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Research Article

Evaluation of Improved Head Cabbage (*Brassica oleraceae* var *capitata oleraceae* L.) Varieties for Head Yield in West Hararghe, Eastern Oromia, Ethiopia

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Abstract

Cabbage (*Brassica olearacea* var *capitata* L.) is one of the most important leafy vegetables worldwide and is adapted to cool, moist conditions. This study aimed to identify high-yielding, disease-tolerant and adaptable cabbage varieties suitable for the study areas. Four head cabbage varieties (Chaka, Tana, Cabbice and Copenhagen Market) were evaluated using randomized complete block design with four replications. The experiment was conducted in Chiro, Tulo and Oda bultum districts during 2023 and 2024 cropping season. The results of the combined analysis of variance (ANOVA) showed the presence of highly significant (P<0.01) differences among varieties for all traits studied, except number of expanded true leaves. The mean squares for location were also significant, indicating the influence of environmental factor on the performances of the tested varieties. From the combined analysis of variances, Cabbice variety produced the highest head yield (126. t ha^{-1}, followed by Tana variety (100.38t ha^{-1}). In contrast, the lowest total head yield (92.52 t ha^{-1}) was recorded from Copenhagen Market variety. AMMI analysis showed that the effect of environments, varieties and their interaction effects were highly significant. The stability and yield performance of the varieties were further explained using a GGE bi-plot. Significant variation in head yield among the varieties was observed across different environments. Cabbice variety exhibited wide adaptability and superior yield performance across high yielding environments. Generally, the study indicated that Cabbice variety was recommended for the study areas and other similar ago-ecologies for further demonstration and scaling up.

Keywords

Adaptation, Cabbage, Genotype x Environment Interaction, Head Yield, Stability Analysis

1. Introduction

Cabbage (*Brassica oleracea var. capitata* L.) is an important Cole crop which is a member of the family *Brassicaceae*. It is native of Western Europe and the Northern Shore of Mediterranean Region [1, 2]. Cabbage originated from the wild, leafy, non-heading types 'Cole wart' (*Brassica olearacea var. sylvestris*) [3]. Cabbage is one of the most ancient vegetables cultivated for more than 4,000 years [1, 4]. Cabbage is used commonly as vegetables. It is also used for salad mixed in tomato, green chilies, beetroot etc. It is a rich source of sulfur containing amino acids, minerals, carotenes ascorbic acid and antioxidants, and is reported to have anti-carcinogenic properties [5]. It is also an excellent source of vitamins

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A, C, K, B1, B2, and B6, calcium, dietary fiber and protein when it is eaten raw as salad and boiled or cooked as stew or soup [6]. There are three types of heading cabbage namely green, red and Savoy. They contain different amounts of nutrients with Savoy being more superior [7].

Cabbage and other *brassicae* are produced in more than 145 countries in the world. The leading cabbage producing countries in the world are China, India, Russian, Federation, Japan and Republic of Korea, respectively. China and India produced about 60% of the world's cabbage production with a share of 46.4% and 12.8% respectively. Cabbage is the second most important vegetable crop in Ethiopia both in area coverage as well as level of production next to red pepper, or *capsicum* species [8].

Head cabbage has a short stem and a globular head of tightly overlapping green to purplish leaves. As far as their heads are concerned, they are compactor loose. It is a biennial crop that is grown as an annual which takes 6 - 11 weeks from planting to the end of the vegetative stage. Cabbage is a cool season crop which requires adequate availability of soil water and plant nutrients for optimum growth. It has a moderately high frost tolerance. It will grow at 7°C, but it does best from 15.5-18°C, above 27°C the plants may bolt, causing the heads to split open [9]. Cabbage seed germinates in about two weeks in soils with temperature as low as 10°C, which allows for early plantings in cooler regions [10]. Depending on the variety, cabbage requires 60 to 100 days from sowing to reach market maturity. A well-drained sandy loam soil with good organic content and soil pH of between 6.0 and 6.5 is preferred [11].

