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Research Article

Grain Quality, Yield, and Physiological Efficiency of Malt Barley Varieties Under Diverse Nitrogen Amounts and Split - Utilization Timings in Ethiopia's Central Highlands

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Abstract

Under optimum Nitrogen (N) fertilizer rate with best-split application time is an abiotic menace resulting in massive yield losses to global food security and malt barley and other major staple crops' quality. To harvest the highest grain yield with good quality, the optimal N-rate must coincide with the ideal split application timing, and variety is essential. Finding out how nitrogen application rates (50, 70, 90, and 110 kg ha^{-1}) and split timing (Treatment 1 = full dose at sowing, Treatment 2 = half at sowing and a half at mid-tillering, and Treatment 3; = 1/4 at sowing, 1/2 at mid-tillering, and 1/4 at anthesis) affected the yield, physiological, and agro-physiological efficiency of various malt barley varieties during the main cropping season of 2022 and 2023 was the primary objective of this study. With an acceptable range of quality criteria (thousand seed weight of 35-45 g and hectoliter weight of 48-62 kg ha^{-1}), the yield increased significantly from 2889.00 to 6611.10 kg ha^{-1}. The IBONE174/03 variety had an appropriate amount of thousand-grain weight (49.82 g) compared to the EH1847 variety. Malt brewers are encouraged to adopt the IBONE 174/03 variety to suit their needs because it provides an ideal grain yield, a tolerable thousand-grain weight, and an acceptable hector litter weight. Optimizing malt quality, productivity, and physiological and agro-physiological efficiency requires using a 110 kg ha-1 N rate and one fourth at sowing, half at mid-tillering, and one fourth at anthesis application time.

Keywords

N-application Time, Nitrogen Fertilization, Hector Litter Weight, Physiological Efficiency, Agro-physiological Efficiency

1. Introduction

After wheat, rice, and maize, barley is the fourth most significant cereal crop in the world [1]. Although it ranks third in terms of yield per unit area, it is Ethiopia's sixth most extensively produced cereal [2]. Barley-based malt is an excellent source of yeast nutrition, which is crucial for the brewing sector.

Malting barley is emerging as a potential industrial crop for resource-constrained farmers with no or very inadequate marketable goods. Malting barley needs to fulfill certain quality

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requirements in addition to producing large yields. More than 90% of the collected grains (i.e., the grain retention fraction) must be larger than 2.5 mm, and barley grains must contain between 9.5% and 11.5% protein by dry weight to be used in the malting and brewing sectors [3]. When grains do not match these criteria, farmers are paid substantially less and may only be able to use them as barley feed [4]. On the other side, usually, there is a negative correlation between grain yield, grain size, and protein content [5]. Grain yield and malted barley quality criteria need to be properly adjusted to meet the standards for malt quality.

Ethiopia's resource-constrained subsistence farmers utilize very little if any, chemical fertilizer. However, such farmland receives di-ammonium phosphate (DAP) fertilizer applications as a source of N/ P_2O_5 at rates ranging from nine to ten kilograms per hectare up to eighteen to twenty kilograms per hectare, which are insufficient for the cultivation of barley [6]. Farmers have been provided with improved agronomic management tools and inputs to significantly increase the yield and productivity of this particular crop [7].

Despite significant efforts to create and put into practice better production technology, the Amhara regional average yield (1.93tha^{-1}) is still low when compared to the global (2.4 tha^{-1}) and nationwide average yields (2.526tha^{-1}) [8, 9]. As a result, continuous research is necessary to get around current production limitations, boost productivity, and increase production, which will help the nation meet its industrial needs and be self-sufficient.

The production and seed quality of malt barley have both significantly improved by selecting an appropriate variety for each agro ecology. Among the nutritional elements, nitrogen is essential for seed quality at its highest level, crop growth, and development. Although a normal nitrogen level enhances seed yield and quality, an excessive level also results in decreased yield and quality of barley seeds. Depending on the environment, different nitrogen doses are best [10]. The quality and yield characteristics of malt barley seed are thus dependent on an adequate nitrogen level. The location, climate, soil, as well as variety utilized, determine the time of the ideal nitrogen quantity [11].

Grain N-uptake, starch, and protein content have increased as a result of nitrogen administration at various phases of the plant (including sowing, tillering, and booting) [12]. To get higher grain yields and better grain quality, nitrogen should be applied in amounts that match each growth stage of the crop [13]. On the contrary, increased nitrogen-use efficiency, the correct nitrogen rate, and proper timing of fertilizer applications are essential for optimal crop management and grain quality [14].

According to recent reports, however, due to Ethiopia's scarcity of malt barley to meet the needs of local breweries, the international and national demand for malt by breweries is growing dramatically [15]. As a result, barley production for malt can play a key role in creating income and improving the highland people's livelihood [16]. Nevertheless, barley production for malt is restricted in some parts of the country. As a result, national breweries must import malt from other countries. Research efforts to increase production and capitalize on the enormous potential of the malting and brewing industries are limited [16]. Limited research is being done to boost output with better quality and take advantage of the great potential of the malting and brewing sectors. This study examined the influences of different nitrogen fertilizer rates and split application time on the productivity, quality, physiological, and agro-physiological efficiency of two Barley cultivars used for malting in the central highlands of Ethiopia.

