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Research Article

Coffee Husk Biochar and NPSB Blended Fertilizer Rates Effect on Growth, Yield and Yield Components of Bread Wheat (*Triticum aestivum* L.) at Bita District, Kaffa Zone, Southwestern Ethiopia

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Abstract

The integrated use of organic and inorganic fertilizers improves soil physicochemical properties and wheat productivity, whereas sole reliance on inorganic fertilizers leads to declining soil fertility. In the Bita District of Southwestern Ethiopia, the limited use of lime and coffee husk biochar constrains soil fertility improvement and wheat yields. To address this challenge, a field experiment was conducted during the 2023 main cropping season to evaluate the effects of integrating coffee husk biochar and blended NPSB fertilizer under limed and unlimed conditions on the yield and yield components of bread wheat. The experiment consisted of three levels of coffee husk biochar (2.5, 5, and 7.5 t ha^{-1}) combined with three rates of NPSB fertilizer (50, 100, and 150 kg ha^{-1}), along with two positive controls (5 t ha^{-1} biochar and 100 kg ha^{-1} NPSB) and one negative control (no fertilizer). Treatments were arranged in a randomized complete block design with three replications in a factorial arrangement. The results indicated that the interaction between coffee husk biochar and NPSB fertilizer significantly increased grain yield. The highest grain yield (3.59 t ha^{-1}) was obtained from the application of 5 t ha^{-1} coffee husk biochar combined with 100 kg ha^{-1} NPSB fertilizer under limed conditions. This treatment also provided the greatest economic return, with a net benefit of 276,280 Birr ha^{-1} and a marginal rate of return (MRR) of 22,076%. Under unlimed conditions, the same combination yielded the highest net benefit (197,080 Birr ha^{-1}). Additionally, applying 7.5 t ha^{-1} coffee husk biochar with 100 kg ha^{-1} NPSB under limed conditions resulted in a net benefit of 221,440 Birr ha^{-1} and an MRR of 13,292%. In conclusion, the application of 5 t ha^{-1} coffee husk biochar combined with 100 kg ha^{-1} NPSB fertilizer, particularly when applied with lime, significantly enhances both the grain yield and economic profitability of bread wheat production in the Bita district.

Keywords: *blended fertilizer, soil fertility, bread wheat, lime, biochar*

1. Introduction

Bread wheat (*Triticum aestivum* L.), a member of the Gramineae family (Feldman & Kislev, 2007; Balkrishna et al., 2021), is one of the world's most widely cultivated cereal crops and a global dietary staple (Bellwood, 2004). Domesticated approximately 8,000 years ago in Europe, West Asia, and Northeast Africa (Bellwood, 2004; Alem & Legese, 2018), wheat expanded from its center of origin in the Fertile Crescent during the Neolithic period, reaching regions such as Ethiopia, India, Ireland, and Spain about 5,000 years ago. Today, it is the most widely cultivated cereal crop globally (Mollasadeghi & Shahryari, 2011; Wato & Mekides, 2020). Wheat ranks as the second most important cereal crop worldwide after maize, with a total production of 728.3 million tons. East Africa contributes 5.7 million tons to this total, of which Ethiopia produces 4.6 million tons (Boliko, 2019; Pant et al., 2020; Dianjaya & Mukti, 2022). Within Sub-Saharan Africa, Ethiopia is the leading wheat producer, followed by South Africa, Sudan, Kenya, Tanzania, Nigeria, Zimbabwe, and Zambia (Tadesse et al., 2019).

Wheat holds particular importance in Ethiopia due to its significant roles in both production and consumption (Ranjana & Suresh Kumar, 2013; Tadesse et al., 2019). Often referred to as the "King of cereals," wheat dominates the global grain trade owing to its extensive cultivation and high yield potential (Shashikala, 2016). It is primarily grown at altitudes ranging from 1500 to 3000 meters above sea level and thrives in well-drained, fertile clay loam soils with moderate water-holding capacity (Wato, 2021). Wheat is a key dietary staple worldwide, supplying energy, protein, and fiber (Rizwana et al., 2010; Weegels, 2019; Wato & Amare, 2020), to an estimated 2.5 billion people in developing countries (Shewry & Hey, 2015). In Ethiopia, wheat serves as a staple food for about 36% of the population (CSA, 2017). National production averages 4.5 million tons annually, cultivated on approximately 1.69 million hectares, with an average yield of 2.66 t ha^{-1} (CSA, 2020). In terms of land coverage and production, wheat ranks fourth after teff, maize, and sorghum (Nahusenay & Kibebew, 2015; FAOSTAT, 2017).

Despite its importance, Ethiopia's average wheat yield (2.768 t ha^{-1}) remains below the global average of 3.320 t ha^{-1} (Nahusenay & Kibebew, 2015; Berhanu & Shimelis, 2021), with even lower yields observed in some regions such as the Kaffa zone. This yield gap is attributed to multiple factors, including suboptimal agronomic practices, limited access to improved wheat varieties, and the absence of site-specific fertilizer recommendations (Alemayehu, 2015; Wato, 2021;). Declining soil fertility further exacerbates reduced wheat productivity (Wato, 2019; Zewide et al., 2021). Additional constraints, including diseases and pests, inadequate irrigation infrastructure, poor farming techniques, and the impacts of climate change, also pose significant challenges to wheat production (Arega et al., 2018; Tadesse et al., 2019). Moreover, overreliance on chemical fertilizers, imbalanced nutrient application, and the lack of integrated soil fertility management strategies remain critical barriers to improving wheat yields (Hochman & Horan, 2018; Wato, 2021).

Efficient fertilizer management is therefore essential for optimizing wheat production (Abebaw & Hirpha, 2018). Regional yield gap analyses are useful tools for identifying key constraints limiting productivity at the farm level (Hochman & Horan, 2018). In the study area, farmers commonly depend solely on chemical fertilizers due to the high cost and limited availability of organic alternatives. Combined with heavy rainfall that promotes nutrient leaching, this practice has led to declining soil fertility and reduced crop yields. Long-term use of chemical fertilizers can also degrade soil health by impairing its chemical, physical, and biological properties (Bitew & Alemayehu, 2017). Consequently, there is growing interest in organic fertilizers as more sustainable and environmentally friendly options (Tadesse, 3013). The integrated application of organic and mineral fertilizers has demonstrated considerable potential for enhancing crop growth by providing a more balanced and sustained nutrient supply, including essential micronutrients. This approach also improves soil structure, chemical properties, and biological activity, thus contributing to long-term soil fertility and sustainable crop production systems (Adugna, 2016).

Among organic amendments, coffee husk biochar has gained attention for its ability to improve soil moisture retention and crop yields (Karthik et al., 2023; Abeba et al., 2024). However, uniform fertilizer recommendations have historically led to nutrient depletion (Malieswarappa et al., 1999; Mbabah et al., 2024), with micronutrient deficiencies, particularly sulfur and boron, significantly limiting wheat productivity (Asefa et al., 2014; Srinivasarao et al., 2023). In response, Ethiopia adopted site- and crop-specific blended fertilizers containing nutrients such as N, P, K, S, Zn, and B (Zewide & Sherefu, 2021). Although most research has focused on nitrogen and phosphorus, recent studies highlight the importance of broader nutrient integration for improving yields (Ishete & Tana, 2019). An integrated fertilization approach that combines organic and inorganic inputs enhances soil structure, nutrient availability, and microbial activity while reducing nutrient loss and environmental impacts.

Despite Ethiopia's large coffee production, coffee husk, an abundant organic residue, remains underutilized and contributes to environmental pollution. According to ATA (2013), integrated nutrient management is rarely practiced in the Kaffa zone, and site-specific fertilizer recommendations are lacking. Wheat farmers in the study area do not apply coffee husk biochar or tailored NPSB fertilizer rates. Therefore, this study was initiated to evaluate the effects of coffee husk-derived biochar combined with blended NPSB fertilizers on the growth and yield performance of bread wheat in the Bita district, Southwestern Ethiopia.

2. Materials and Methods

2.1. *Description of the study area and permission.* The field experiment was conducted at the Farmers' Training Center (FTC) located in Sheda Kebele, Bita District, Kaffa Zone, Southwestern Ethiopia, during the 2023 main cropping season (Fig. 1). The site is managed by the Bita District Agricultural Office and is commonly used for demonstration and research purposes. Prior to the commencement of the experiment, official permission was obtained from the Bita District Agricultural Office and the management of the Farmers' Training Center. As per the objectives and procedures of the study were clearly communicated to the responsible authorities, and approval was granted to conduct the field experiment and to collect soil and wheat samples. Finally, all research activities were carried out in accordance with local regulations and standard ethical practices for agricultural field studies.