According to a CSA (Central Statistical Agency) report, in [12] and [13], in Ethiopia the total production of head cabbage was 245,650.47 and 561,042.34 quintals, respectively which were increased by 128.39%. In the same year the area covered by head cabbage was 3,629.92 and 6,649.67 ha, respectively which was increased by 83.19%. Similarly, in Oromia the crop is now produced by 268,506.47 farmers with area coverage of the crop 4,198.46 ha and who collectively yield 92.59qt/ha [13]. The productivity of cabbage in Ethiopia is very low (9.259 t ha^{-1}) [13]. According to [14] under rain fed conditions, yields of 25 to 35 tone ha-1 fresh heads are normal, with a maximum of about 50 tone ha-1 when sprayed and well-fertilized. Under ideal climatic conditions and good irrigation and crop management, yields can be as high as 85ton/ha.

In the West hararghe zone, head cabbage is produced by small scale farmers for food stuff and local markets throughout the year; however, the growers are growing less productive and unimproved varieties. In order to increase the production and productivity of head cabbage, there was no exhaustive research done so far; rather some adaptation and agronomic trial was conducted in some other part of Ethiopia. So far there has been no cabbage adaption trial conducted in the study area. However, there is a shortage of research on head cabbage in terms of variety release, adaptation and agronomic aspects in west hararghe despite the importance of the crop. So, it is very important to support the production of head cabbage by research in order to improve the production and productivity. For this reason, the experiment was conducted with the objective of selecting and identifying the most adaptable, high yielding and disease tolerant/resistant head cabbage varieties for the study areas.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted under rain fed conditions during the year 2023 and 2024 cropping season at Chiro, Tulo and Oda Bultum distincts.

Table 1. *Description of the study area.*

Distincts	Latitude	Longitude	Altitude (m a.s.l)	Annual Average Temperature (°C)	Annual Rainfall (mm)
Chiro	9°07′N	40°87′E	1792	21	876
Tulo	9°20′N	41°10′E	1800	19	995
Oda Bultum	8°91′N	40°77′E	1703	20	1053

2.2. Experimental Materials and Design

The experiment was conducted using four recently released varieties of head cabbage: Chaka, Tana, Cabbice and Copenhagen Market. The experiment was laid out in Randomized Complete Block Design (RCBD) with four replications. Each plot measured 3.2 m x 2.4 m = 7.68m^2 wide and consisted of four rows, with 8 plant per row, making a total 32 plants per plot. Cabbage seedling were raised on a flatbed nursery for one month and then transplanted onto the sides of the ridge when they develop two pairs of true leaves or reached a height 8 - 13cm. Spacing was maintained at 40cm between plants and 60cm between rows. All Agronomic practices were applied with recommended the crop management practices.

Table 2. Description of Cabbage varieties.

S/No	Variety Name	Year of Release	Seed Source
1	Chaka	2021	Green Life Trading PLC.
2	Tana	2018	Markos Trading PLC.
3	Cabbice	2021	Green Life Trading PLC.
4	Copenhagen Market	1909	Green Life Trading PLC.

2.3. Data Collection

Data was collected from ten plants of two internal rows of each plot and randomly tagged and the relevant data was recorded. All plants from the net plot/ two internal rows of each were subjected to yield and yield traits evaluation. The following major parameters were recorded: *Plant height (cm):* The height of the plant was measured by placing a meter scale from ground level to the tip of the outer longest leaf of an individual centimeter (cm) plant at the time of 90% days to head maturity. *Number of expanded true leaves per plant:* The number of leaves per plant was counted and the mean of ten plants was recorded before the start of head initiation excluding unfolded and dead leaves. *Fresh weight of trimmed head mass:* The fresh weight of marketable head per plant was found from the average weight of ten plants and expressed in kilogram (kg) when yield data was taken. *Fresh weight of untrimmed head mass:* The fresh weight of head with unfolded leaves per plant was found from the expressed in kilogram (kg) yield data was taken. *Head height:* Head height (cm) was obtained from ten representative plants per plot and measured by cutting vertically using a ruler at the time of harvesting. *Diameter of head (t ha^{-1}):* Head diameter was obtained from ten representative plants per plot and measured by cutting vertically using a ruler at the time of harvesting. *Marketable head yield (t ha^{-1}):* Heads which were free from any damages and decay as well as those which haven't loose and open heads were considered as marketable. *Unmarketable head yield (t ha^{-1}):* Those heads which did not fulfill the criterion including the wrapper leaves were considered as unmarketable *Total Head yield (t ha^{-1}):* The total yield was then obtained by adding the marketable and unmarketable yields and used for further analysis.