2. Experimental Methodology

2.1. Research Area

In the central highlands of Ethiopia, specifically the Basso-nan Worana district of the Amhara Region, we conducted two consecutive seasons of field research (2022 and 2023) on a local farmer's field during the principal production period (Figure 1). The testing sites are at an altitude of 2807 m a.s.l. and are situated between latitudes 9 °34' 43" N. The minimum and maximum average annual temperatures in the region are 5.48 ℃ and 20.99 ℃, respectively. Over the past two years, the average yearly precipitation has been between 483.52 mm and 1 071.30 mm (Figure 2), information obtained from the National Meteorological Data Agency. The main crops farmed there are wheat, potatoes, and food grains. The soil type in the region is Camisole [17].

2.2. Treatment Conditions and Study Design

A factorial combination of four N rates (50, 70, 90, and 110 kg ha^{-1}), two malt barley varieties (IBONE 174/03 and EH 1847), and three split times of N application (T1 = full dose at sowing, T2 = half dose at sowing and half dose at mid-tillering, and T3 = one forth quantity at sowing, half quantity at mid-tillering, and one forth quantity at anthesis) were appraised in this study. Additionally, one plot with no N application (controls), all varieties were represented in each replication to allow comparison. The experiment used a factorial arrangement of treatments and was arranged as a randomized complete block design (RCBD) with three replications (4 × 3 × 2). Each experimental unit (plot) measured 3 m × 2 m. The distance between adjacent plots was 0.5 m, while the distance between blocks was 1 m. Within a plot there were 10 rows, each 2 m long, spaced 30 cm apart. The harvestable area of each plot was 4.8 m^2 (2.4 m × 2 m) and comprised eight rows of 2 m length.