The site is located approximately 62 km from Bonga town in Sheda Kebele and 488 km from Addis Ababa, the capital city of Ethiopia. Its geographical coordinates are 07°18′N latitude and 36°96′E longitude, with an altitude of 1,822 meters above sea level (m.a.s.l). The region experiences a bimodal rainfall pattern, with two main rainy seasons: *Belg* (March-June) and *Meher* (July–November).

According to data from the Wush Wush Meteorological Station, the average annual rainfall in 2021 was 1,367 mm (WWMS, 2021). The climate is mild, with mean annual minimum and maximum temperatures ranging from 20 to 25°C.

Sheda Kebele is recognized for its suitability for mixed crop-livestock farming systems. Major crops cultivated in the area include wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), enset (*Enset ventricosum* L.), faba bean (*Phaseolus* spp.), field pea (*Pisum sativum* L.), and potato (*Solanum tuberosum* L.). The dominant soil type in the area is Nitisols, with a clay loam texture. According to Mengist et al. (2022), the total population of Sheda Kebele is 125,696, comprising 59,479 males and 66,217 females. The total land area of the kebele is 161,000 ha, of which 41,000 ha are covered by natural forest, 14,000 ha by wetlands, 45,000 ha by plantation crops, and 61,000 ha are used for annual crops. The study crop, wheat, occupies approximately 6% of the annual crop area, equivalent to 1,016.6 ha. In terms of topography, 62% of the kebele is classified as "Dega" (highland), while the remaining 38% is "Woyina Dega" (midland) (Mengist et al., 2022).

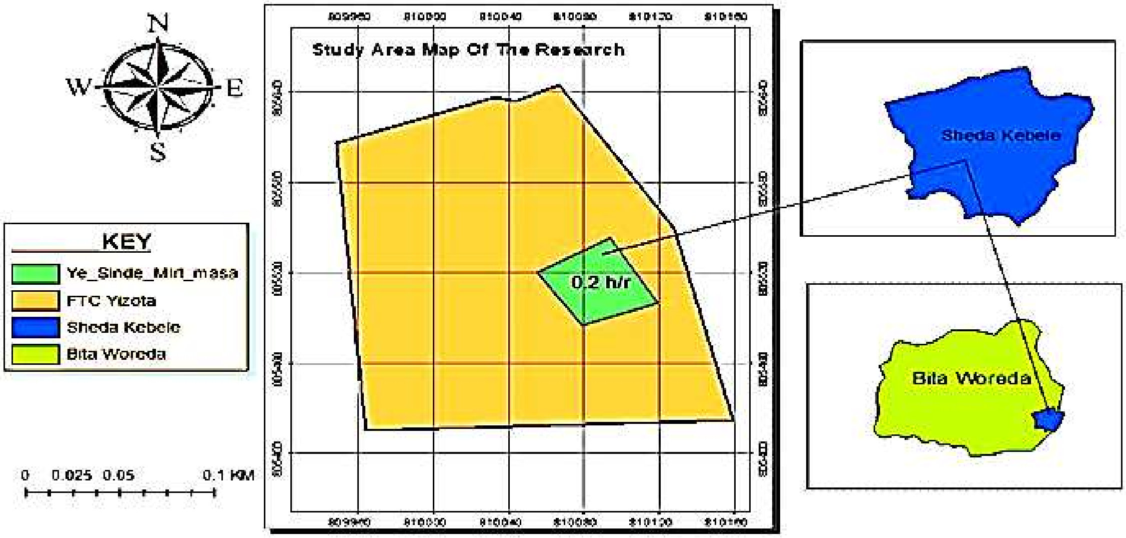

Fig. 1: *Map of the study area at Bita Woreda Sheda kebele (Source: Bita Woreda Agricultural office)*

2.1.1. Soil Physiochemical Properties of the study area. The Tepi soil laboratory examined composite surface soil (0–20 cm depth) samples that were taken before crop sowing to assess the physicochemical characteristics of the soil. The soil was classified as clay loam by FAO (1998) standards based on the particle size distribution, which showed that it included 40.2% sand, 21.3% silt, and 35.5% clay. Clay loam is thought to be the best soil type for growing wheat.

Based on the classification by Tekalign (1991), the soil response at the testing site showed a pH of 5.23, classifying it as strongly acidic. Wheat crops should be grown in a pH range of 5.5 to 7.0 (Roy et al., 2006). Additionally, Haile et al. (2012) reported that wheat grows best when the soil pH is between 6 and 7. As a result, the experimental soil's pH is within the ideal range for soil that is productive.

The Cation Exchange Capacity (CEC) is an important parameter of the soil as it indicates the type of clay mineral present in the soil and its capacity to retain nutrients against leaching. The soil at the experimental site exhibited low CEC values (25.35 meq /100 g soil). According to Landon (1999), top soils with a CEC greater than 40 cmol (+) kg^{-1} are rated as very high, 25-40 cmol (+) kg^{-1} as high, 15-25, 5-15, and <5 cmol (+) kg^{-1} of soil are classified as medium, low, and very low, respectively. These soil parameters provide useful information on the soil's nutrient availability and overall fertility status, both of which are important variables in deciding crop productivity and management tactics.

The organic carbon content at the experimental location was roughly 0.45%, which puts it in the moderate rating range defined by Horneck et al. (2011). Tekalign (1991) categorization system classifies soil total N concentration as follows: less than 0.05% is considered very low, 0.05-0.2% is considered poor, 0.12-0.25% is considered intermediate, and more than 0.25% is considered high.

The total nitrogen content of the soil samples, as determined by analysis, was found to be 0.04%, indicating a very poor nitrogen status and suggesting a limiting factor for ideal crop growth. According to FAO (2008), the soil's accessible phosphorus level of 28.10 mg P_2O_5 kg^{-1}, or 12.27 ppm, indicated a medium rating. This suggests that external phosphorus fertilizer supplies are necessary for increased crop development and output (Bashour & Sayegh, 2007). Additionally, the examination of accessible sulfur in the experimental soil revealed a value of 1.04 mg kg^{-1}, which is classified as extremely low (Woldetsadik et al., 2019), indicating a constraint on wheat production in the research location. The removal of agricultural residue, limited soil organic matter, and inadequate soil parent material containing inferior sulfur could cause this restriction.

2.2. ***Experimental materials.*** Bread wheat varieties, including Shorima, were used as test crops in the experiment. Shorima, released in 2011 by the Kulumsa Agricultural Research Center, requires 105–150 days to reach maturity and performs well in areas receiving 600–900 mm of annual rainfall at altitudes between 1900 and 2600 m a.s.l. Its yield potential ranges from 36–46 quintals ha^{-1} under farmers' field conditions and 44–63 quintals ha^{-1} under research station conditions (MoANR, 2016).

Biochar, produced from biomass such as agricultural residues, was applied as an organic soil amendment to enhance soil fertility and structure. The coffee husk biochar (CHB) used in this study was prepared manually using locally available materials and traditional techniques, following these steps:

(i) Fresh coffee husks were collected from nearby coffee processing sites.

(ii) The husks were sun-dried for about one week until the moisture content dropped below 15%. A conical earth pit was then dug to serve as the pyrolysis chamber, with a small amount of firewood placed at the base to initiate combustion.

(iii) The dried husks were gradually added to the pit, allowing the fire to spread slowly upward. The top of the pit was partially covered with clay or soil to limit oxygen and promote slow pyrolysis.

(iv) The husks were stirred occasionally to ensure uniform carbonization. When the husks turned black and released white smoke, the fire was extinguished by sprinkling water to stop combustion.

(v) After cooling, the biochar was crushed and sieved to achieve a uniform particle size suitable for soil application.

(vi) The processed biochar was stored in dry sacks to prevent moisture absorption and maintain quality until use.

The nutrient composition of the prepared CHB was as follows: pH = 7.8, organic carbon = 62%, total N = 0.95%, available P = 1.15%, exchangeable K = 2.3%, Ca = 2.1%, Mg = 0.5%, ash content = 18%, and cation exchange capacity (CEC) = 27%.

Blended NPSB fertilizer, with a nutrient composition ratio of 18.1:36.1:6.7:0.71 (N:P:S: B), was used to supply essential nutrients required for wheat growth and development. Lime was applied as a soil amendment to reduce soil acidity and adjust pH, using carbonate-, oxide-, or hydroxide-based materials to enhance nutrient availability and improve overall soil health. Urea, containing 46% nitrogen, was applied as an additional nitrogen source to support key physiological processes, promote vigorous vegetative growth, and maximize yield potential.

