climates [1].

In Ethiopia, garlic plays an important role for dietary as well as medicinal functions. It is regarded as queen of the kitchen and used in preparing foods, particularly some kinds of stews and in making dried foods to improve storability [3]. Traditionally, it is used in the treatment of headaches, bites, worms and tumors. In Ethiopia, it is widely cultivated around home gardens. But nowadays, garlic production has spread throughout the country, being cultivated both under irrigated as well as rain-fed conditions and it is primarily produced in the country's mid and highland areas. The crop is also produced as a cash crop to earn foreign currency by exporting to Europe, the Middle East, and the USA [4] Nowadays, its production is practiced on some large farms [5] and in the 2020/21 main cropping season, about 15979.54 ha of land is covered under garlic cultivation (CSA, 2021). From the annual country level garlic production of 53,093.99 tons, 44.85% is produced in Amhara Region. Similarly, the North Shewa zone in Amhara Region contributes about 10.2% of the country's annual garlic production area with a production of 13,249.93 tons and with an average productivity of 8.14 t ha^{-1} [6].

As compared to world production, the production and productivity of garlic in Ethiopia is very low, which is due to many biotic and abiotic bottlenecks. Lack of improved varieties, non-availability of quality bulb seeds coupled with susceptibility to diseases, the nature of propagation, poor agronomic management practices and lack of irrigation facilities are the most serious causes of the low production and productivity of garlic in the country [5] The varieties released in Ethiopia until now are not more than seven, and most of them are suitable for mid-altitude areas. Therefore, the objective of this study was to evaluate and develop the most stable, high yielding, and disease tolerant garlic variety for the highlands of North Shewa.

Materials and Methods

Description of the study area

The preliminary observation nursery and preliminary variety trial (PVT) field experiments were carried out at the main station of Debre Birhan Agricultural Research Center (DBARC) during the main rainy season in 2013 and 2014, respectively. Meanwhile the regional variety trials (RVT) and variety verification trial (VVT) were conducted at Debre Birhan and Ankober trial stations of DBARC and the surrounding farmers' fields in 2015 2016 and 2017. The soil of DBARC is Pellic Vertisols while that of Ankober is Cambisols, representing a clay-loam textural class. Faba bean, potato, and barley are the major crops grown, with sheep being the most common livestock in the experimental areas. A detailed climatological and geographic description of the study area is indicated in **Table 1.**

Treatments, Experimental design and procedure

The regional level garlic accession collection was done by the

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Table 1: Geographic and climatological descriptions of the study area.

Locations	Distance in km from A. A	Altitude (m.a.s.l.)	Longitude	Latitude	Mean annual RF (mm)	Mean Temp.(ºc)	
						Max	Min
Debre birhan	130	2850	39º 29' 00" E	09º 35' 00" N	934	19.82	7.08
Ankober	172	3145	39° 44' 00" E	09 º 38' 00" N	1700	19.16	10.33

Amhara Agricultural Research Institute from North Shewa and North Gondar Zones of Amhara region in 2013. About 132 garlic accession were collected, characterized and evaluated under preliminary observation nursery trial in augmented block design in the same year. From this evaluation, 49 accessions were advanced to a preliminary variety trial (PVT) and evaluated in 2014. Of these, 15 promising garlic accessions were advanced to the regional variety trial (RVT). From this three promising garlic candidates (i.e. NG0048/04, NG0052/04 and NG0008/04) were advanced to the Variety Verification Trial (VVT). In 2020, the advanced candidate genotypes along with standard check (Kuriftu) were evaluated on 10 m x 10 m plots in five locations under the supervision of the National Variety Releasing Committee. Generally, preliminary observation nursery till the variety verification trials was conducted from 2013 to 2020.