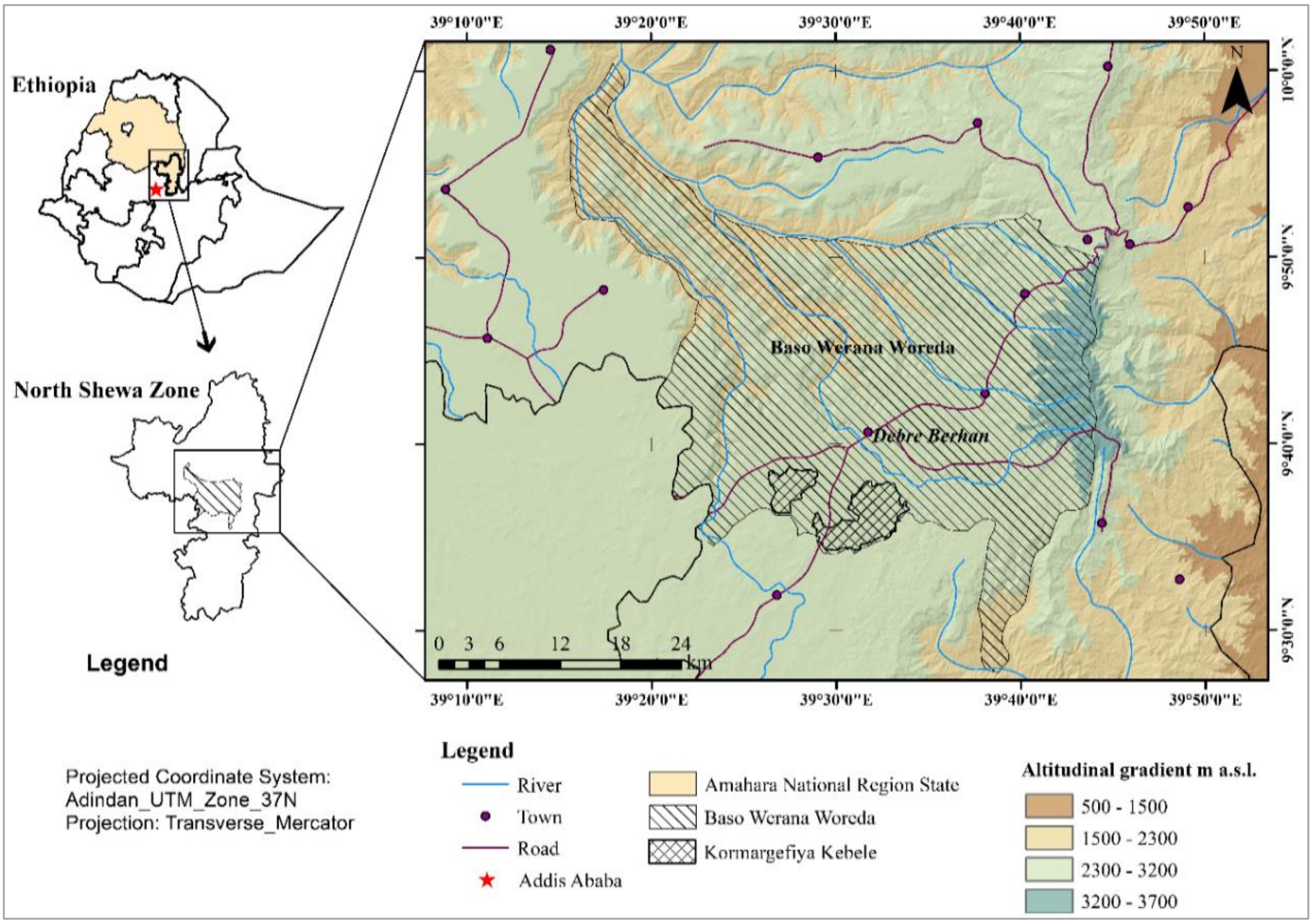

Figure 1. *Map of the study area.*

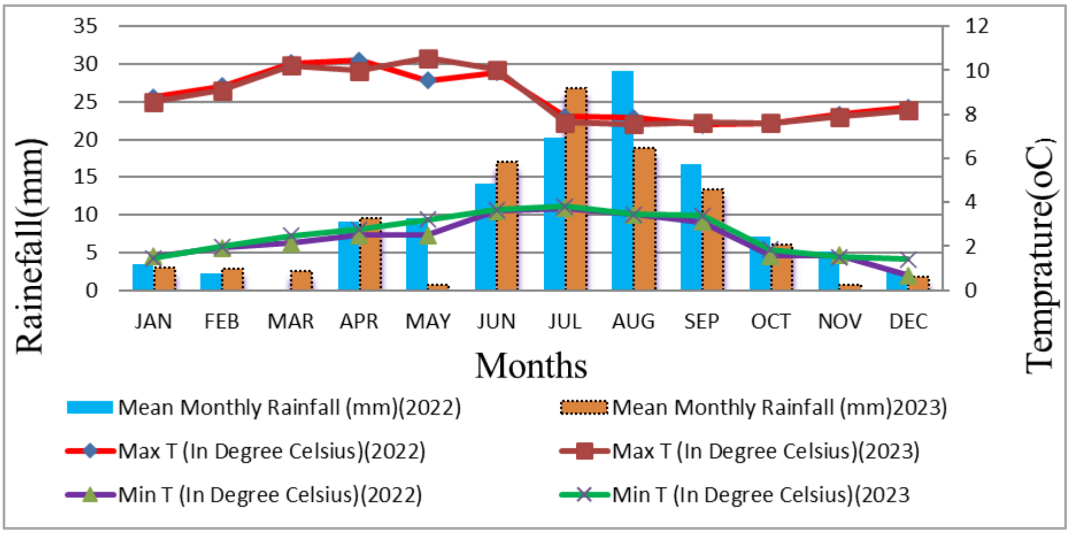

Figure 2. *Monthly totals of rainfall (mm) alongside the peak (Max T) and trough (Min T) temperatures (℃) observed in 2022 and 2023. Source: National Metrological Data Agency.*

2.3. Data Acquisition and Analysis

Successful data collection and analysis were achieved for the soil, yield, quality, and physiological efficiency criteria. Surface soil sample (0-30 cm) soil was sampled. A single composite specimen was generated by thoroughly mixing 17 sub-samples collected by using an auger in a diagonal arrangement. The soil was air-dryed, passed through a 2 mm sieve, and then analyzed for texture, total nitrogen (TN), available phosphorus (Av. P), pH, organic carbon (OC), and cation-exchange capacity (CEC).

The soil texture was assessed using the hydrometer methods [16]. The wet digestion method of Walk & Black [18], was used to determine the soil's organic-carbon (OC) content. Total nitrogen in the soil was measured by the Kjeldahl digestion method using sulfuric acid [19]. A separate suspension prepared at a 1:2.5 soil-to-water ratio served for pH analysis with a glass electrode attached to a digital potentiometer [20]. The amount of organic carbon was calculated using the volumetric method [21]. Olsen's colorimetric technique was utilized to evaluate the available P [22]. Cation exchange capacity (CEC) was calculated by extracting the soil with 1 M ammonium acetate buffered to pH 7, then measuring the exchanged cations [23].

Grain yield from each net plot area was measured following harvest, open-air drying, and threshing (4.8 m^2). Quality criteria; one thousand grains were counted manually, after which their combined mass was measured on a high-sensitivity balance. Using the grain analysis computer (GAC) 2100, a typical laboratory weight tool, to measure the hectoliter weight of dockage-free samples, as detailed in [24]. Straw nitrogen was quantified by the micro-Kjeldahl digestion procedure outlined in the Food and Agriculture Organization (FAO) laboratory manual for plant-nutrient analysis [25].

At maturity, representative samples of non-grain aboveground plant components (stems, leaves, and chaff) were gathered from the central unit areas of each plot. The plant samples were washed gently with distilled water to remove surface contaminants and placed in a drying oven set to 70 ℃ and left until their weight stopped decreasing, indicating a constant dry mass. Finally, the dry weight of each specimen was measured using an electronic analytical balance. After pulverizing the samples in a rotor mill and sieving them to ≤ 0.5 mm, we digested the residue with 0.1N H_2SO_4 containing a 10:1 (K_2SO_4:$CuSO_4$) digestion mixture, employing the ground material from every treatment. The American Association of Cereal Chemists (AACC) digestion method was employed to determine both the straw-nitrogen concentration and the total grain-nitrogen content of fertilized (treated) and unfertilized (untreated) plots using dry-flour samples [24].