2.3. ***Experimental Design and Treatment.*** The experiment was conducted using a randomized complete block design (RCBD) with a factorial arrangement consisting of 12 treatment combinations, replicated three times. The treatments included three NPSB fertilizer rates (50, 100, and 150 kg ha^{-1}) and three biochar rates (2.5, 5, and 7.5 t ha^{-1}), applied according to the treatment structure.

The gross plot size consisted of eight rows, each 2 m long, giving a total area of 1.6 m × 2 m = 3.2 m^2. The net plot area used for data collection comprised the central six rows (1.2 m × 2 m = 2.4 m^2). The outermost rows on both sides served as border rows and were excluded from data collection to minimize border effects. Thus, all measurements were taken from the six central rows (6 × 0.2 m × 2 m = 2.4 m^2).

The blended NPSB fertilizer used in the study typically contains 18.9% P_2O_5, 6.95% S, and 0.1% B. Lime was applied at a rate of 4 t ha^{-1} based on soil test recommendations. Biochar was uniformly incorporated into the soil before sowing according to the assigned treatment levels. Treatments were allocated to plots using the lottery method, ensuring that each treatment appeared once within each replication. The spacing between plots, rows, and replications was 0.5 m, 0.2 m, and 1 m, respectively.

All field operations, including land preparation, planting, fertilizer application, and weeding, were carried out following local production practices. Data on phenological traits, growth parameters, yield components, and grain yield were collected from the central rows of each plot. The combination of biochar at 5 t ha^{-1} and NPSB at 100 kg ha^{-1} served as the benchmark treatment. Coffee Husk Biochar was applied as an organic soil amendment along with NPSB fertilizer at planting. Wheat was sown by row drilling, and all other crop management practices were implemented according to standard recommendations for the area.

3.4. ***Experimental Procedure and Field Management.*** The experimental field at Sheda FTC was meticulously prepared using the conventional tillage practice common to the area, involving oxen-mounted traditional *Maresha* before wheat sowing. Following the experimental design, the field was laid out accordingly, and each treatment combination was randomly assigned to plots within each block. The land was thoroughly cleaned and leveled before sowing.

Bread wheat was sown in July 2023 in the Bita District of the Kaffa Zone, Sheda Kebele, using hand drilling in rows and lightly covering the seeds with soil to a depth of 3–4 cm. Biochar and lime were applied one month before sowing, while NPSB fertilizer was applied in a band at sowing based on the required treatment rates. Seeds were drilled at the recommended rate of 125 kg ha^{-1} with an inter-row spacing of 20 cm.

All plots received NPSB fertilizer according to their respective treatment levels. Urea (46% N) was applied at a total rate of 100 kg ha^{-1} in two splits: one-third at sowing, applied within the rows together with the full dose of NPSB, and the remaining two-thirds side-dressed at the mid-tillering stage. Other important agronomic practices were uniformly applied across all plots.

The Shorima wheat variety, which has shown superior grain yield and notable lodging resistance in previous studies (Legesse et al., 2023), was used in this experiment. Weeding and crop management practices, including pest and disease control, were carried out as required. Border rows on each side of each plot were left undisturbed, and data collection was performed on the central six rows. Each plot also received urea fertilizer at the recommended rate of 100 kg ha^{-1} (Saha et al., 2017). Manual weeding was conducted twice during early tillering and booting stages to maintain the plots weed-free. Harvesting was performed manually using hand sickles.

3.5. ***Soil sampling and analysis.*** Soil samples were collected before planting using a systematic zigzag sampling pattern from a depth of 0–20 cm. The samples were then taken to the Tepi Soil and Plant Tissue Analysis Center for the assessment of various physical and chemical properties. Each subsample was carefully collected using an auger to ensure uniform depth and volume. After collection, the samples were air-dried, ground with a pestle and mortar, and sieved to obtain a consistent fine soil fraction.

The composited soil samples were processed to prepare working samples for laboratory analysis. These samples were analyzed for cation exchange capacity (CEC), organic carbon, available phosphorus, total nitrogen, available sulfur, available boron, and soil pH following standard laboratory procedures. Total nitrogen was determined using the Kjeldahl method (Kenny & Durbin, 1982), while available phosphorus was analyzed using the Bray-II method (Bray & Kurtz, 1945). Organic carbon content was measured using the Walkley-Black method (Walkley & Black, 1934), and available sulfur was quantified using the turbidimetric method (Chesin & Yien, 1950). Soil pH was determined in a 1:2.5 soil-to-water suspension using a pH meter. CEC was measured using the 95% ethanol extraction method (Sahlemedhin & Taye, 2000).

3.6. Data collected

Days to seedling emergence (Days): It was calculated as the number of days from the date of seeding to the time 50% of seedlings sprouted in each plot, as judged by visual inspection.

Days to heading (Days): It was calculated by noting the number of days from planting to 50% plant in the plot that produced a spike.

Days to physiological maturity (Days): The number of days from planting to 90% of the plants reached the respective phonological stage.

Plant height (cm): It was measured at the height of the plant from the soil surface to the top of the spike (awns excluded). It was recorded as the average of ten randomly selected plants from each plot at physiological maturity.

Number of fertile spikes (N<u>o</u> per plant): It was obtained by counting the number of spikes in four rows, 1 m row length converted into m^2.

Spike length (cm): It was measured by ten spikes selected randomly from each plot. Each spike was measured from the base of the spike to the apex, excluding the awn, and taken as an average.

Number of seeds per spike (N<u>o</u> per plant): Ten randomly chosen spikes from each plot were counted to determine the number of grains in each spike. The grains of each spike were counted, and an average was calculated after each spike was threshed independently.

Number of productive tillers (N<u>o</u> per plant): It was recorded at physiological maturity by counting all spikes from two randomly selected rows, every 0.5 meters in length, within the net plot area.

Thousand seed weight (g): It was determined based on the weight of 1000 kernels sampled from the grain yields of each treatment, using an electric seed counter, weighing with an electronic balance, and adjusting to a 12.5% moisture level.

Aboveground dry biomass yield (kg ha^{-1}): The plants in the net plot area were harvested at ground level, and sun-dried for about 10 days until constant weight was attained and weighed by spring balance to obtain the total biomass yield and expressed in kg ha^{-1}.

Grain yield (kg ha^{-1}): It was determined by harvesting the crop of the entire net plot area and was adjusted to 12.5% moisture content. (Measured by grain moisture tester).

Harvest index (HI) (%): HI was calculated as the percentage ratio of grain yield (in kg ha^{-1}) to the total above-ground biomass yield (in kg ha^{-1}) multiplied by 100.

3.7. ***Data Analysis.*** Data were subjected to analysis of variance (ANOVA) using SAS version 9.4 (SAS, 2012). The difference between treatment means was compared using the least significant difference (LSD) at a 5% level of significance.

3.8. ***Partial budget analysis.*** Following CIMMYT guidelines (1988), a partial budget analysis was conducted to assess the economic viability of each treatment alongside agronomic performance. Grain yield data were adjusted by 10%, and wheat was valued at an average market price of 80 ETB/kg at harvest (BWTMDO, 2023). Treatments were ranked by total variable cost, and dominance analysis was used to eliminate costlier options with lower net returns. Total costs included inputs such as labor, fertilizers, and harvesting. Net returns per hectare were calculated by subtracting production costs from gross income. Non-dominated treatments with the highest net benefits were considered economically viable (CIMMYT, 1988).

Gross Average Yield (GAY) (kg ha^{-1}). It is the average grain yield of each treatment.

Adjusted Yield (ADY) (kg ha^{-1}). To account for the discrepancy between the experimental output and the farmer's yield, the average yield was deducted by 10%.

$ADY = GAY - (GAY \times 0.1)$ ---eqn. 1

Total Variable Cost (TVC in ETB ha^{-1}). The total of the variable expenses, such as the price of blended NPSB and lime at planting time and the farm's daily labor expenditures for row-making, seed drilling, and fertilizer application based on the Kaffa zone, was added together.

Gross Field Benefit (GFB). Calculated as the adjusted yield of the crop multiplied by the field/farm gate price that farmers earn when they sell it.

$GFB = ADY * \text{Field/Farm gate price for the crop}$ -------------------------------eqn. 2

Total Cost (TC). For the experiment, it is the price of fertilizers, lime, and the cost of creating rows and applying fertilizer. Other input and production technique expenses, such as labor costs for clearing land, planting, weeding, and harvesting, were either thought to stay the same or to be negligible across treatments.

Net Benefit (NB). NB was calculated by subtracting the total costs from GFB for each treatment.

$\text{Net Benefit} = \text{Gross Field Benefit} - \text{Total cost}$ --eqn. 3

Dominance analysis. The procedure involved initially ranking all therapies in ascending order based on their total variable cost (TVC). The net benefit (NB) of each therapy was recorded separately. A therapy was classified as *dominant* (denoted "D") and *non-dominated* (denoted "ND") if it exhibited a higher TVC but an equal or lower NB compared to the preceding therapy in the cost-ordered list.