The regional variety trial was conducted from 2015-2017 at Ankober and Debre Birhan, consisting of 15 accessions were advanced from the preliminary yield trial for comparison against the standard check (Kuriftu) and one local check. The RVT was conducted using a randomized complete block design (RCBD) with three replications. The gross plot size was 1.6x1.2m (1.96 m2). The spacing was 30 and 10 cm between rows and plants, respectively. It accommodates a total of 16 and 64 plants per row and plot, respectively. The spacing between plots and replications was 1 m and 1.5 m, respectively. Healthy and uniform cloves of each accession were selected and planted on beds of about 20 cm in height by hand with a planting depth of 3 cm and covered lightly with soil. NPS and Urea fertilizer were applied at the rate of 242 and 150 kg ha-1. The whole dose of NPS was applied during planting while Urea in splits: 1st half at the time of planting and the remaining half 45 days after planting [5] Although white rot and garlic rust diseases were observed in the experimental areas, there was no any fungicide chemical application for the purpose of natural selection and disease reaction. Hand weeding and hoeing have been applied uniformly to the entire plot two to three times based on the infestation of the weed. Following the cessation of rainfall, supplementary irrigation of 30 liters per plot at seven-day intervals was applied in all environments.

Data Collection

The morphological, yield, and yield component traits were collected according to the descriptors of garlic [**7**]**.** Morphological and yield related traits were collected from five randomly selected plants at the central two rows. While bulb yield data was obtained from the whole plants found in the central two rows.

Data Analysis

The collected data was subjected to analysis of variance (ANOVA) using SAS statistical software. Difference between treatment means was compared using Duncan's multiple range test (DMRT) at 5% probability levels. Homogeneity of error variances was tested prior to combined analysis over location in each year as well as over locations and years. In combined analysis, locations and years were treated as random factors while varieties were fixed effect.

Analyses of variance were computed for six environments using Additive Main Effects and Multiplicative Interaction (AMMI) model to partition the interaction using interaction principal component axes using GenStat software. In combined analysis, locations and years were treated as random factors while varieties were fixed effect. In AMMI biplot, main effects (genotype and environment means) were plotted on the abscissa and the IPCA 1 scores for the same cultivars and environments on the ordinate [**8**]. AMMI 1 biplot was constructed to investigate the interaction of genotypes with the testing environments while to examine the degree of interaction AMMI 2 was plotted. In addition, AMMI stability values (ASV) was calculated for each accessions using the following formula as suggested by [**9**]**.**

$$ASV = \sqrt{\left[\frac{SSIPCA1score}{SSIPCA2score} \times IPCA1score\right]^2 + (IPCA2score)^2}$$

Where IPCA1 sum of square/IPCA2 sum of square is the weight given to the IPCA1-value by dividing the IPCA1 sum of squares (from the AMMI analysis of variance table) by the IPCA2 sum of squares. The larger the IPCA score is, either negative or positive, the more adapted a genotype is to a certain environment. Smaller ASV scores indicate a more stable genotype across environments [**10**]**.**

Results and Discussions

Growth, yield related traits and disease reaction of garlic accessions

The combined analysis of variance over six environments revealed the presence of a statistically significant difference ($p < 0.05$) amongst garlic accessions for all measured agronomic traits as well as reaction to rust. Based on the overall environment performance of the accessions, NG0048/04 gave the highest plant height (68.4 cm), trunk diameter (13.33 cm), bulb diameter (4.69 cm), and clove diameter (1.09 cm). In contrary, the standard check variety "Kuriftu" gave the lowest score in almost all agronomic traits except it has showed a moderate level of tolerance reaction for rust disease.

The released variety has deep green foliage and vigorous growth. It has a pseudo stem height of 25.08 cm and requires an average of 138 days for physiological maturity. The variety has nine leaves per plant, and 19.66 cloves per bulb. The variety produces large-sized bulbs and cloves that are white-skinned and creamy in flesh color. It has a large clove as well as bulb diameter which intern gives higher bulb yield of 13.03 t ha^{-1} **(Table 2).**

Garlic rust is a destructive and one of the most important fungal diseases of the crop in Ethiopia causing a total bulb yield loss as high as 58.75% [**11**]. Using host plant resistance to manage diseases is economical, long-lasting, effective, easy to handle and environmentally friendly. In view of this, we found that the newly released garlic variety "Qundi" is moderately susceptible to garlic rust disease with 55.83% rust severity. Hence, it is important to use this variety in combination with other cultural and chemical management practices. Bulb yield and yield advantage of Qundi (NG0048/04).

The combined analysis of variance over six environments revealed the presence of a statistically significant difference ($p < 0.05$) amongst garlic accessions for bulb yield. In a similar fashion as the agronomic traits, the newly released variety, Qundi (NG0048/04) shown superior

Table 2: Agronomic characters of Garlic genotypes combined over locations and year.