The ratio of biological yield to nutrient uptake known as physiological efficiency (PE) was calculated by…

$$PE = \frac{Byf - Byu}{Nf - Nu}$$

In the equation, Byf denotes the above-ground biomass yield (grain + straw) of the fertilized plot, expressed in kg ha^{-1}; Byu denotes the same measurement for the unfertilized plot; Nf is the total nutrient absorption (grain + straw) by the fertilized plot, also in kg ha^{-1}; and Nu is the nutrient uptake of the unfertilized plot (grain + straw), again in kg ha^{-1}.

Agro-physiological efficiency (APE) was determined as

$$APE = \frac{Gf\ (kg) - Gu\ (kg)}{Nf\ (kg) - Nu\ (kg)}$$

$G_{(f)}$ and $G_{(u)}$ denote the grain yields from the fertilized and unfertilized plots, respectively. $N_{(f)}$ is the total nitrogen uptake (grain + straw) of the fertilized plot (in kg), and $N_{(u)}$ is the total nitrogen uptake (grain + straw) of the unfertilized plot (in kg) [26].

2.4. Statistical Analysis

The Analysis of variance (ANOVA) was conducted using SAS version 9.2 (Statistical Analysis System; SAS, 2004) as described by Gómez and Gómez [27]. The homogeneity test (an F-test following Gómez & Gómez [27]) showed no significant differences between the two years for any parameter at any location. Consequently, we merged the two years into a single dataset for the subsequent analysis. Whenever a treatment produced a statistically important outcome, we compared the group means using the least significant difference (LSD) test (α = 0.05). For the factorial analysis, the control was deliberately left out to reduce model complexity.

3. Result and Discussion

3.1. Selected Soil Physical and Chemical Properties

The physicochemical characteristics of the soils, taken before planting at the experimental locations in Bassonan Worra District, are presented in Table 1.

The soils of the two-year testing site belonged to the sandy clay textural class. This is good for crop cultivation. Soil reaction (pH) at the 2022- and 2023-year testing site is slightly acidic. Across both years, the site fell into the low-range category for both soil organic carbon (OC) and total nitrogen [28]. The measured available phosphorus was marginally below 10 mg P ha^{-1} for both years, which does not meet the critical soil-available P benchmark of 10 mg P kg^{-1} that has been established for some soils in Ethiopia [29]. The soils from both years' sites had a markedly high exchangeable K concentration [28]. Both soils possessed cation-exchange capacities that classify them as high [30]. The soil analysis presented in Table 1 shows that the study-area soils are deficient in nitrogen (N) and phosphorus (P), indicating that supplemental N and P fertilizers are required for optimal crop yields.

Table 1. *Selected physicochemical characteristics of the experimental soils prior to sowing.*

	Physical Properties				Chemical properties					
Year	**Sand**	**Clay**	**Silt**	**Textural Class**	**pH**	**OC**	**TN**	**Ava. P**	**Ex. K**	**CEC**
	%				**%**			**mg kg^{-1}**	**Cmol kg + kg^{-1}**	
2022	52.4	36.7	10.9	Sandy Clay	5.9	1.4	0.13	7.9	119	15.3
2023	51.8	37.6	10.6	Sandy Clay	6.1	1.6	0.14	8.8	121	16.7

where: pH (soil reaction), OC (organic carbon), available P (available phosphorus), Ex K (exchangeable potassium), CEC (cation-exchange capacity), and TN (total nitrogen).

3.2. Grain Yield

A two-year combined ANOVA showed that nitrogen (N) rate, timing of N application, and their interaction each had a highly significant effect on grain yield ($P < 0.001$). In contrast, the cultivar (variety) main effect and all other interactions, including the three-way interaction among the treatments, were not significant for malt-barley grain yield. (Table 3).

The mean grain yield obtained with the low-rate (50 kg ha^{-1}) nitrogen applied at T1 was 2 889 kg ha^{-1}. Switching to the high-rate (110 kg ha^{-1}) nitrogen at T3 raised the yield to 3 722 kg ha^{-1}, which is a 128.84% increase relative to the T1 result (Table 2). According to Gauer et al. [31] and Ali [32], each incremental addition of N fertilizer produced a proportional (linear) boost in grain yield. According to Endale [16], when the highest nitrogen dose (110 kg per hectare) was divided into three applications 25% at planting, 50% at mid-tillering, and the final 25% at heading the crop delivered a grain yield of 3 722.1 kg ha^{-1}, which is 128.84% higher than the untreated plot.

The superior grain yield recorded with the highest N rates stems from a combination of full nutrient satisfaction and a three-split N-fertilizer regimen. By distributing the N input over three applications, the malt-barley plants were able to utilise the nutrient more efficiently, which in turn stimulated the development of other yield-determining traits and led to a higher overall harvest. It is likely that the result stems from the alignment of the crop's greatest N requirement with sufficient soil-available N at the specified stages. Ellen and Spiertz [33] reported a similar pattern: when a high N rate was divided into separate applications ($T_2 \rightarrow T_3 \rightarrow T_4$), grain yield increased more reliably than when the same amount of N was applied all at once.