Marginal Rate of Return (MRR) (%). It was calculated by dividing the change in net benefit (ΔNB) by the change in total variable cost (ΔTVC) times hundred.

$MRR = \frac{\text{Change in net benefits } (\Delta NB)}{\text{Change in cost } (\Delta TVC)} * 100$ ---------------------------------------eqn. 4

4. Results and Discussion

4.4. *Phenological Parameters of Bread Wheat*

4.4.1. Days to emergence (Days). The mean days to 50% emergence of bread wheat were significantly ($p \leq 0.05$) influenced by the integrated application of coffee husk biochar (CHB) and NPSB fertilizer (Table 1). Under limed soil conditions, the shortest time to 50% emergence (5.42 days) was recorded with the combined application of 7.5 t ha^{-1} CHB and 150 kg ha^{-1} NPSB fertilizer, whereas the longest emergence period (6.33 days) was observed in the control treatment (Table 1). Similarly, under unlimed soil, the minimum days to 50% emergence (6.11 days) occurred with the combination of 2.5 t ha^{-1} CHB and 100 kg ha^{-1} NPSB fertilizer, while the maximum emergence period (7.33 days) was recorded in the untreated control (Table 1).

The accelerated emergence observed in treatments receiving integrated nutrient management may be attributed to the availability of essential macronutrients, particularly nitrogen and phosphorus, which promote early seedling vigor, rapid cell division, and faster root and shoot development. Additionally, biochar likely improved soil physical properties such as moisture retention and aeration, creating favorable conditions for faster germination and seedling growth. Lime application further enhanced nutrient availability in acidic soils, supporting early crop establishment. These findings are consistent with previous research. For example, Adera (2016) reported that the use of blended fertilizers significantly reduced the days to 50% emergence of wheat compared to control treatments. Overall, the results indicate that integrated nutrient management, combining organic amendments, inorganic fertilizers, and lime, can accelerate wheat emergence, leading to more uniform and vigorous crop stands.

4.4.2. Days to heading (Days). The mean result of days to 50% heading was significantly ($p \leq 0.05$) affected by the combined application of NPSB blended fertilizer rate and coffee husk biochar, and lime-treated soil of the experiment (Table 1). It was observed that when the rate of CHB increases from 2.5 to 7.5 t ha^{-1} and when NPSB fertilizer increases from 50-150 kg ha^{-1}, days to 50% heading were prolonged from 67.33 to 79 days recorded from lime-treated soil and 66.11 to 91.33 days from lime-untreated soil in the experimental site (Table 1). The days to heading of the bread wheat plants were generally greatly extended across all treatment rates when the rates of NPSB and CHB fertilizer were increased in soil treated with lime. The delay in days to 50% heading of bread wheat with increased fertilizer rates may have been caused by the administration of high NPSB and CHB fertilizer rates. The plants' rapid vegetative growth and development were further promoted by the lime treatment, maybe as a result of the nutrient availability in the soil, timing the plant's requirement for nutrient uptake. In line with current research, the application of mixed fertilizer primarily supplies macronutrients such as N and P, which are essential elements necessary for faster vegetative development and crop flowering dates (Adera, 2016).

4.4.3. Days to grain filling period (Days). The analysis of variance revealed that the combined application of nutrients and lime had a significant effect ($p \leq 0.05$) on the days to grain filling period of bread wheat (Table 1). The longest grain-filling duration (112.11 days) was recorded under the treatment that received 150 kg ha^{-1} NPSB fertilizer combined with 7.5 t ha^{-1} coffee husk biochar (CHB). In contrast, the shortest grain-filling periods were observed under the limed control treatment (98.56 days) and the unlimed control treatment (88.67 days), respectively (Table 1).

This indicates that increasing the rates of NPSB fertilizer and biochar tends to prolong the grain-filling period of wheat. The extended grain-filling phase under higher nutrient inputs may be attributed to enhanced vegetative growth and delayed physiological maturity, likely resulting from improved soil fertility, increased nutrient availability, and better soil physical conditions provided by biochar and lime amendments. Longer grain-filling duration generally allows for more assimilate accumulation, which can potentially contribute to higher grain yield provided that moisture and other environmental conditions remain favorable.

Similar findings were reported by Marshner & Rengel (2012), who observed that increasing blended fertilizer rates containing sulfur (S), boron (B), and zinc (Zn) significantly prolonged the flowering, maturity, and grain-filling periods in teff. This consistency across studies suggests that higher nutrient availability can modify crop phenology by extending developmental stages.

4.4.4. Days to physiological maturity (Days). The analysis of variance (ANOVA) revealed that the combined application of nutrients and lime had a significant effect ($p \leq 0.05$) on the number of days required for wheat to reach 90% physiological maturity (Table 1). The longest maturity period (133.33 days) was recorded when 7.5 t ha^{-1} of coffee husk biochar (CHB) was applied together with 150 kg ha^{-1} of NPSB fertilizer. In contrast, the control treatment on limed soil and the unlimed control exhibited the shortest maturity durations (Table 1). This pattern suggests that higher nutrient inputs, particularly nitrogen-rich fertilizers combined with biochar, tend to prolong the growth cycle of wheat. The delay in maturity is likely associated with extended vegetative growth rather than an acceleration of reproductive development. Adequate or elevated nitrogen availability typically promotes vigorous vegetative growth, increases chlorophyll content, and sustains active photosynthesis for a longer period, thereby postponing the onset of senescence.

In nitrogen-deficient plants, early yellowing of spikes, leaves, and stems was observed, indicating premature physiological maturity caused by limited nutrient availability. Conversely, wheat plants treated with NPSB, especially at higher nitrogen levels, remained noticeably greener throughout the growing season (Sepat et al., 2010). This sustained greenness may be linked to reduced abscisic acid synthesis or enhanced cytokinin activity, both of which are influenced by nitrogen availability and are known to delay leaf senescence. These findings align with the observations of Wato (2021), who reported that high nitrogen application rates generally delay crop maturity across various cereal crops. The prolongation of developmental phases under higher nutrient inputs is consistent with the physiological role of nitrogen in maintaining vegetative growth and delaying senescence.

TABLE 1: Effects of CHB and NPSB fertilizer rates on phenological parameters of wheat in limed and unlimed conditions.

Treatment	**Limed**				**Unlimed**			
	DE (days)	**DH (days)**	**DGFP (days)**	**DM (days)**	**DE (days)**	**DH (days)**	**DGFP (days)**	**DM (days)**
Control	6.33^{a}	67.33^{b}	98.56^{d}	123.00^{c}	7.33^{a}	66.11^{e}	88.67^{e}	120.00^{c}
5 t ha^{-1} Biochar	5.88^{a}	69.00^{b}	101.78^{d}	124.44^{c}	6.89^{a}	67.11^{e}	91.33^{de}	118.44^{c}
100 kg ha^{-1} NPSB	5.88^{a}	72.00^{ab}	107.11^{bcd}	130.89^{bc}	6.89^{a}	71.94^{de}	101.67^{abcd}	117.89^{bc}
50 kg NPSB ha^{-1} and 2.5 t CHB ha^{-1}	6.11^{a}	78.33^{a}	116.44^{ab}	130.56^{bc}	7.11^{a}	76.89^{cd}	104.33^{abc}	139.56^{a}
50 kg NPSB ha^{-1} and 5 t CHB ha^{-1}	6.11^{a}	66.44^{b}	97.89^{d}	123.56^{c}	7.11^{a}	68.22^{e}	96.11^{cde}	122.56^{c}
50 kg NPSB ha^{-1} and 7.5 t CHB ha^{-1}	6.22^{a}	68.33^{b}	101.33^{d}	127.00^{c}	6.22^{a}	70.56^{de}	100.56^{bcde}	121.00^{c}
100 kg NPSB ha^{-1} and 2.5 t CHB ha^{-1}	6.11^{a}	71.11^{ab}	107.11^{bcd}	132.78^{abc}	6.11^{a}	70.56^{de}	99.56^{bcde}	130.78^{abc}
100 kg NPSB ha^{-1} and 5 t CHB ha^{-1}	6.33^{a}	77.78^{a}	110.78^{a}	132.67^{ab}	7.00^{a}	77.78^{cd}	109.89^{ab}	138.67^{ab}
100 kg NPSB ha^{-1} and 7.5 t CHB ha^{-1}	5.89^{a}	73.11^{ab}	103.44^{cd}	125.78^{c}	5.89^{a}	81.67^{bc}	104.84^{abC}	120.78^{c}
150 kg NPSB ha^{-1} and 2.5 t CHB ha^{-1}	6.3^{a}	73.56^{ab}	104.00^{cd}	126.00^{c}	7.34^{a}	84.68^{abc}	109.67^{ab}	122.00^{c}
150 kg NPSB ha^{-1} and 5 t CHB ha^{-1}	6.00^{a}	74.52^{ab}	105.33^{cd}	126.67^{c}	6.00^{a}	87.33^{ab}	109.33^{ab}	123.67^{c}
150 kg NPSB ha^{-1} and 7.5 t CHB ha^{-1}	5.42^{a}	79.00^{a}	112.11^{abc}	133.33^{a}	7.22^{a}	91.33^{a}	114.00^{a}	131.33^{abc}
LSD (0.05)	0.79	8.29	9.58	14.03	0.79	8.11	12.82	14.03
Significance	NS	**	**	*	NS	*	**	**
CV (%)	7.75	6.75	5.17	6.36	7.75	6.29	7.39	6.36