Genotypes	PH	LN	TH	TDM	BD	CNB	CDM	RS (%)
NG0008/04	67.4 ^{a}	8.05 ^{cde}	24.9 ^{ab}	12.88 ^{bc}	4.47 $^{a-d}$	21.74 ^{abc}	0.95 ^{bc}	45.83^{a-d}
NG0044/04	59.71 ^{e}	7.61 e	20.62^{g}	11.83 ^{cde}	4.39 $^{a-f}$	21.53 ^{abc}	0.91 ^{bc}	46.66 $^{a-d}$
NG0060/04	67.3^{a}	8.24 ^{bcd}	24.51 ^{ab}	13.95^{a}	4.15 c-f	20.25 $^{b-e}$	1.02^{ab}	50.83^{abc}
NG0062/04	62.48 ^{bcd}	8.5 ^{abc}	21.68 ^{fg}	12.73 ^{bcd}	4.20 $^{c-f}$	22.44 ^{ab}	0.91 ^{bc}	31.66^{de}
NG0048/04	68.84 ^{a}	8.61 ^{ab}	25.08 ^{ab}	13.33 ^{a}	4.69^{a}	19.66 $^{b-e}$	1.09 ^{a}	55.83 ^{a}
NG0049/04	60.78 ^{de}	8.64 ^{ab}	22.62 ^{def}	11.89 ^{cde}	4.32^{b-f}	17.58 ^{ef}	1.01 ^{ab}	35 $^{b-e}$
NG0055/04	68.05^{a}	8.32 $^{a-d}$	24.92 ^{ab}	13.3^{ab}	4.46a-e	21.05 ^{abc}	1.00 ^{ab}	39.16^{a-d}
DB052	66.74 ^{a}	7.97 ^{cde}	23.97 $^{a-d}$	12.41 $^{b-e}$	4.13^{def}	23.36 ^{a}	0.90 ^{bc}	53.33^{ab}
NG0007/04	63.94 ^{b}	8.81 a	24.16 ^{abc}	12.48 $^{b-e}$	4.29^{c-f}	20.65 $^{a-d}$	0.92 ^{bc}	30.83 ^{de}
NG0054/04	63.74 ^{bc}	8.22 ^{bcd}	23.85 $^{a-d}$	12.35 $^{b-e}$	4.67^{ab}	23.31 ^{a}	0.92 ^{bc}	48.33 $^{a-d}$
NG0047/04	62.96 ^{bcd}	8.3 ^{bcd}	22.96 $^{c-f}$	11.83 ^{cde}	4.28^{c-f}	23.11 ^{a}	0.86 ^{cd}	33.33^{cde}
NG0058/04	64.04 ^{b}	8.28 ^{bcd}	23.88 $^{a-d}$	11.8 ^{cde}	4.52^{abc}	17.91 ^{def}	0.98 ^{abc}	50.83 ^{abc}
NG0052/04	67.37 ^{a}	8.08 ^{cde}	25.22 ^{a}	12.62 ^{bcd}	4.34^{a-f}	19.76 $^{b-e}$	0.99 ^{abc}	48.33^{a-d}
NG0043/04	61.98 $^{b-e}$	7.83 ^{de}	22.3^{ef}	12.71 ^{bcd}	4.23^{c-f}	19.38 ^{cde}	1.00 ^{ab}	43.33 $^{a-d}$
MM-98	61.15 ^{cde}	8.31 $^{a-d}$	21.68 ^{fg}	11.62 ^{de}	4.07^{f}	19.94 $^{b-e}$	0.90 bc	32.5 ^{cde}
KURIFTU	46.91 ^{f}	7.88 ^{de}	15.73 ^{h}	9.04 ^{f}	3.$^{36 g}$	17.72 ^{ef}	0.77 ^{d}	19.16 ^{e}
LOCAL	60.71 ^{de}	7.68 ^{e}	23.58 $^{b-e}$	11.45 ^{e}	4.10 ^{ef}	16.16^{f}	0.98 ^{abc}	45.0 $^{a-d}$
Mean	63.18	8.2	23.04	12.25	4.27	20.33	0.94	41.76
CV (%)	5.89	8.23	8.77	11.54	11.2	18.09	17.15	32.7

PH: Plant height (cm), LN: leaf number, TH: trunk height (cm), TDM: trunk diameter (cm), BY: bulb yield (tha^{-1}), BD: bulb diameter (cm), CNB: clove number per bulb, CDM: clove diameter (cm), and RS: rust severity (%)

Table 3: Mean bulb yield of garlic genotypes across environments and their yield advantage.