2.4. Data Analysis

Analysis of variance procedures was used on every measured parameter to determine the significance of differences between means of treatments by using R statistical software version 4.5.2 for each parameter and separated by the least significant difference (LSD) using the statistical package. The means was compared using LSD at a probability level of 5%.

2.4.1. AMMI Analysis

Head yield was analyzed using the additive main effect and multiplicative interaction (AMMI) model, which was proposed for the AMMI analysis of variance (ANOVA) [15].

The AMMI model equation is as follows:

$$Yij=\mu + Gi +Ej+K=1nkikjk+pij+\varepsilon ij$$

Where, Yij is the mean grain yield of the ith genotype in the jth Environment, μ is the grand mean;

G_i and E_j are the genotype and environment deviation from the grand mean, respectively, ik and jk are the eigenvalue of the kth interaction PCA (IPCA) sustained in the AMMI model, the eigenvectors for the ith genotype from nth IPCA, and the eigenvectors for the jth Environment from the nth IPCA, respectively. n is the maximum number of multiplicative terms; pij is the GEI residual; ε_{ij} is the residual error term.

2.4.2. GGE- biplot Analysis

Head yield was analyzed using the genotype main effect and genotype plus environment interaction effect (GGE) model. The GGE model equation described according to [16] was used as below:

$$Yij\text{-}\mu\ \text{-}\beta j=\lambda 1\xi i1\text{-}\eta j1+\lambda 2\xi\ i2 - \eta j2 + \varepsilon ij$$

Where, Y_{ij} is the mean for the ith genotype in the jth Environment, μ is the grand mean, β_j is the main effect of environment j, λ_1 and λ_2 are the singular values decomposition of the first and second principal components (PC1 and PC2), ξ_{i1} and ξ_{i2} are the PC_1 and PC_2 scores, respectively, for genotype ith, η_{j1} and η_{j2} are the eigenvectors for the jth Environment for PC1 and PC2, and ε is the residual error term.

3. Results and Discussion

The results of analysis variances (ANOVA) based on the combined means across locations are presented in (Table 3). Highly significant differences ($P < 0.01$) among varieties were observed for all measured traits except number of expanded true leaves.

This indicated the existence of substantial genetic variability among tested head cabbage varieties. Similarly, location had significant (P<0.05) to highly significant (P<0.01) effects on most traits, indicating the strong influence of environmental conditions on varietal performance. The year effect was significant for head length, head diameter, marketable height yield and total head yield, showing variable climatic conditions between seasons. However, fresh weight of trimmed head, number of expanded true leaves per plant, plant height and unmarketable head yield were not significantly affected by year. The Interaction effect of varieties by location (GxE) was showed significant (P<0.05) affect for all considered traits number of expanded true leave per plant, unmarketable head yield and plant height, suggesting differential varietal responses across environments.

Table 3. Mean squares from the analysis variance of four head cabbage varieties for head yield and yield related traits at three locations over two years.

Mean Square										
Source of variation	**DF**	**PH**	**NETL**	**FWTH**	**FWUTH**	**HL**	**HD**	**MHY**	**UMHY**	**THY**
Variety (V)	3	310.79**	1.45ns	2.32**	4.63**	16.00**	30.44**	2142.60**	1387.90*	5205.00**
Location (L)	2	202.04**	11.86**	1.48**	2.30**	78.58**	3.72ns	1423.50**	8198.00**	3145.10*
Rep	3	7.86ns	1.73ns	0.06ns	0.16ns	4.02ns	1.03ns	58.70ns	1478.50*	1943.20*
Year (Y)	1	17.09ns	0.14ns	0.20ns	1.30*	27.86**	33.54**	4061.40**	100.30ns	5438.50**
Variety: Location	6	16.01ns	1.68ns	0.45*	0.71*	6.76*	6.19**	677.00**	262.40ns	1269.40*
Variety: Year	3	22.77ns	1.84ns	0.26ns	1.04*	3.94ns	1.07ns	150.30ns	120.60ns	395.20
Location: Year	2	230.72**	37.42**	7.57**	10.48**	84.30**	88.47**	9320.80**	244.00ns	11090.30**
V: L: Y	6	25.70*	1.52ns	0.63**	0.59*	3.82ns	3.45ns	498.80*	257.90ns	392.70ns
Residuals	69	11.40	1.23	0.18	0.27	2.32	1.99	217.60	503.40	654.10