*Where: NPSB = nitrogen, phosphorus, sulfur, boron blended fertilizers, CHB = coffee husk biochar, DE= days to emergence, DH = days to heading, DGFP = days to grain filling period, and DM = days to maturity. **=highly significant, *=significant, NS= Non-significant, Means with the same letter are not significantly different.*

4.5. *Growth Parameters of Bread Wheat*

4.5.1. Plant height (cm). The analysis of variance (ANOVA) indicated that bread wheat plant height was significantly ($p \leq 0.05$) influenced by the application of lime and the combined use of NPSB fertilizer and coffee husk biochar (CHB) (Table 2). The study results demonstrated that increasing the rates of CHB and NPSB fertilizer led to a marked improvement in plant height, whereas the shortest plants were observed in the control plots and in treatments without lime application. Specifically, the tallest wheat plants (100 cm) were recorded under the combined application of 150 kg ha^{-1} NPSB fertilizer and 7.5 t ha^{-1} CHB. In contrast, the shortest plants were observed in the unlimed control treatment (77 cm) and in the overall control group (73 cm) (Table 2).

The observed increase in plant height with higher nutrient and biochar application can be attributed to several physiological mechanisms. The provision of adequate macronutrients and micronutrients through NPSB fertilizer supports enhanced cell division and elongation, leading to greater stem elongation and biomass accumulation. Additionally, the incorporation of CHB likely improved soil physical properties, such as water retention, aeration, and nutrient-holding capacity, which together contribute to more robust vegetative growth. Lime application further enhanced plant growth by correcting soil acidity and increasing nutrient availability, particularly of phosphorus, calcium, and magnesium, which are critical for structural development in wheat. These findings are consistent with those of Adera (2016), who reported that blended fertilizers enriched with essential nutrients promote greater vegetative growth, including increased plant height. The results highlight the positive impact of integrated nutrient management practices, including the combined use of organic and inorganic amendments, on wheat growth performance. Such practices not only enhance plant height but also improve overall crop vigor, which can ultimately contribute to higher yield potential.

4.5.2. Number of effective tillers (no per plant). The combined application of NPSB fertilizer and coffee husk biochar (CHB) had a significant ($p \leq 0.05$) effect on the number of productive tillers per bread wheat plant (Table 2). Among the treatments, the application of 100 kg ha^{-1} NPSB fertilizer in combination with 5 t ha^{-1} CHB produced the highest number of effective tillers per plant, averaging 11.33, whereas the non-fertilized and non-limed control produced the lowest number, with an average of 4.6 tillers per plant (Table 2).

The increase in productive tiller number with integrated nutrient application can be attributed to improved nutrient availability and enhanced vegetative growth. Adequate nitrogen, phosphorus, sulfur, and boron from the NPSB fertilizer, in combination with the soil-improving effects of biochar, likely promoted greater tiller initiation and survival. Biochar improves soil structure, water retention, and nutrient-holding capacity, which supports the development of more spike-bearing tillers. Lime application may have also contributed indirectly by correcting soil acidity, thereby enhancing nutrient uptake and tiller formation. These findings are consistent with previous studies. For instance, Raghavendra et al. (2020) and Tariku et al. (2018) reported a significant increase in early vegetative growth and a higher number of spike-bearing tillers following enhanced nutrient application. Similarly, Kamil et al. (2020) observed that the combined use of farmyard manure (FYM) and NPSB fertilizer significantly increased the number of productive tillers per plant. According to Laghari et al.

(2010), application of 200 kg ha^{-1} NPSB fertilizer produced the highest counts of effective tillers per square meter (476.1 and 451.7), whereas unfertilized control plots had substantially lower values (218.9 and 240 tillers per m^2, respectively).

4.5.3. Spike length (cm). Integrated nutrient management had a significant ($p \leq 0.05$) effect on the mean spike length of bread wheat compared to unfertilized and unlimed plants (Table 2). The longest spike length (13.81 cm) was recorded when 100 kg ha^{-1} NPSB fertilizer was applied in combination with 5 t ha^{-1} coffee husk biochar, while the shortest spikes (8.67 cm) were observed in treatments on lime-untreated soil (Table 2).

The observed increase in spike length under integrated nutrient management can be attributed to the synergistic effects of macronutrients (such as nitrogen, phosphorus, potassium, and sulfur) and micronutrients (zinc and boron). Nitrogen and phosphorus, in particular, play key roles in promoting cell division, elongation, and spike development, while other nutrients such as sulfur, potassium, zinc, and boron further support metabolic processes, reproductive development, and structural growth of the spike. The addition of biochar likely enhanced nutrient retention and soil physical properties, further promoting spike elongation. These findings are in agreement with previous studies. For instance, Firehiwot (2014) reported that increasing nitrogen rates significantly enhanced wheat spike length. Similarly, Nasser & Gizawy (2014) found that the combined application of 64 kg P_2O_5 and 46 kg N per hectare produced the longest wheat spikes (8.29 cm). Moreover, studies by Debnath et al. (2011), Adera (2016), and Awulachew (2019) demonstrated that the addition of zinc and boron, alongside macronutrients, significantly increased wheat spike length. Overall, these results highlight the critical role of integrated nutrient management, including both macro- and micronutrients, in enhancing wheat spike development, which is a key determinant of grain yield potential.

TABLE 2: Combined effects of CHB and NPSB fertilizer rates on growth parameters of wheat with limed and unlimed conditions.

Treatments	**Limed**			**Unlimed**		
	PH (cm)	**NET (no^{-1})**	**SL (cm)**	**PH (cm)**	**NET (no^{-1})**	**SL (cm)**
Control	77.67^{f}	3.76^{g}	7.67^{h}	73.00^{g}	3.17^{d}	6.67^{e}
5 t ha^{-1} CHB	79.00^{f}	4.87^{fg}	9.08^{gh}	77.00^{fg}	4.87^{bcd}	8.08^{de}
100 kg ha^{-1} NPSB	80.50^{f}	5.11^{efg}	9.29^{fg}	79.17^{f}	4.67^{cd}	9.09^{cd}
50 kg NPSB ha^{-1} and 2.5 t CHB ha^{-1}	81.91^{ef}	5.33^{defg}	10.61^{def}	80.33^{ef}	3.67^{d}	9.44^{cd}
50 kg NPSB ha^{-1} and 5 t CHB ha^{-1}	85.60^{de}	5.18^{efg}	11.00^{cdE}	84.00^{de}	4.67^{cd}	9.17^{cd}
50 kg NPSB ha^{-1} and 7.5 t CHB ha^{-1}	86.85^{d}	7.16^{cd}	12.16^{bc}	85.00^{d}	6.00^{bc}	11.33^{ab}
100 kg NPSB ha^{-1} and 2.5 t CHB ha^{-1}	89.00^{d}	8.00^{bc}	12.83^{ab}	87.00^{d}	6.33^{bc}	11.27^{ab}
100 kg NPSB ha^{-1} and 5 t CHB ha^{-1}	94.29^{c}	11.33^{a}	13.81^{a}	92.00^{c}	8.67^{a}	12.81^{a}
100 kg NPSB ha^{-1} and 7.5 t CHB ha^{-1}	95.83^{bc}	9.17^{b}	11.57^{bcd}	94.67^{bc}	7.00^{ab}	10.23^{bc}
150 kg NPSB ha^{-1} and 2.5 t CHB ha^{-1}	98.67^{abc}	9.17^{b}	10.00^{efg}	97.33^{ab}	6.00^{bc}	8.83^{cd}
150 kg NPSB ha^{-1} and 5 t CHB ha^{-1}	101.96^{a}	6.82^{cde}	9.63^{efg}	99.66^{a}	6.15^{bc}	8.00^{de}
150 kg NPSB ha^{-1} and 7.5 t CHB ha^{-1}	100.00^{ab}	5.93^{def}	9.33^{fg}	98.00^{ab}	4.67^{cd}	8.67^{cd}
LSD (0.05)	4.44	1.86	1.52	4.23	2.14	1.80
Significance	**	**	*	**	*	**
CV (%)	2.94	16.03	8.47	2.86	23.07	11.24

Where: Means with the same letter are not significantly different. PH= plant height, NET **=** *number of effective tillers, SL= spike length, **=highly significant, *=significant, Means with the same letter are not significantly different*

4.6. *Yield and yield components of Bread Wheat*

4.6.1. Number of seeds per spike (no per plant). The combined application of coffee husk biochar (CHB) and NPSB fertilizer had a significant ($p \leq 0.05$) effect on the number of seeds per spike of bread wheat compared to the control treatments (Table 3). The highest number of seeds per spike (47.33) was observed when 100 kg ha^{-1} NPSB fertilizer was applied in combination with 5 t ha^{-1} CHB under lime-treated soil. In contrast, the lowest number of seeds per spike (29.09) occurred in plots without lime and without fertilizer application (Table 3).