Genotypes	Debre birhan			Ankober			Overall mean	YAOSC (%)	YAOLC (%)
	2015	2016	2017	2015	2016	2017			
NG0008/04	12.40 ^{bcd}	6.37^{abc}	9.96 ^{a}	12.48 ^{ab}	11.66 $^{a-d}$	19.30 ^{bc}	12.03 ^{b}	200.95	29.91
NG0044/04	11.63 $^{b-e}$	6.00 $^{a-d}$	9.26 ^{abc}	10.05 $^{c-f}$	10.11 ^{cde}	19.01 ^{bcd}	11.01 ^{d}	175.54	18.94
NG0060/04	13.11 ^{abc}	5.63 ^{bcd}	8.02 $^{a-d}$	11.01 $^{a-d}$	10.74 $^{b-e}$	18.18 $^{b-e}$	11.12 ^{cd}	178.14	20.06
NG0062/04	11.32^{b-e}	5.08 ^{d}	8.34 $^{a-d}$	9.39 ^{def}	8.45 ^{e}	15.20 $^{e-i}$	9.63 ^{e}	141.00	4.03
NG0048/04	13.00^{abc}	6.71 ^{ab}	9.66 ^{ab}	11.81 ^{abc}	14.03^{a}	22.98 ^{a}	13.03 ^{a}	226.11	40.77
NG0049/04	12.99 ^{abc}	5.13 ^{cd}	8.04 $^{a-d}$	10.28 $^{b-f}$	8.28 ^{e}	13.45 ^{hi}	9.70 ^{e}	142.65	4.74
NG0055/04	13.00 ^{abc}	5.75 $^{a-d}$	9.07 $^{a-d}$	11.18 $^{a-d}$	11.34 $^{a-e}$	18.85 ^{bcd}	11.53 ^{bcd}	188.54	24.55
DB052	11.47 $^{b-e}$	5.55 ^{bcd}	8.70 $^{a-d}$	11.42 $^{a-d}$	12.17^{abc}	20.24 ^{ab}	11.59 ^{bcd}	190.02	25.19
NG0007/04	14.05 ^{ab}	5.47 ^{bcd}	7.98 $^{a-d}$	8.70 ^{ef}	9.93 ^{cde}	14.05 ^{ghi}	10.03 ^{e}	151.00	8.35
NG0054/04	12.45 ^{bcd}	6.12 $^{a-d}$	9.39 ^{ab}	10.52 $^{b-f}$	13.33 ^{ab}	18.02 $^{b-f}$	11.64 ^{bcd}	191.20	25.70
NG0047/04	9.86 ^{de}	5.70 ^{bcd}	6.87 ^{d}	9.45 ^{def}	9.39 ^{cde}	16.57 $^{c-g}$	9.64 ^{e}	141.25	4.14
NG0058/04	11.73 $^{b-e}$	4.92 ^{d}	7.62 ^{bcd}	10.26 $^{b-f}$	9.58 ^{cde}	16.68 $^{c-g}$	10.13 ^{e}	153.55	9.45
NG0052/04	15.52^{a}	6.95 ^{a}	9.13 $^{a-d}$	12.82 ^{a}	10.37 $^{b-e}$	17.97 $^{b-f}$	12.13 ^{b}	203.43	30.98
NG0043/04	10.64^{cde}	6.01 $^{a-d}$	8.12 $^{a-d}$	8.48 ^{ef}	9.79 ^{cde}	16.12 $^{d-h}$	9.86 ^{e}	146.70	6.49
MM-98	9.17^{e}	5.90 $^{a-d}$	6.99 ^{cd}	8.29 ^{ef}	8.94 ^{de}	12.70 ^{i}	8.66 ^{f}	116.81	(-6.41)
KURIFTU	4.59^{f}	3.29 ^{e}	8.10 $^{a-d}$	4.23 ^{g}	3.07 ^{f}	5.61 ^{j}	3.99 ^{g}	0	(-56.83)
LOCAL	9.71^{de}	5.05 ^{d}	3.17 ^{e}	8.18 ^{f}	9.56 ^{cde}	14.95 $^{f-i}$	9.26 ^{ef}	131.67	0
Mean	11.50	5.63	8.14	9.91	10.04	16.46	10.29		
CV %	12.49	11.35	14.23	12.06	16.27	9.98	12.92		