In addition, the authors observed that nitrogen availability closely followed the crop's demand throughout the growing season when the fertilizer was applied in split doses. A one-year field trial by Mitiku et al. [34] corroborated this finding: applying nitrogen as ¼ at sowing, ½ at mid-tillering and the remaining ¼ at anthesis produced a grain yield of 6 611 kg ha^{-1}, whereas a single application of 50 kg N ha^{-1} at sowing yielded only 2 889 kg ha^{-1}.

Table 2. *Nitrogen Rate × Timing: Impacts on Barley Yield, Agro-Physiological Efficiency, Thousand-Kernel Weight & Hectolitre Weight.*

Treatments	GY	TKW	HLW
NR1T1	2889.00e	46d	57.21de
NR2T1	3420.10de	46.04d	57.07de
NR3T1	3774.30cd	47.41cd	57.80ce
NR4T1	3225.70de	48.65cd	59.00be
NR1T2	3302.10de	46.53d	57.00e
NR2T2	4396.00c	49.16cd	59.67be
NR3T2	3396.00de	52.65bc	59.33be
NR4T2	5534.70b	56.70b	60.00bd
NR1T3	3392.40de	49.63cd	57.02de
N2T3	3680.6d	56.22b	60.23bc
NR3T3	5468.70b	58.08ab	61.11b
NR4T3	6611.10a	62.27a	68.83a
LSD	673.07	6.0264	2.4788
EMS	373233.7	20.264949	5.0175167
CV	14.9340	8.722176	3.763945

Means followed by the same letter within a column are not significantly different at a 5% level of significance, Where, T1= full dose at sowing, T2= ½ dose at sowing and ½ dose at mid tillering, T3=1/4 dose at sowing, ½ dose at mid tillering and ¼ dose at anthesis; R1=50 kg ha^{-1} N; R2=70 kg ha^{-1} N; R3=90 kg ha^{-1} N; R4=110 kg ha^{-1} N; GY=grain yield; TKW (thousand-seed weight), HLW (hectolitre weight), LSD (least-significant difference), MS (error mean square), and CV (coefficient of variation).

Table 3. *Mean square from analysis of variance (ANOVA) for grain yield and quality parameters of malt barley varieties.*

SOV	PE	GY	AgPE	TSW	HLW
Time	NS	***	NS	***	***
Variety	***	NS	***	**	NS
N rate	NS	***	NS	***	***
TxV	*	NS	**	NS	NS
TxNr	NS	***	*	**	***
VxNr	NS	NS	NS	NS	NS
TxVxNr	NS	NS	NS	NS	NS
CV	13.64	14.9340	13.70	8.722176	3.763945

*, **, ***, and For the NS group, the test yielded significant differences at the 0.05, 0.01 and 0.001 probability levels, while all other comparisons failed to achieve statistical significance. Where; T = time of N application; Nr = N rate; V= verities; PE= physiological efficiency; Gy=grain yield; AgPE =Agro physiological efficiency; TSW= thousand seed weight; HLW= hectolitre weight; CV= coefficient of variation

3.3. Thousand-seed Weight

In a combined two-year study, the thousand-seed weight of malt barley was strongly influenced ($P < 0.001$) by three primary factors how much nitrogen was applied, when it was applied, and which variety was grown. The only interaction that mattered was the synergy between nitrogen rate and application timing; every other interaction tested failed to produce a measurable change in seed weight (Table 3).

The main effect results revealed that EH 1847 produced a higher thousand seed weight (53.40gm) than the IBONE, 174/03 variety (49.82 gm). The observed thousand-gram disparity in seed weight across the varieties is probably a result of their distinct genetic make-up (Table 4).

The interaction between application timing and nitrogen rate caused a low thousand-seed weight of 46 g at T1 when the low rate (50 kg N ha^{-1}) was used. Conversely, at T3 the same low rate (50 kg N ha^{-1}) yielded a higher thousand-seed weight of 62.27 g, a value that was also obtained with the higher nitrogen rate (100 kg N ha^{-1}) at the same sampling time (Table 2). Lower thousand seed weight due to the low rate of N with no N splitting could be due to a non-satisfying crop nutrient requirement and N loss because of one-time application/no splitting, which could lead to a decrease in photosynthesis and carbohydrate accumulation in grain, resulting in light grains. According to Bekele, *et al.*, [35], the thousand seed weight of malt barley should be greater than 45 gm for two-rowed barley and greater than 42 gm for six-rowed barley. According to the Ethiopian Quality Standard Authority (EQSA), the permissible range is 35-45 g, while raw barley should weigh 25-35 g per thousand kernels; the observed value was higher than both of these limits [36].

Table 4. *The impact of varietal variation on thousand seed weight.*

Parameters	
Variety (V)	**TSW**
IBONE 174/03	49.82b
EH 1847	53.40a
LSD	3.0836
EMS	42.886594
CV	12.68858

In each column, values that are followed by the identical letter are statistically indistinguishable at the 5% significance level; Where TKW=Thousand seed weight; physiological efficiency; LSD=least significant difference; MS=error mean squire's=coefficient of variation

3.4. Hectoliter Weight

An analysis of variance conducted over two years showed that the main effects of nitrogen rate, the timing of nitrogen application, and their interaction all had a highly significant effect ($P < 0.001$) on the hectoliter weight (HLW) of malt-barley grain. Variety and the other treatment interactions did not affect grain hectoliter weight (Table 3).