key: **: Highly Significant (P<0.01); *: Significant (P<0.05), ns: non-significant,; DF: Degree of Freedom; PH: Plant Height (cm); NETL: Number of True Leaves per plant; FWTH: Fresh Weight of Trimmed Head (kg); FWUTH: Fresh Weight Untrimmed Head (kg); HL: Head Length (cm), HD: Head Diameter (cm); MHY: Marketable Head Yield (t ha^{-1}); UMHY: Unmarketable Head Yield (t ha^{-1}) and THY: Total Head yield (t ha^{-1})

3.1. Performance of Varieties for Growth Traits

Plant Height

The tallest plant height was recorded from Chaka variety (36.14cm), followed by Cabbice (30.88cm), which did not differ statistically from Tana (30.67cm). The shortest plant height was recorded for the Copenhagen variety (27.45cm) (Table 4). The variation in plant height among the tested varieties likely reflects genetic differences and environmental effects. These result is agree with [17], who found a significant effect of environments and varieties on plant height in western Ethiopia.

3.2. Performance of Varieties for Head Yield and Yield Related Traits

3.2.1. Fresh Weight of Trimmed and Untrimmed Head Mass

The highest fresh weight of trimmed head mass was recorded from Cabbice variety (2.56kg), which was statistically similar to Chaka variety (2.49kg) and the lowest fresh weight of trimmed head mass was recorded from Copenhagen variety (1.91kg) (Table 4). The variation may be attributed to the differences in genetic potential among head cabbage varieties. These results agree with [18], who found significant differences in fresh weight of trimmed and untrimmed head mass among cabbage varieties.

3.2.2. Head Length and Head Diameter

The maximum head length was recorded from Cabbice variety (18.10cm), which did not differ statistically from Chaka (18.07cm) and Tana (17.46cm) varieties, while the lowest head length was recorded from Copenhagen variety (16.35cm) (Table 4). The maximum head diameter was recorded from the Cabbice variety (19.34cm), which was statistically similar to Chaka variety (18.71cm). The lowest head diameter was recorded from the Copenhagen variety (16.71cm) (Table 4). The variation among varieties for agronomic and yield traits, indicated the presence of variability, which could be attributed to the genetic potential of the varieties used among the evaluated varieties and for the traits under consideration. This result is agreed with the findings of [19], who found significant differences in head length and head diameter among cabbage varieties.

3.2.3. Marketable and Unmarketable Head Yield

The highest marketable head yield was recorded from Cabbice variety (91.29t ha^{-1}), followed by Chaka (83.69 t ha^{-1}) while, the Copenhagen (69.89 t ha^{-1}) had the lowest marketable head yield (Table 4). The highest unmarketable head yield was recorded from Cabbice variety (34.8 t/ha), which was statistically similar to Tana (25.68 t ha^{-1}) and Copenhagen (22.21 t ha^{-1}), which could be due to disease and produce under size heads. However, the lowest unmarketable head yield (16.67 t ha^{-1}) was recorded from the Chaka variety (Table 4). Variation among varieties for unmarketable yield could be attributed to their genetic make-up. The research reported that marketable head yields significantly varied among varieties [17, 19]. Similarly, other authors reported significant differences in marketable head yield among cabbage varieties [18, 20].