YAOSC: yield Advantage over the standard check and YAOLC: yield Advantage over the standard check

yielding ability compared to all accessions and the checks with a mean bulb yield of 13.3 t ha^{-1}. The mean bulb yield of the newly released variety exceeded the standard and local check cultivars by 226.11 and 40.77%, respectively **(Table 3).**

Stability Analysis

A variety is considered to be more stable if it has a high mean yield but a low degree of fluctuation in yielding ability across diverse environments **[12].** Additive main effect and multiplicative interaction (AMMI) analysis has been shown to be more effective than the conventional two-way fixed effects model with interaction as it incorporates both the additive and multiplicative components of the two-way data structure **[8].** With this in mind, the AMMI analysis computed for the bulb yield of the genotypes revealed a significant difference among Environments, Genotypes and GxE interaction. Environment accounted for 62.27%, whereas genotype and GxE interaction accounted for 21.55 and 8.14% of the total variation, respectively **(Table 4).** The larger environmental sum square explained is an indication of a difference in the testing environments (i.e. seasonal variability and location effect). In addition, it indicates that the environment is the basic factor that influences the yield of garlic in Ethiopia. Genotype mean square revealed highly significant (P<0.01) variations for bulb yield. This is an indication of genetic differences among the tested genotypes for bulb yield. The GxE interaction was also significant and it is an indication of the varying bulb yield performance of garlic genotypes across the testing environments. As the first two

Table 4: AMMI analysis of variance for bulb yield (t ha^{-1}) of garlic accessions tested in six environments (i.e., two locations (Debrebirhan and Ankober) for three cropping seasons (2015-17).

Source	DF	SS	MS	Sum of square explained	
				% Total	% G x E
Total	305	543071	1781**		
Treatments	101	499434	4945**	91.96	
Genotypes	16	117028	7314**	21.55	
Environments	5	338175	67635**	62.27	
Block	12	9607	801**	1.77	
Interactions	80	44231	553**	8.14	
IPCA 1	20	29125	1456**		65.85
IPCA 2	18	9327	518**		21.09
Residuals	42	5779	138		13.07
Error	192	34029	177**	6.27	

* and **, significant at P<0.05 and P<0.01, respectively. IPCA 1 and 2 = interaction principal component axis one and two, respectively.

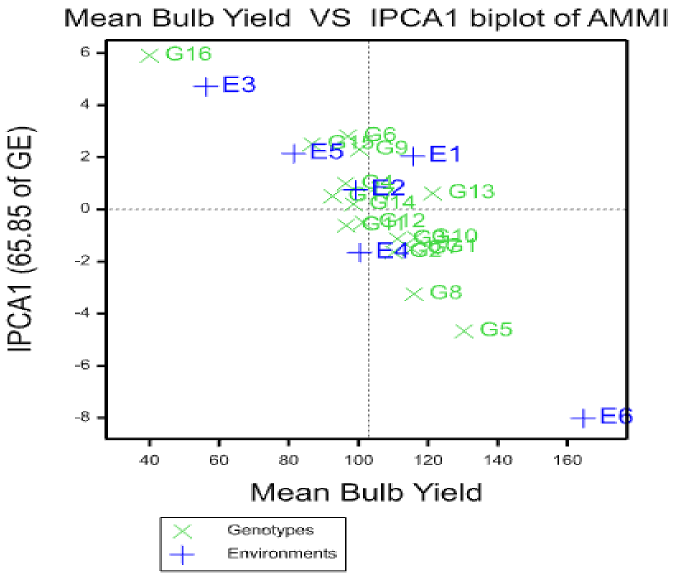

Figure 1: AMMI 1 biplot of mean bulb yield VS IPCA 1.