The increase in seed number per spike under integrated nutrient management can be attributed to improved nutrient availability and uptake, which enhance reproductive development and floret fertility. Nitrogen, phosphorus, sulfur, and boron play critical roles in spikelet formation, floret survival, and grain set, while the addition of biochar improves soil physical properties and nutrient retention, supporting better spike development. Lime application further improves nutrient availability in acidic soils, thereby enhancing reproductive growth and spike productivity. These findings are consistent with previous studies. For example, Saidu (2012) reported that higher rates of fertilizer application resulted in a significant increase in the number of seeds per spike. Overall, the results indicate that integrating organic amendments, inorganic fertilizers, and lime can effectively enhance reproductive traits in wheat, contributing to higher grain yield and improved yield components.

4.6.2. Thousand seed weight (g). The combined application of organic and inorganic nutrients, along with lime, had a significant ($p \leq 0.05$) effect on thousand-seed weight of bread wheat compared to the control treatments (Table 3). The highest thousand-seed weight (54.00 g) was recorded when 5 t ha^{-1} coffee husk biochar (CHB) was applied in combination with 100 kg ha^{-1} NPSB fertilizer under limed soil conditions. In contrast, the lowest seed weight (34.67 g) was observed in the control treatment and in plots without lime application (Table 3).

The improvement in seed weight under integrated nutrient management can be attributed to several factors. The addition of CHB and NPSB fertilizer enhances nutrient availability, including nitrogen, phosphorus, sulfur, and boron, which are essential for reproductive development, grain filling, and seed development. Lime application further improved soil chemical properties by correcting acidity, thereby enhancing nutrient uptake from both organic and inorganic sources. Together, these amendments promote better assimilation and translocation from vegetative tissues to developing grains, resulting in heavier seeds. These results are consistent with previous studies. For instance, Demissie et al. (2017) and Feyisa (2020) reported that the application of 5 t ha^{-1} farmyard manure in combination with 50% of the recommended rates of inorganic nitrogen and phosphorus fertilizers resulted in the highest grain weight, while the absence of fertilizer led to the lowest seed weight. Collectively, these findings support the conclusion that integrated nutrient management combining organic amendments, inorganic fertilizers, and lime can significantly enhance wheat seed weight and overall yield quality.

4.6.3. Biomass yield (kg ha^{-1}). The combined application of coffee husk biochar (CHB) and NPSB fertilizer had a significant ($p \leq 0.05$) effect on the dry biomass production of bread wheat (Table 3). Under limed soil conditions, the highest dry biomass (6.67 t ha^{-1}) was obtained with the application of 100 kg ha^{-1} NPSB fertilizer combined with 7.5 t ha^{-1} CHB. Although the treatment with 100 kg ha^{-1} NPSB fertilizer + 5 t ha^{-1} CHB produced slightly lower biomass, the difference was not statistically significant. In contrast, the lowest biomass under limed conditions (4.00 t ha^{-1}) was observed in plots that received only 100 kg ha^{-1} NPSB fertilizer without biochar (Table 3).

Similarly, in the unlimed control soil, the combination of 100 kg ha^{-1} NPSB fertilizer + 5 t ha^{-1} CHB resulted in the highest dry biomass (5.54 t ha^{-1}), whereas the control plots without lime and fertilizer produced the lowest biomass (3.62 t ha^{-1}) (Table 3). These results indicate that integrating organic and inorganic nutrient sources with lime application can substantially enhance vegetative growth and biomass accumulation in wheat.

The observed increase in biomass can be attributed to improved nutrient availability, particularly nitrogen, phosphorus, sulfur, and boron, as well as the enhanced soil physical properties provided by biochar, such as increased water retention, aeration, and cation exchange capacity. Nitrogen plays a critical role in promoting vegetative growth, protein synthesis, and chlorophyll production, which collectively contribute to greater above-ground biomass. These findings are supported by previous studies. For example, Ishete & Tana (2019) reported that unfertilized plots produced the lowest biomass yield, while applications of 200 kg ha^{-1} NPSB fertilizer resulted in the highest above-ground biomass (13.8 t ha^{-1}), followed by 150 kg ha^{-1} NPSB fertilizer (11.8 t ha^{-1}). Likewise, Haileselassie et al. (2016) observed that plots without nitrogen supplementation had the lowest biomass yield (10,150 kg ha^{-1}), whereas the highest biomass (11,728 kg ha^{-1}) was obtained at 92 kg N ha^{-1}. These studies indicate a clear positive relationship between nitrogen application and wheat biomass accumulation, further emphasizing the importance of integrated nutrient management in optimizing crop growth and productivity.

4.6.4. Grain yield (kg ha^{-1}). The application of NPSB fertilizer and coffee husk biochar (CHB) had a significant ($p \leq 0.05$) effect on bread wheat grain yield (Table 3). The combined use of lime, CHB, and NPSB fertilizer resulted in a substantial increase in grain yield compared to the control treatments. The highest grain yield (3.99 t ha^{-1}) was recorded under the treatment that received lime in combination with the recommended rates of NPSB fertilizer and CHB, whereas the control treatment with lime but no fertilizer produced 1.60 t ha^{-1}, and the unfertilized, unlimed soil yielded the lowest grain production at 1.01 t ha^{-1} (Table 3). These results clearly demonstrate that integrating lime with appropriate organic and inorganic nutrient amendments significantly enhances wheat productivity.

The observed yield increase can be attributed to several factors. Lime application improved soil pH and nutrient availability, particularly phosphorus, calcium, and magnesium, while biochar enhanced soil structure, moisture retention, and nutrient-holding capacity. Meanwhile, NPSB fertilizer supplied essential macronutrients (nitrogen, phosphorus, sulfur) and micronutrients (boron), supporting robust vegetative growth, effective tillering, spike development, and efficient grain filling. The synergistic interaction of lime with organic and inorganic fertilizers optimized nutrient uptake and physiological processes, ultimately translating into higher grain yield. These findings are consistent with previous studies. For instance, Adera (2016) reported that increasing nitrogen application from 0 to 120 kg ha^{-1} significantly enhanced bread wheat grain yield. Similarly, Eshetu et al. (2017) and Abdeta et al. (2022) observed a 6.8% increase in wheat grain yield when the phosphorus rate was increased from 46 to 69 kg P_2O_5 ha^{-1}. Additionally, Alemayehu et al. (2023) demonstrated that the application of essential nutrients, including potassium (K), sulfur (S), zinc (Zn), magnesium (Mg), and boron (B), significantly improved grain yield and yield components compared to unfertilized controls. Collectively, these results emphasize the importance of integrated nutrient management, particularly the combined use of lime, biochar, and balanced fertilizers, in achieving higher wheat productivity.

4.6.5. Harvest index (%). The analysis of variance (ANOVA) revealed that the combined application of NPSB fertilizer and coffee husk biochar (CHB) had a significant ($p \leq 0.05$) effect on the harvest index (HI) of bread wheat (Table 3). The highest harvest index (53.76%) was obtained when 100 kg ha^{-1} NPSB fertilizer was applied together with 5 t ha^{-1} CHB, indicating a greater proportion of grain yield relative to total above-ground biomass under this treatment (Table 3). In contrast, lower nutrient and biochar application rates, as well as control treatments, resulted in reduced harvest index values, reflecting less efficient partitioning of assimilates to the grain.