Table 4. *Combined means yield and yield related traits of head cabbage varieties at three locations (Chiro, Tulo and Oda bultum,) over two years.*

Variety	PH	NETL	FWTH	FWUTH	HL	HD	MHY	UMHY	THY
Cabbice	30.88b	9.33	2.56a	2.97a	18.10a	19.34a	91.29a	34.80a	126.10a
Chaka	36.14a	9.9	2.49a	3.13a	18.07a	18.71ab	83.69a	16.67b	100.36b
Copenhagen	27.45c	9.73	1.91b	2.15c	16.35b	16.71c	69.89b	22.21ab	92.10b
Tana	30.67b	9.75	2.10b	2.56b	17.46a	18.10b	75.05b	25.68ab	100.73b
Means	31.29	9.68	2.27	2.7	17.5	18.22	79.98	24.84	104.82
LSD (5%)	1.94	0.66ns	0.24	0.3	0.92	0.84	8.52	13.5	15.19
CV (%)	10.79	11.77	18.72	19.09	9.10	8.02	18.44	90.00	25.1

Key: PH: Plant Height (cm); NETL: Number of True Leaves per plant; FWTH: Fresh Weight of Trimmed Head (kg); FWUTH: Fresh Weight Untrimmed Head (kg); HL: Head Length (cm); HD: Head Diameter (cm) MHY: Marketable Head Yield (t ha^{-1}); UMHY: Unmarketable Head Yield (t ha^{-1}) and THY: Total Head Yield (t ha^{-1})

3.2.4. Total Head Yield

The highest total head yield was recorded from Cabbice variety (126.10t ha^{-1}), followed by Tana (100.73 t ha^{-1}), while the lowest total tuber yield was recorded from Copenhagen market variety (92.10 t ha^{-1}) (Table 4) and (Table 5). The variation between varieties for head yield might be due to the presence of genetic differences used in the development of these varieties. This result is similar with the findings of [19] who found significant differences in total head yield (88.72-118.11 t ha^{-1}) among cabbage varieties. These result similar with [17], who found a significant effect of environments and varieties. [18] also reported that cabbage varieties had a significant difference with respect to total head yield (124.49-164 t ha^{-1}).

Table 5. *Means of head yield (t ha^{-1}) Cabbage varieties at three locations and over two years.*

Distincts							
Variety	Oda bultum		Tulo		Chiro		Overall Mean
	2023	2024	2023	2024	2023	2024	
Cabbice	164.41a	105.34	146.29a	98.52a	103.71a	138.26a	126.09a
Chaka	120.36ab	102.34	100.54b	73.83ab	88.71ab	116.40ab	100.36b
Copenhagen	113.29b	67.56	110.19b	94.96a	70.1b	96.59b	92.10b
Tana	144.31ab	111.87	112.75ab	65.68b	73.55ab	96.20b	100.73b
Means	135.59	96.77	117.44	83.25	84.02	111.86	104.82

Distincts							
Variety	Oda bultum		Tulo		Chiro		Overall Mean
	2023	2024	2023	2024	2023	2024	
LSD 5%	45.46	44.46ns	34.83	26.13	32.9	26.30	14.73
CV%	20.96	28.72	18.54	19.62	24.49	14.70	24.40

3.3. AMMI Analysis of Variance (AMMI ANOVA)

AMMI analysis indicated that head yield was significantly ($p<0.01$) affected by environments (E), varieties (G) and the first interaction principal components axis (IPCA1), while the second interaction principal component axis (IPCA2) was not significant. The genotype x environment (GxE) interaction was indicated significant at ($P<0.05$) in (Table 6). This showed that the varieties responded differently to different environments or those varieties responses were affected by the environment, and thus, the test environment were highly variable. The AMMI model (Table 6) explained three of the principal component axes, demonstrating the existence of GxE interaction. Many researchers observed that the most accurate AMMI model estimate can be made using the first two IPCAs [16]. The remaining interaction principal component axis captured mostly non-predictive random variation and did not fit to predict validation observations [21, 22]. Based on this, the first and second interaction principal components explained 87.5% of the total variation (IPCA1= 61.8% and IPCA2 = 25.7%). The first two interaction principal components (IPCA1 and IPCA2) together captured above 50% interaction principal components.

Table 6. Analysis variance of AMMI model for head yield of Cabbage varieties.