Where, Environments E1=Fajie in 2015, E2=Ankober in 2015, E3=Fajie in 2016, E4=Ankober in 2016, E5=Fajie in 2017, E6=Ankober in 2017) and Genotypes, G1= NG0008/04, G2= NG0044/04, G3=NG0060/04, G4= NG0062/04, G5= NG0048/04, G6= NG0049/04, G7= NG0055/04, G8= DB052, G9= NG0007/04, G10= NG0054/04, G11= NG0047/04, G12= NG0058/04, G13= NG0052/04, G14= NG0043/04, G15= MM-98, G16 = Kuriftu, and G17 = Local)

IPCA axes only were significant and explained the larger portion of the interaction, 86.94%. [**13**] suggested that the first two IPCA axes are the best predictive of the model the GxE interaction of this trait is going to be predicted by the first two IPCA axes only.

Based on AMMI 1 biplot, environments located at the right side of the vertical line are high yielding accessions and also environments located at the right side of the vertical line are favorable environments. Genotypes that are located closer to the horizontal line are deemed to be stable. Hence, it is only E1 and E6 are favorable environments as they are located at the right side of the vertical line. With respect to the genotypes, G5(NG0048/04), G8(DB052), G2(NG0044/04), G7(NG0055/04), G1 (NG0008/04), G3(NG0060/04), G10(NG0054/04) and G13(NG0052/04) are a high yielding genotypes as they had above average bulb yield and are located at the right side of the vertical line. Among the high yielder genotypes, G1(NG0008/04),G2(NG0044/04), G3(NG0060/04), G7(NG0055/04), G10(NG0054/04) and G13(NG0052/04) are the most stable genotypes as they are located close to the horizontal line. (**Figure 1**).

According to AMMI 2, environments located close to the origin are considered as less sensitive to the interaction and their contribution to the interaction is minimal and can be considered as the least discriminating environments and the reverse is true. Similarly, genotypes that are located near the origin are less sensitive to the interaction and can be taken as broadly adapted genotypes whereas those located far from the origin are sensitive to the interaction and considered as unstable or specifically adapted genotypes. Hence, based on the position of the environments on the biplot, E6, and E3 are the most discriminating environments as their vector from the origin is longer while E2, E4, E1 and E5 are the least discriminating environments as their vector from the origin is shorter. With respect to the genotypes, G1(NG0008/04), G2(NG0044/04), G3(NG0060/04), G4(NG0062/04), G7(NG0055/04), G10(NG0054/04), G11(NG0047/04), G12(NG0058/04), G14(NG0043/04) and G17(Local) are the most stable genotypes as they are located close to the biplot origin (**Figure 2**). Yet, calculating AMMI Stability Value (ASV) is a recommended metric to accurately rank genotypes based on their stability.

Based on the AMMI Stability Value, the genotype with the lower ASV is broadly adapted, while the genotype with larger ASV indicates the instability or the specific adaptability of the genotype. Thus based on AMMI stability value, the standard check variety Kuriftu, NG0048/04 and DB 052 are the most unstable genotypes or are specifically adapted genotypes as they have large AMMI stability value of 18.67, 14.62 and 10.19 respectively. In contrary NG0043/04, NG0058/04, and NG0047/04 and the local check genotype are the most stable or widely adapted genotypes as they scored least AMMI Stability value of 1.56, 1.83, 2.37 and 2.39, respectively (**Table 5**). Though NG0048/04 lacks stability it is the high yielder variety in almost all individual environments as well in overall mean of the test environments. In addition, NG0008/04 and NG0052/04 are high yielder genotypes with relatively broad adaptability.

Released variety characteristics and registration

Based on the yield performance generated from RVT, three promising garlic candidates such as NG0048/04, NG0052/04 and NG0008/04 were advanced to the Variety Verification Trial (VVT). These advanced candidate genotypes along with standard check (Kuriftu) were evaluated on 10 m x 10 m plots in five locations under the supervision of the National Variety Releasing Committee (NVRC) in 2021.

Table 5: IPCA 1 Score, IPCA 2 Score and AMMI Stability value of the tested garlic accessions.