The interaction effect revealed that the higher nitrogen rate (110 kg ha^{-1}) applied at the T3 timing produced the greatest haul-load weight (HLW) of 68 kg ha^{-1}, whereas the lowest HLW (57.21 kg ha^{-1}) was obtained with the lowest nitrogen rate (50 kg ha^{-1}) applied at the T1 timing (Table 2).

This may result from applying the higher nitrogen rate in three separate doses, which allows carbohydrates to accumulate in the endosperm cells during the grain-filling process. Both Derebe and Temesgen [37] and Gezahegn & Kefale [38] reported that increasing the applied nitrogen-fertilizer rate leads to a greater hectolitre weight. The experiment demonstrated that the hectoliter weight of both varieties remained within the Ethiopian Quality Standard Authority's (EQSA) permissible interval of 60-65 kg hl^{-1} across all nitrogen-fertilizer levels. In contrast, the literature cites a broader acceptable test-weight window for raw barley, namely 48-62 kg hl^{-1} [36]. According to Rick et al. [39], barley is considered acceptable when its hectoliter weight lies between 66.1 kg hl^{-1} and 72.8 kg hl^{-1}. In the present study, however, no variety met this criterion at any nitrogen-fertilizer level.

3.5. Physiological Efficiency

A two-year combined analysis of variance showed that physiological efficiency (PE) was significantly (P 0.001) influenced by the main effects of variety and therefore the interaction effect of time of N application and variety (P 0.05), but not by the main effects of nitrogen (N) rates or time of application; rather, it is the interactions between N rates and time of application, between variety and N rates, and the three-way interaction among variety, N rates, and time of application that matter (Table 3).

Regarding the primary impact of variety, the IBONE 174/03 cultivar was 28% more efficient at converting nutrient uptake into biological yield than EH 1847 (Figure 3b).

The interaction effects of the time of N-fertilizer application and variety, on the other hand, showed that the IBONE 174/03 variety produced a higher protein efficiency (PE) of 86.1%, whereas the EH 1847 variety yielded a lower PE of 67.0% (T1) (Figure 3a). Genetic diversity may explain the observed differences in physiological efficiency, a conclusion that aligns with Gauer *et al.* [31], who demonstrated that crop genotype is the chief driver of physiological efficiency. Contrary to earlier reports, Haile Deresse *et al.* [40] reported that the PE parameter reaches its highest value under low nitrogen applications and its lowest value when nitrogen application is high.