Source of Variation	Df	SS	MS	%G*E	% Accumulated Interaction
Environment (E)	5	33909.38	6781.88**		
Varieties (G)	3	15614.89	5204.96**		
Interaction (G*E)	15	11158.33	743.89*		
IPCA1	7	6900.80	985.83*	61.8	61.8
IPCA2	5	2865.27	573.05ns	25.7	87.5
IPCA3	3	1392.26	464.09ns	12.5	100
Residuals	54	27132.92	502.46		

**: highly significant ($P<0.01$); *: significant ($P<0.05$); IPCA1: Interaction principal component axis 1; IPCA2 = Inter principal component 2; IPCA3 = Inter principal component axis 3; DF: Degree freedom; SS: Total sum squares; MS: Mean sum squares; %G*E: Percentage of genotype by environment interaction

3.4. Genotype and Genotype by Environment Interaction (GGE) Bi-plot Stability Analysis

Genotypes that fall in the central (concentric) circle are considered as ideal stable genotypes [23]. A genotype is more desirable if it is located closer to the ideal genotype. Thus, using the ideal genotype as the center, concentric circles were drawn to help visualize the distance between each genotype and the ideal genotype. Therefore, the ranking based on the genotype-focused scaling assumes that stability and mean yield are equally important [24]. Accordingly, Cabbice variety fell into the nearest of concentric circles and thus was found to be the ideal variety in terms of higher yielding ability and stability, compared with the rest of the varieties (Figure 1).

Figure 1. *GGE Biplot view of ranking Cabbage varieties. Blue and green colors stand for genotypes and environments, respectively.*

3.5. Mean Performance and Stability of Varieties

The AEC Y- axis or the stability axis passes through the plot origin with a double arrow head and is perpendicular to the AEC X-axis. The single – arrowed line is the AEC abscissa, pointing to higher mean yield across location. A genotype which has shorter absolute length of projection in either of the two directions of AEC ordinate (located closer to AEC abscissa), represents a smaller tendency of variety by location interaction, which means it is the most stable and adaptable variety across different environments. Therefore, mean performance and stability of varieties indicated that variety Cabbice was highly stable, while Tana, Chaka and Copenhagen were found to be the most variable with low yield performances and unstable (Figure 2).