NO.	*Accessions*	MBY	IPCA 1 Score	IPCA 2 Score	ASV
1	NG0008/04	12.03	-1.45202	0.17774	4.54
2	NG0044/04	11.02	-1.63675	0.50505	5.14
3	NG0060/04	11.12	-1.13228	-1.5794	3.87
4	NG0062/04	9.64	0.98579	-0.60521	3.14
5	NG0048/04	13.04	-4.67121	0.96331	14.62
6	NG0049/04	9.70	2.80719	-2.77684	9.19
7	NG0055/04	11.54	-1.50266	-0.89002	4.78
8	DB052	11.59	-3.25149	0.87934	10.19
9	NG0007/04	10.04	2.29905	-2.61767	7.64
10	NG0054/04	11.64	-1.08358	0.98015	3.52
11	NG0047/04	9.65	-0.61432	1.38824	2.37
12	NG0058/04	10.14	-0.49281	-0.99256	1.83
13	NG0052/04	12.13	0.61826	-3.6843	4.16
14	NG0043/04	9.86	0.20203	1.42803	1.56
15	MM-98	8.67	2.50715	2.22482	8.13
16	KURIFTU	4.00	5.9086	2.81945	18.67
17	LOCAL	9.26	0.50904	1.77986	2.39

MBY: mean bulb yield in tha^{-1}; and ASV: AMMI Stability Value

Table 6: Agro morphological characteristics of 'Qundi' (NG0048/04) garlic variety as compared to standard check 'Kuriftu'.

Character	Qundi(NG-0048/04)	Kuriftu
Altitude	2850 to 3145 m a.s.l (Mid to high altitude garlic grown areas of North shewa)	1800-2500 m above sea level (Medium to high altitude)
Rainfall	934-1700 mm	760-1010 mm
Planting season	Year-round under both rain-fed and irrigated conditions	Year-round under both rain-fed and irrigated conditions
Planting date	At the start of the main rainy season (mid to late June) and at any time with irrigation considering the frost period	At the start of the main rainy season (June) and at any time with irrigation considering the frost period
Seed rate (t ha^{-1})	0.8-1.4	0.8 – 1.0
Row spacing (cm)	30	30
Plant spacing (cm)	10	10
Fertilizer rate (kg ha^{-1})	92 kg P_2O_5(242 kg NPS), and 46 kg N (100 kg Urea)	92 kg P_2O_5 (200 kg DAP), 105 kg N (69 kg N from 150 kg Urea and 36 kg N from the 200 kg DAP)
Fertilizer application time and method	Whole dose of phosphorus is applied by drilling in rows just before planting through NPS at planting plus half of N at planting and the remaining half of N 45 days after planting.	Whole dose of phosphorus is applied by drilling through DAP (200 kg) plus half N through DAP and 36 kg urea ha^{-1} at planting and half N (114 kg urea) at active vegetative growth stage
Days to maturity	138	140
Crop pest reaction	Moderately susceptible to garlic rust	Moderately resistant to garlic rust
Foliage color	Green	Green
Skin color	White	white
Flesh color	Creamy	Creamy
Number of cloves per bulb	19.66	16.16
Plant height(cm)	68.84	55.12
Shaft length(cm)	25.08	24.12
Shaft thickness(cm)	13.33	1.63
Leaves per plant	8.61	9.4
Cloves per bulb	19.66	16.16
Yield (tha^{-1}): research field	13.03	3.99
Yield (tha^{-1}):farmers' field	6.68-14.62	1.83-5.9
Year of release	2021	2010
Breeder/Maintainer	DBARC/ARARI	DZARC/EIAR

Finally, based on the result of VVT, the NVRC has decided to release and registration of accession NG-0048/04 as a new variety for production in the highlands of North Shewa and other similar agro-ecologies in Ethiopia. Moreover, based on the ownership of Deber Brihan Agricultural Research Center, the name of the newly released garlic variety is decided to be "Qundi". Detail Qundi variety characteristics, disease reaction and yield advantage over the candidates are presented in **Table 6.**

Agro morphological characteristics of the released variety

The released variety has deep green foliage and vigorous growth. It has a pseudo stem height of 68.84 cm and requires an average of 138 days for physiological maturity. The variety has nine leaves per plant, 19.66 cloves per bulb, and a 4.69 cm bulb diameter. The variety produces large-sized bulbs and cloves that are white-skinned and creamy in flesh color. It has a large clove as well as a bulb diameter,