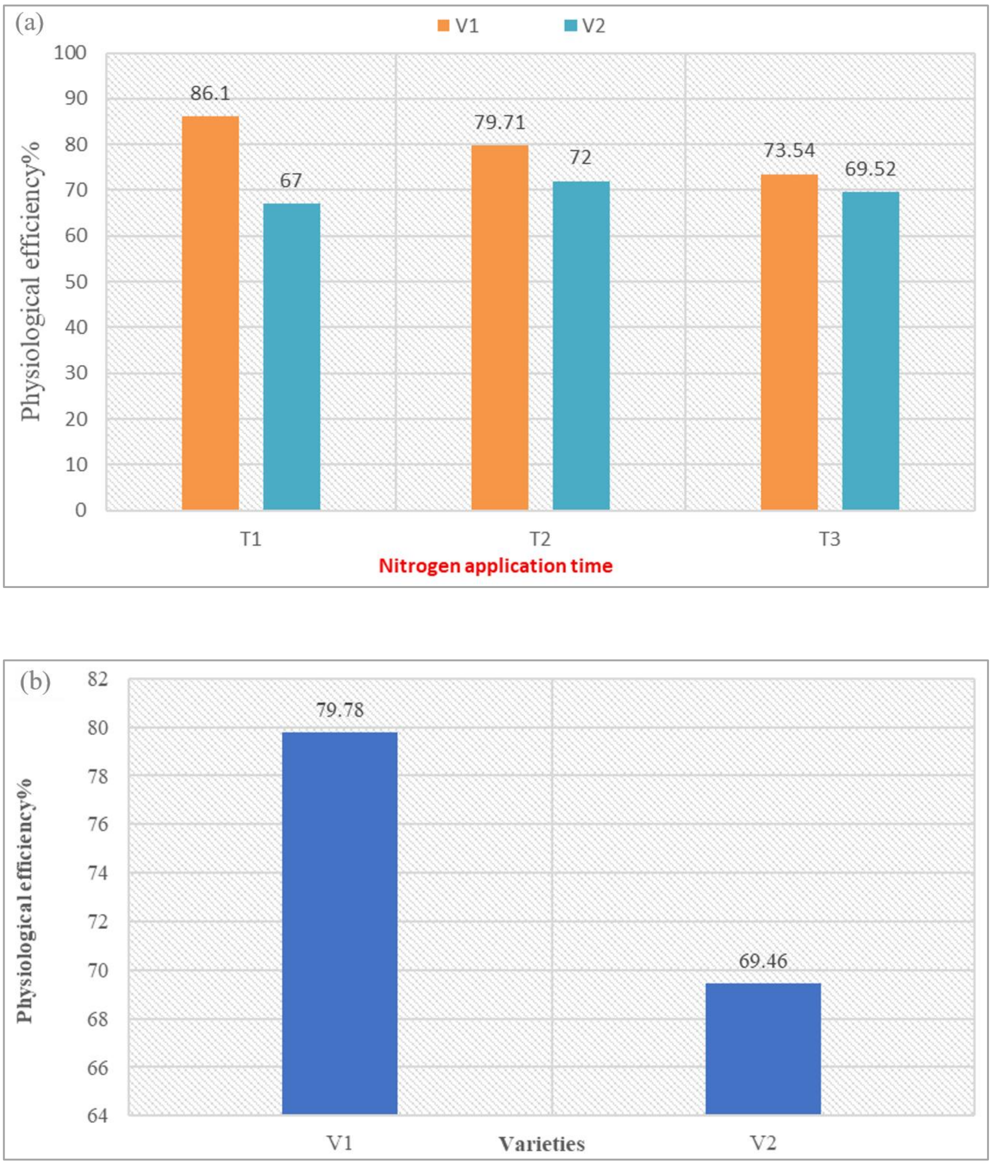

Figure 3. *(a) Interaction between cultivar and the timing of split nitrogen application; (b) Main effect of cultivar, both influencing physiological efficiency.*

3.6. Agro-physiological Efficiency

A two-year combined analysis of variance showed that agro-physiological efficiency was significantly ($p < 0.05$) influenced by the main effect of variety, the interaction of variety with the time of N-fertilizer application, N rates, the time of application, and the three-way interaction among treatments. In contrast, N rate, the time of application, and the interaction between variety and N rate had no significant effect on this parameter (Table 3).

The interaction between the first N-fertilizer application (T1) and crop variety yielded inconsistent outcomes among the treatments. Specifically, the combination of T1 + IBONE 174/03 produced the highest AgPE value (43.13%), while T1 + EH 1847 gave the lowest (31.54%) (Figure 4b). This agro-physiological difference caused by varietal differences could be the result of genotype differences between the two varieties.

The interaction effects of nitrogen (N) rates and the timing of N-fertilizer application showed that the highest agronomic phosphorus efficiency (AgPE) - 40.00% - was obtained with the highest N rate (110 kg ha^{-1}) applied at time T3, whereas the lowest AgPE - 31.44% occurred with the lower N rate (90 kg ha^{-1}) applied at time T2 (Figure 4a).

This Higher agro-physiological efficiency from a higher N rate and more splitting may be due to the splitting of N fertilizer into many doses, which may increase the efficiency of the fertilizers used by decreasing N losses largely in favor of the most splitting. According to Haile Deresse *et al.* [40], Tena *et al.* [41], and Belete *et al.* [42], the extreme values of this parameter are observed at the lowest and highest nitrogen application rates, respectively, across all wheat cultivars during the study period. Our own results mirror these findings.