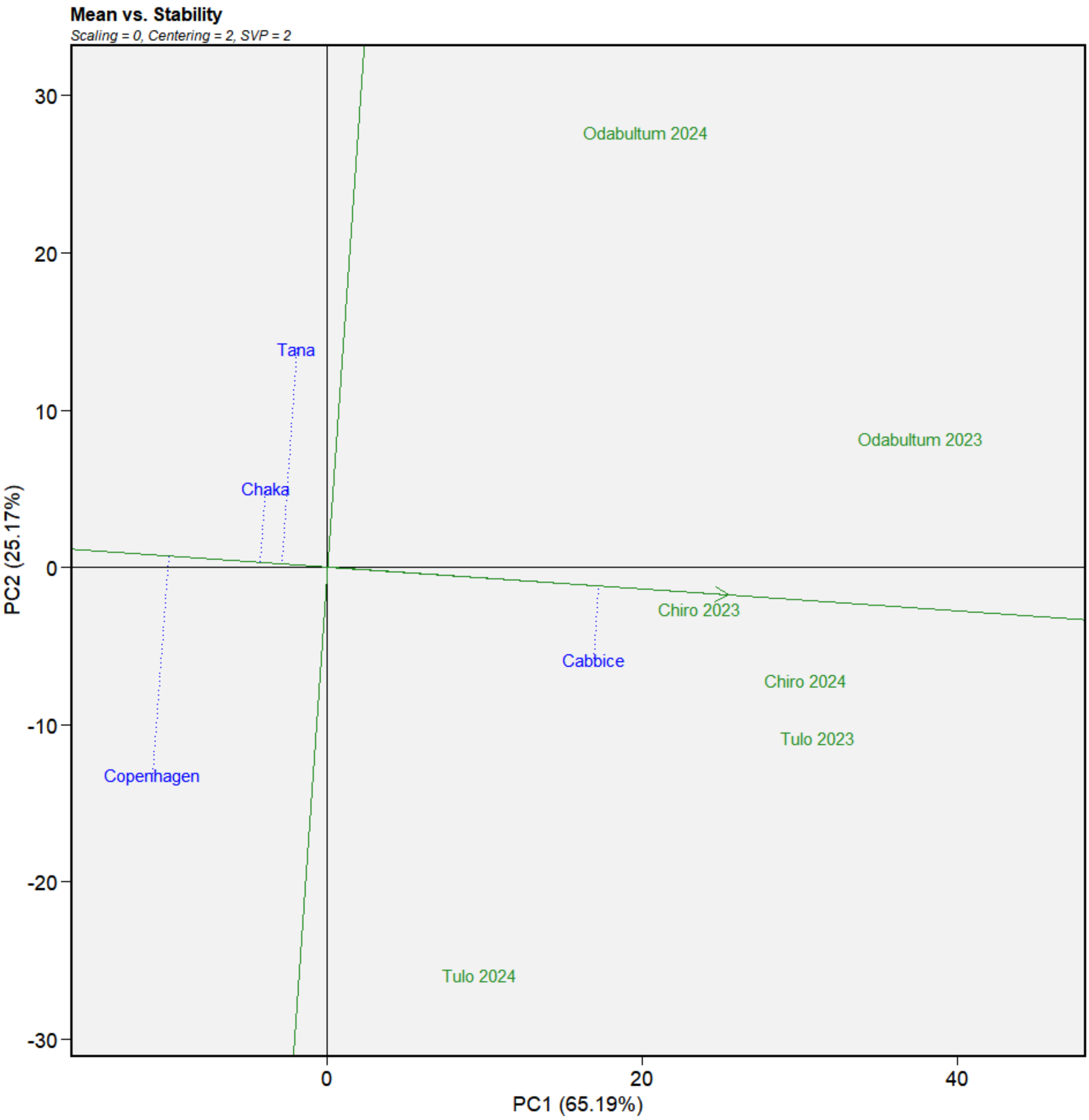

Figure 2. *Mean vs. stability pattern of GGE biplot showing interaction effect of cabbage varieties. Blue and green colors stand for genotypes and environments, respectively.*

3.6. "Which-Won-Where" Patterns of Genotypes and Environments

Visualization of the which-won-where pattern is important for studying the possible presence of different mega-environments (ME) in a region [16]. The polygon view of a GGE-biplot explicitly shows the which-won-where pattern and hence, concise summary of the GEI (Figure 3). By connecting the markers of the genotypes and the rays as showed, the ray in Figure 3 are lines that are perpendicular to the sides of the triangular or their extensions. These three (3) rays divide the biplot into three (3) sectors, but environments fall into two of them, so the genotypes vertex in these sectors may have higher or the highest yield compared to other parts in all environments [22]. Five environments, Oda bultum 2023, Tulo 2023, Chiro 2023, Tulo 2024 and Chiro 2024, fell into sector 2, and the vertex variety for this sector was Cabbice, suggesting that this is a higher- yielding variety for these five environments (Figure 3). One environment, Oda bultum 2024 fell into sector 1, and the vertex varieties for this sector were Tana and Chaka, suggesting that these are higher-yielding varieties for this one environment (Figure 3).