The observed increase in HI can be attributed to improved nutrient availability, which enhances photosynthetic efficiency, biomass accumulation, and effective translocation of assimilates to the developing grains. Nitrogen, phosphorus, sulfur, and boron play critical roles in supporting reproductive development, while biochar improves soil fertility and water retention, creating favorable conditions for efficient grain filling and higher harvest index. These findings are consistent with previous studies. For example, Haile et al. (2012) reported a mean harvest index of nearly 50% in wheat, showing a positive trend with increasing NPSB fertilizer and biochar application rates. Comparable results have been documented in other crops, including teff (Rabuma et al., 2022) and black cumin (Tadesse et al., 2022), where integrated nutrient management significantly improved harvest index. Furthermore, Shahzadi et al. (2024) observed that the highest HI value of 53.3% was achieved in wheat with the combined application of 100 kg ha^{-1} NPSB and 2.5 t ha^{-1} farmyard manure (FYM), and a similar HI value (53.3%) was recorded when the FYM rate was increased to 5 t ha^{-1}, demonstrating the beneficial effect of combining organic and inorganic nutrient sources on assimilate partitioning and grain yield efficiency. Overall, these results underscore the importance of integrated nutrient management including the combined use of NPSB fertilizer and organic amendments such as biochar in enhancing the harvest index and improving the productivity and efficiency of bread wheat production.

TABLE 3: Combined effects of CHB and NPSB fertilizer rates on yield and yield components of Wheat in limed and unlimed conditions.

	Limed					**Unlimed**				
Treatments	**NSPS**	**TSW(g)**	**GY (t ha^{-1})**	**AGBY (tha^{-1})**	**HI (%)**	**NSPS**	**TSW (g)**	**GY (t ha^{-1})**	**AGBY (t ha^{-1})**	**HI (%)**
Control	29.00e	37.00^{e}	1.60^{d}	4.30^{de}	39.65^{bc}	29.00^{e}	34.67^{e}	1.01^{de}	3.62^{e}	35.20^{ab}
5 t CHB ha^{-1}	31.67^{de}	39.00^{e}	1.73^{d}	4.67^{cde}	35.49^{c}	30.33^{e}	36.67^{e}	1.00^{e}	3.80^{cde}	29.31^{b}
100 kg NPSB ha^{-1}	31.33^{e}	39.67^{e}	1.74^{d}	4.00^{e}	38.11^{bc}	31.67^{de}	37.67^{de}	1.37^{e}	4.00^{e}	31.92^{ab}
50 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	34.67^{cd}	41.33^{de}	2.10^{bcd}	4.67^{cde}	46.23^{abc}	31.33^{e}	38.00^{de}	1.47^{cd}	4.67^{cde}	40.67^{ab}
50 kg NPSB ha^{-1} + 5 t CHB ha^{-1}	35.00^{c}	44.33^{cd}	2.33^{bcd}	4.67^{cde}	44.50^{abc}	34.67^{cd}	41.00^{cd}	1.60^{cd}	4.67^{cde}	41.83^{a}
50 kg NPSB ha^{-1} + 7.5 t CHB ha^{-1}	40.67^{b}	45.50^{cd}	2.53^{bc}	5.33^{bcd}	44.50^{abc}	35.00^{c}	41.67^{cd}	1.93^{bc}	5.33^{bcd}	42.40^{a}
100 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	47.00^{a}	47.13^{bc}	2.63^{b}	6.00^{ab}	43.94^{abc}	40.67^{b}	43.33^{bc}	2.27^{bc}	5.40^{ab}	37.83^{ab}
100 kg NPSB ha^{-1} + 5 t CHB ha^{-1}	47.33^{b}	54.00^{a}	3.99^{a}	6.67^{a}	53.76^{a}	42.00^{a}	50.00^{a}	2.89^{a}	5.54^{a}	43.71^{a}
100 kg NPSB ha^{-1} + 7.5 t CHB ha^{-1}	42.33^{b}	50.33^{ab}	3.27^{a}	6.67^{a}	50.12^{ab}	42.33^{b}	46.33^{ab}	2.50^{ab}	5.33^{a}	38.98^{ab}
150 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	42.26^{b}	47.33^{bC}	2.45^{bc}	5.67^{abc}	45.96^{abC}	42.27^{b}	41.67^{cd}	1.93^{cd}	5.47^{abc}	37.00^{ab}
150 kg NPSB ha^{-1} + 5 t CHB ha^{-1}	40.00^{b}	44.87^{cd}	2.34^{bc}	5.00^{bcde}	46.22^{abc}	40.00^{b}	41.33^{cd}	1.94^{cd}	5.00^{bcde}	39.33^{ab}
150 kg NPSB ha^{-1}+ 7.5 t CHB ha^{-1}	39.33^{b}	39.49^{e}	1.93^{cD}	4.00^{e}	50.28^{ab}	39.33^{b}	37.67^{de}	1.70^{de}	4.30^{de}	43.61^{A}
LSD (0.05)	3.24	4.53	0.61	1.27	13.65	3.24	4.26	0.45	1.27	12.04
Significance	**	**	*	**	*	**	**	*	**	**
CV (%)	5.17	6.06	15.66	14.7	17.95	5.17	6.17	13.68	14.7	18.47

Where: Means with the same letter are not significantly different. NSPS= number of seeds per spike, TSW = thousand seed weight, AGBY = above ground biomass yield, GY= grain yield, HI = harvest index.

4.7. *Partial Budget Analysis.* In this study, the application of 150 kg ha^{-1} NPSB fertilizer combined with 7.5 t ha^{-1} coffee husk biochar (CHB) resulted in the highest total variable cost, followed by the combination of 150 kg ha^{-1} NPSB with 5 t ha^{-1} CHB. The elevated costs associated with these treatments were primarily due to the higher input rates of both NPSB fertilizer and CHB. Additionally, the increased crop yields under these treatments contributed to the overall total variable cost.

Regarding gross returns, the application of 100 kg ha^{-1} NPSB fertilizer combined with 5 t ha^{-1} CHB produced the highest gross return of 287,280 Birr ha^{-1} under limed conditions, while the combination of 100 kg ha^{-1} NPSB with 7.5 t ha^{-1} CHB under the same lime treatment yielded 235,440 Birr ha^{-1}. Under unlimed conditions, the highest gross return (208,080 Birr ha^{-1}) was also obtained from the 100 kg ha^{-1} NPSB + 5 t ha^{-1} CHB treatment. These higher gross returns were largely a result of the superior grain yields obtained under these integrated nutrient management treatments.

In terms of net benefits, the combination of 100 kg ha^{-1} NPSB fertilizer with 5 t ha^{-1} CHB resulted in the highest net benefit of 276,280 Birr ha^{-1} and the greatest marginal rate of return (MRR) of 22,076%. This was followed by the 100 kg ha^{-1} NPSB + 7.5 t ha^{-1} CHB treatment under limed conditions, which generated a net benefit of 221,440 Birr ha^{-1} and an MRR of 13,292%. Under unlimed conditions, the highest net benefit (197,080 Birr ha^{-1}) was again achieved with 100 kg ha^{-1} NPSB + 5 t ha^{-1} CHB, whereas the 100 kg ha^{-1} NPSB + 7.5 t ha^{-1} CHB treatment produced a net benefit of 166,000 Birr ha^{-1}.

Overall, these results demonstrate that the combined application of moderate rates of NPSB fertilizer (100 kg ha^{-1}) with 5 t ha^{-1} CHB under both limed and unlimed conditions is the most economically advantageous strategy, as it optimizes both yield and profitability while maintaining a high marginal rate of return. This highlights the potential of integrated nutrient management to improve not only crop productivity but also economic returns for farmers.

TABLE 4: Results of partial budget analysis to estimate the net benefit of fertilizer management of bread wheat production under lime treated experiment site.