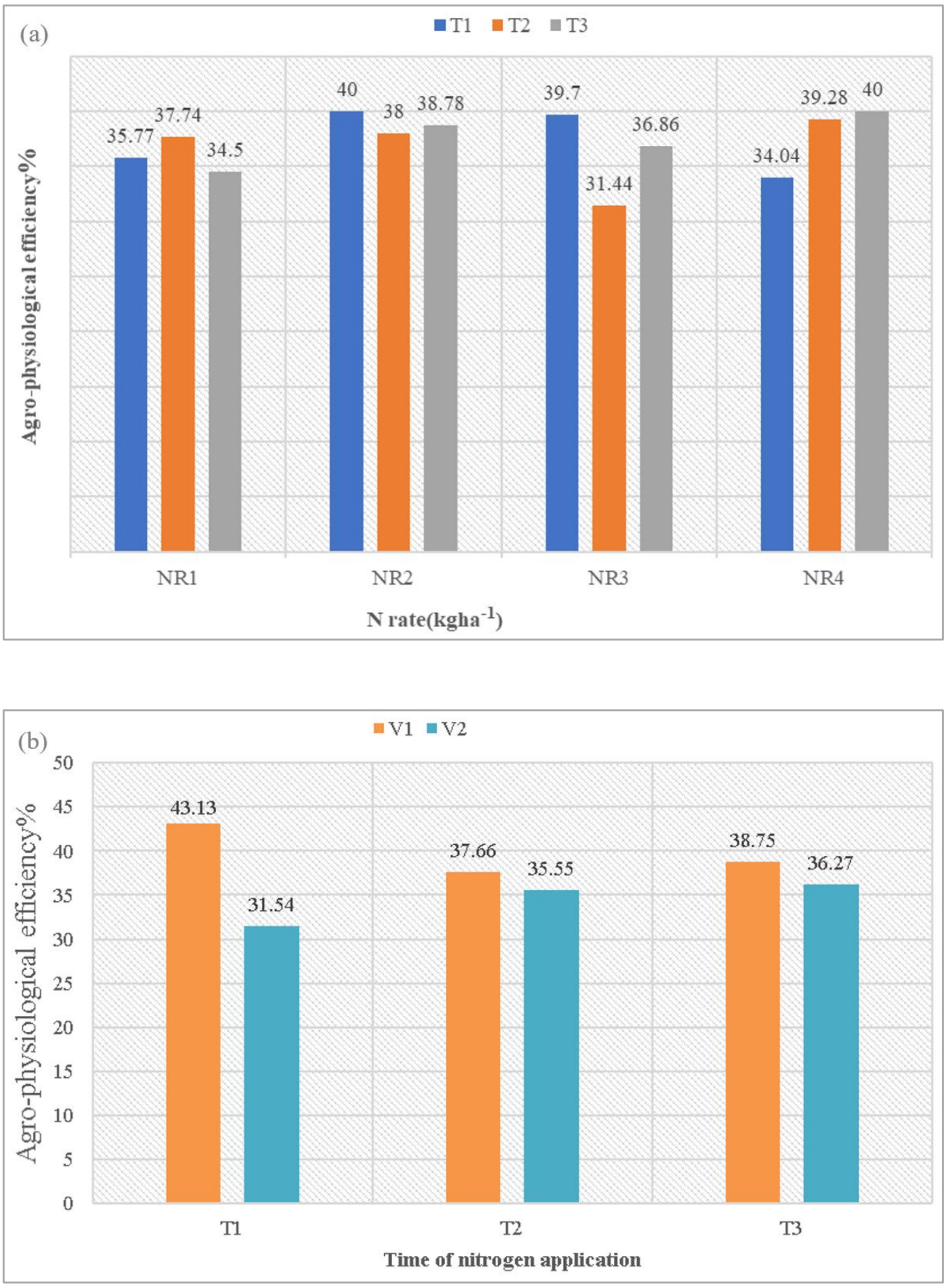

Figure 4. *The interaction effect of N rate and time of nitrogen fertilizer split application (a) and varieties and time of nitrogen fertilizer application (b) on Agro - physiological efficiency.*

4. Summary and Conclusions

The success of malt-barley production hinges on detailed knowledge of how different varieties react to nitrogen (N) fertilizer, specifically the amount applied and the stage of growth at which it is applied. Grain yield and malting quality are not uniform; they fluctuate with regional conditions, the N rate, and the timing of application. Consequently, future research must concentrate on identifying the optimal N dose and application window for each locally-adapted variety. By doing so, growers can increase yields through improved physiological efficiency while preserving grain quality at the levels required for malting. Because protein content is a critical quality parameter, is strongly affected by both variety and N management; establishing variety-specific N-rate and timing recommendations is indispensable for producing high-quality malt-barley grain.

The effects of nitrogen-fertilizer rate and timing of application on grain yield, quality, and physiological efficiency of two released malt-barley varieties showed that yield, thousand-seed weight, hectoliter weight, physiological efficiency, and agro-physiological traits all increased as nitrogen rates and the number of applications rose. However, lower nitrogen rates still produced satisfactory grain yields with acceptable quality and good physiological efficiency.

In addition, genotypic variation was observed for thousand-seed weight and physiological efficiency. The maximum yield with acceptable quality occurred with the top nitrogen dose (110 kg ha^{-1}) applied at the T3 stage. At this level, cultivars IBONE 174/03 and EH 1847 reached thousand-kernel weights of 49.82 g and 53.40 g, respectively. Well above the EQSA standard of 25-35 g and higher than the >45 g minimum recommended for 2-rowed barley (Anonymous, 2012).

Although the three-factor interaction was not statistically significant for grain yield, the maximum yield (6 917 kg ha^{-1}) occurred when the highest nitrogen rate (110 kg ha^{-1}), the T3 application timing, and the IBONE 174/03 variety were combined, and the grain met all quality specifications. Overall, nitrogen level and application timing were the primary determinants of yield increase, with no negative impact on malt-barley quality. Therefore, it is possible to conclude that integrated application of 110kg ha^{-1} N fertilizer rates and IBONE 174/03 variety in three-split (¼ dose at the time of sowing, ½ dose at mid-tillering, and ¼ dose at anthesis) N application was recommended for the study location and areas of the similar agro-ecological zone, in the central highlands of Ethiopia. Fertilizer recommendations are generally derived from soil tests that measure plant-available nutrients. Because the present study was limited to a single site and one cropping season, a definitive recommendation cannot yet be made. Consequently, multi-season, multi-location trials are required to pinpoint the optimal nitrogen rate and application timing that maximize physiological efficiency, grain yield, and malt-barley quality.

Abbreviations

AACC	American Association of Cereal Chemists
ANOVA	Analysis of Variance
CEC	Cation-Exchange Capacity
DAP	Diammonium Phosphate
EQSA	Ethiopian Quality Standard Authority
FAO	Food And Agriculture Organization
GAC	Grain Analysis Computer
HLW	Hectoliter Weight
LSD	Least Significant Difference
OC	Organic Carbon
RCBD	Randomized Complete Block Design
TN	Total Nitrogen

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Author Contributions

Mitiku Ashenafi: Conceptualization, Data curation, Methodology, Resources, Software, Supervision, Writing – original draft

Endale Lemma: Conceptualization, Data curation, Methodology, Software, Writing – original draft

Wondwosen Tena: Methodology, Resources, Software, Supervision, Writing – review & editing

Conflicts of Interest

The author and co-authors have no conflict of interest.

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