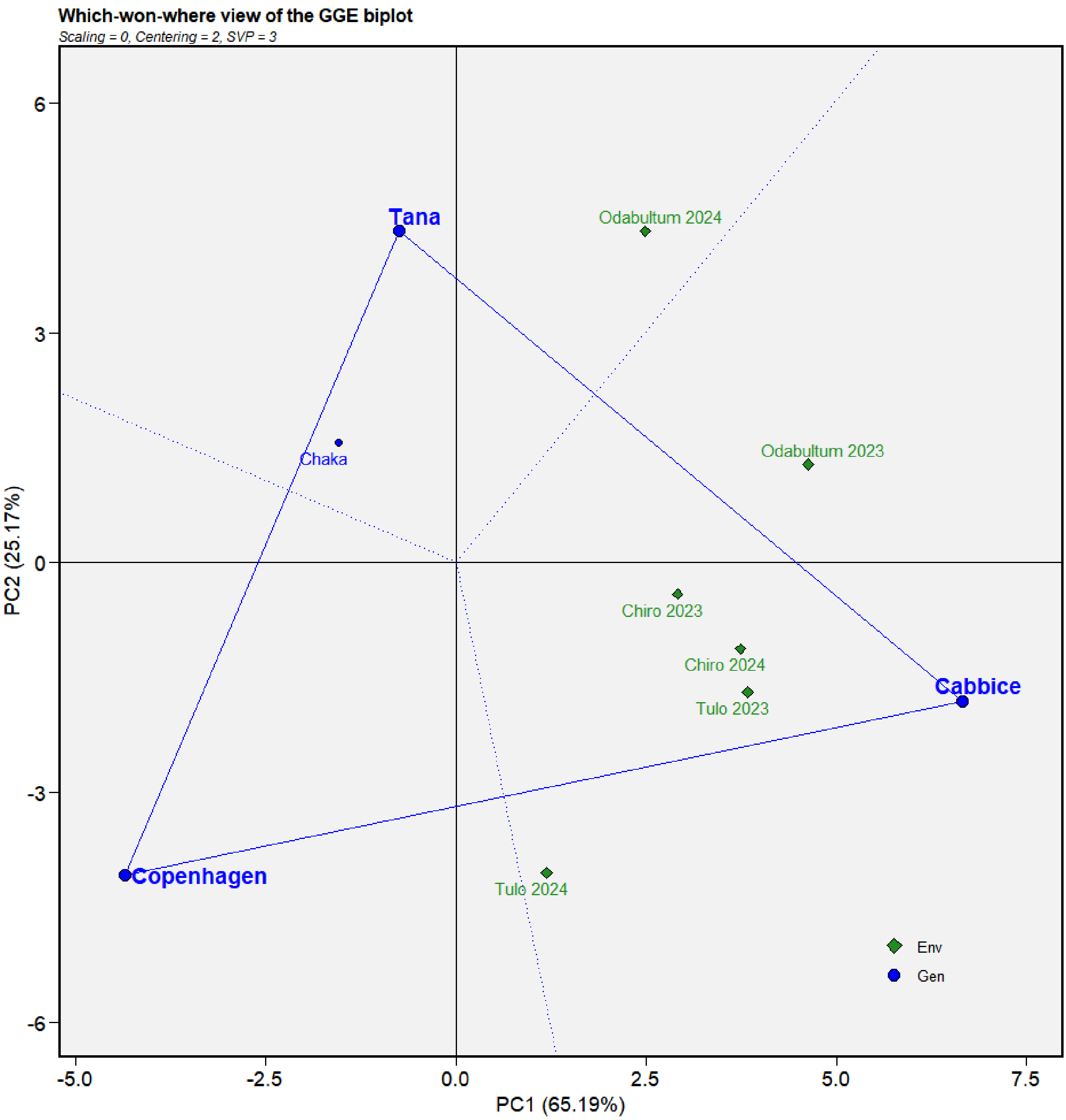

Figure 3. GGE-biplot views of the which-won-where pattern for cabbage varieties and environments. Blue and green colors stand for varieties and environments, respectively.

4. Conclusion and Recommendation

The Analysis results indicated significant variation among cabbage varieties for important agronomic and yield traits including, head length, fresh weight of trimmed head per plant, head diameter, marketable and total head yield were significantly different among the head cabbage varieties. Accordingly, the highest marketable head yield (91.29 t ha^{-1}) and total head yield (126.10 t ha^{-1}) was recorded from the Cabbice variety respectively. Generally, Cabbice variety was identified as the highest head yielding and adaptable variety to the study area under rain fed condition. Therefore, Cabbice variety was recommended for the study areas and other similar ago-ecologies for further demonstration and scaling up.

Abbreviations

ANOVA	Analysis of variance
AMMI	Additive Main Effects and Multiplicative Interaction
CSA	Central Statistical Agency
FAO	Food Agricultural Organization
GEI	Genotype by Environment Interaction

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Author Contributions

Dagne Assefa: Conceptualization, Methodology, Project administration, Data curation, Software, Formal Analysis, Investigation, Validation and visualization, Writing – original draft

Gezahegn Assefa: Data curation, Supervision, Investigation, Writing – review & editing

Dereje Deresa: Data curation, Supervision, Investigation, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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