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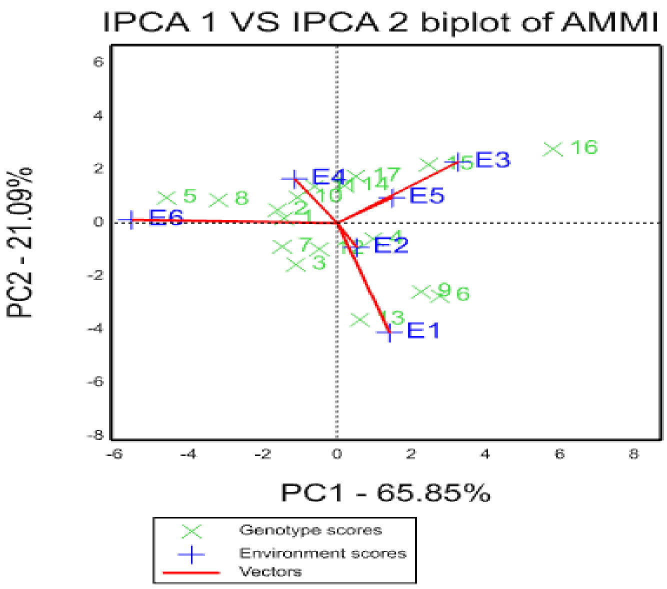

Figure 2: AMMI 2biplot of IPCA1 VS IPCA 2.

Where, Environments E1=Fajie in 2015, E2=Ankober in 2015, E3=Fajie in 2016, E4=Ankober in 2016, E5=Fajie in 2017, E6=Ankober in 2017) and Genotypes, G1=NG0008/04, G2= NG0044/04, G3=NG0060/04, G4= NG0062/04, G5= NG0048/04, G6= NG0049/04, G7= NG0055/04, G8= DB052, G9= NG0007/04, G10= NG0054/04, G11= NG0047/04, G12= NG0058/04, G13= NG0052/04, G14= NG0043/04, G15= MM-98, G16 = Kuriftu, and G17 = Local)

which intern gives a higher bulb yield (i.e., 13.03 t ha^{-1} and 6.68-14.62 t ha^{-1} at research and farmers' field, respectively) **(Table 3).**

Disease reaction of the released variety

Garlic rust is a destructive and one of the most important fungal diseases of the crop in Ethiopia causing a total bulb yield loss as high as 58.75% **[11,14]** Using host plant resistance to manage diseases is economical, long-lasting, effective, easy to handle and environmentally friendly. In view of this, we found that the newly released garlic variety "Lake" is moderately susceptible to garlic rust disease. Hence, it is important to use this variety in combination with other cultural and chemical management practices **[15,16].**

Yield potential and advantage of the released variety

The newly released variety, Qundi (NG0048/04), showed better performance on the morphological and agronomic characteristics compared to the standard check (Kuriftu). It has shown superior yielding ability, producing a mean bulb yield of 13.3 t ha^{-1}. The mean bulb yield of the newly released variety exceeded the standard and local check cultivars by 226.11 and 40.77%, respectively **(Table 3).**

Conclusion and Recommendations

The ultimate goal of any breeding program is to develop a cultivar which are adapted to a specific or wider range of environments with due consideration to the existing biotic and abiotic constraints and preferences of end users. Based on the result obtained from RVT and VVT, the candidate variety Qundi (NG-0048/04) was found superior to the standard check Kuriftu and other candidate accessions in terms of clove number per bulb, clove weight and bulb yield. The average bulb yield of Qundi across locations and years was about 13.03 t ha^{-1}. It also has better yield stability than the checks. The candidate variety has the yield advantage of 226.11 and 40.77% over the standard check 'Kuriftu' and Local check cultivars, respectively. Therefore, Qundi (NG-0048/04) should be released as one improved variety for the sustainably and profitable garlic production in the highlands of North Shewa and other similar agro-ecologies in Ethiopia. moreover, maintenance, multiplication and popularization of the released variety in the should be done by by DBARC.

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