Fertilizer management	Adj.GY (kg ha^{-1})	GB (ETB ha^{-1})	IVC (ETB ha^{-1})		LC (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	D
			NPSB	CHB				
Control (no fertilizer applied)	1440	115200	0	0	0	0	115200	
100 kg NPSB ha^{-1}	1566	125280	4000	0	1000	5000	120280	ND
50 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	1890	151200	2000	2500	1000	5500	145700	ND
5t CHB ha^{-1}	1557	124560	0	5000	1000	6000	118560	D
100 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	2367	189360	4000	2500	1500	8000	181360	ND
50 kg NPSB ha^{-1} + 5 t CHB ha^{-1}	2097	167760	2000	5000	1500	8500	159260	D
150 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	2205	176400	6000	2500	2000	10500	165900	ND
100 kg NPSB ha^{-1} + 5 t CHB ha^{-1}	3591	287280	4000	5000	2000	11000	276280	ND
50 kg NPSB ha^{-1} + 7.5 t CHB ha^{-1}	2277	182160	2000	7500	2000	11500	170660	D
150 kg NPSB ha^{-1} + 5 t CHB ha^{-1}	2106	168480	6000	5000	2500	13500	154980	D
100 kg NPSB ha^{-1} + 7.5 t CHB ha^{-1}	2943	235440	4000	7500	2500	14000	221440	ND
150 kg NPSB ha^{-1}+ 7.5 t CHB ha^{-1}	1737	138960	6000	7500	3000	16500	122460	D

Where; Adj.Y = Adjusted yield (kg ha^{-1}), TVC = Total variable cost (ETB ha^{-1}), IVC= input variable cost (ETB ha^{-1}), LC labor cost (ETB ha^{-1}), NB = Net benefit (ETB ha^{-1}), MRR = Marginal rate of return, MC = marginal cost, MNB = marginal net benefit, D = dominance. ND = non-dominance, Cost of NPSB Fertilizer = 50kg NPSB ha^{-1} = 2000birr ha^{-1}, 100kg NPSB ha^{-1} = 4000birr 150kg NPSB = 6000birr ha^{-1}, Labor cost for NPSB fertilizer application =5person ha^{-1}, each 50 ETB day^{-1} CHB =2.5tha^{-1} = 2500birr, 5 t ha^{-1}= 5000birr, 1.7t ha^{-1} = 75000birr, Labour cost for CHB = 5 labourer ha^{-1}, 200birr each day^{-1}

TABLE 5: Marginal rate of return for CHB and NBSB fertilizer for bread wheat production under limed conditions**.**

Fertilizer management	Adj. GY (kg ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	MC (ETB ha^{-1})	MNB (ETB ha^{-1})	MRR (%)
Control (no fertilizer applied)	1440	0	115200			
100 kg NPSB ha^{-1}	1566	5000	120280	5000	5080	101.6
50 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	1890	5500	145700	500	25420	5084
100 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	2367	8000	181360	2000	62800	3140
150 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	2205	10500	165900	2000	6640	332
100 kg NPSB ha^{-1} + 5 t CHB ha^{-1}	3591	11000	276280	500	110380	22076
100 kg NPSB ha^{-1} + 7.5 t CHB ha^{-1}	2943	14000	221440	500	66460	13292

Where; Adj.Y = Adjusted yield (kg ha^{-1}), TVC = Total variable cost (ETB ha^{-1}), IVC= input variable cost (ETB ha^{-1}), LC= labour cost (ETB ha^{-1}), NB = Net benefit (ETB ha^{-1}), MRR = Marginal rate of return, MC = marginal cost, MNB = marginal net benefit, D = dominance. ND = non-dominance, Cost of NPSB Fertilizer = 50kg NPSB ha^{-1} = 2000birr ha^{-1}, 100kg NPSB ha^{-1} = 4000birr 150kg NPSB = 6000birr ha^{-1}, Labour cost for NPSB fertilizer application =5person ha^{-1}, each 50 ETB day^{-1} CHB =2.5 tha^{-1} = 2500birr, 5 t ha^{-1} = 5000birr, 1.7t ha^{-1} = 75000birr, Labour cost for CHB = 5 labourer ha^{-1}, 200birr each day^{-1}

TABLE 6: Results of partial budget analysis to estimate the net benefit of fertilizer management of bread wheat production under unlimed conditions.

Fertilizer management	Adj.GY (kg ha^{-1})	GB (ETB ha^{-1})	IVC (ETB ha^{-1})		LC (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	D
			NPSB	CHB				
Control (no fertilizer applied)	909	72720	0	0	0	0	72720	
100 kg NPSB ha^{-1}	1233	98640	4000	0	1000	5000	93640	ND
50 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	1323	105840	2000	2500	1000	5500	100340	ND
5 t CHB ha^{-1}	900	72000	0	5000	1000	6000	66000	D
100 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	2043	163440	4000	2500	1500	8000	155440	ND
50 kg NPSB ha^{-1} + 5 t CHB ha^{-1}	1440	115200	2000	5000	1500	8500	106700	D
150 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	1737	138960	6000	2500	2000	10500	128460	ND
100 kg NPSB ha^{-1} + 5 t CHB ha^{-1}	2601	208080	4000	5000	2000	11000	197080	ND
50 kg NPSB ha^{-1} + 7.5 t CHB ha^{-1}	1737	138960	2000	7500	2000	11500	127460	D
150 kg NPSB ha^{-1} + 5 t CHB ha^{-1}	1746	139680	6000	5000	2500	13500	126180	D
100 kg NPSB ha^{-1} + 7.5 t CHB ha^{-1}	2250	180000	4000	7500	2500	14000	166000	ND
150 kg NPSB ha^{-1} + 7.5 t CHB ha^{-1}	1530	122400	6000	7500	3000	16500	105900	D

Where; Adj.Y = Adjusted yield (kg ha^{-1}), TVC = Total variable cost (ETB ha^{-1}), IVC= input variable cost (ETB ha^{-1}), LC labour cost (ETB ha^{-1}), NB = Net benefit (ETB ha^{-1}), MRR = Marginal rate of return, MC = marginal cost, MNB = marginal net benefit, D = dominance. ND = non-dominance, Cost of NPSB Fertilizer = 50kg NPSB ha^{-1} = 2000birr ha^{-1}, 100kg NPSB ha^{-1} = 4000birr 150kg NPSB = 6000birr ha^{-1}, Labour cost for NPSB fertilizer application =5person ha^{-1}, each 50 ETB day-1 CHB =2.5tha^{-1} = 2500birr, 5 t ha^{-1} = 5000birr, 1.7t ha^{-1} = 75000birr, Labour cost for CHB = 5 labourer ha^{-1}, 200birr each day^{-1}

TABLE 7: Marginal rate return for CHB and NBSB fertilizer for bread wheat production under unlimed conditions.

Fertilizer management	Adj.GY (kg ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	MC (ETB ha^{-1})	MNB (ETB ha^{-1})	MRR (%)
Control (no fertilizer applied)	909	0	72720			
100 kg NPSB ha^{-1}	1233	5000	93640	5000	20920	418.4
50 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	1323	5500	100340	500	6700	1340
100 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	2043	8000	155440	2000	89440	4472
150 kg NPSB ha^{-1} + 2.5 t CHB ha^{-1}	1737	10500	128460	2000	21760	1088
100 kg NPSB ha^{-1} + 5 t CHB ha^{-1}	2601	11000	197080	500	68620	13724
100 kg NPSB ha^{-1} + 7.5 t CHB ha^{-1}	2250	14000	166000	500	39820	7964

Where; Adj.Y = Adjusted yield (kg ha^{-1}), TVC = Total variable cost (ETB ha^{-1}), NB = Net benefit (ETB ha^{-1}), MRR = Marginal rate of return, MC = marginal cost, MNB = marginal net benefit

5. Conclusion

The interaction between CHB and NPSB fertilizer significantly enhanced wheat yield and yield components, including the number of effective tillers, seeds per spike, and thousand-grain weight. Higher NPSB fertilizer rates combined with CHB consistently outperformed both the control and the unlimed treatments. The highest grain yield (3.59 t ha^{-1}) was obtained from the application of 5 t ha^{-1} CHB combined with 100 kg ha^{-1} NPSB fertilizer under limed conditions. Under unlimed conditions, the same treatment produced a yield of 2.6 t ha^{-1}. Although the combination of 150 kg ha^{-1} NPSB fertilizer and 7.5 t ha^{-1} CHB incurred the highest total variable cost, the resulting yield gains compensated for the additional inputs. The maximum gross return (287,280 Birr ha^{-1}) and the highest net benefit (276,280 Birr ha^{-1}) were achieved with the application of 5 t ha^{-1} CHB and 100 kg ha^{-1} NPSB fertilizer under limed conditions, yielding a marginal rate of return (MRR) of 22,076%. This was followed by the combination of 7.5 t ha^{-1} CHB with 100 kg ha^{-1} NPSB fertilizer, which resulted in a net benefit of 221,440 Birr ha^{-1} and an MRR of 13,292%. Under unlimed conditions, the same treatment 100 kg ha^{-1} NPSB fertilizer combined with 5 t ha^{-1} CHB also provided the highest net benefit (197,080 Birr ha^{-1}). Therefore, the most effective and economically viable treatment was the application of 5 t ha^{-1} CHB together with 100 kg ha^{-1} NPSB fertilizer, particularly when applied under limed conditions. This combination significantly improved wheat productivity and profitability in the study area.

Author Contributions

KB & IZ: Conceptualization of the study, preparation of the first draft, data analysis and interpretation, supervision, and writing of the original draft manuscript. TW: Reviewed, provided comments, and proofread the manuscript. IZ & TW: Managed the process from journal selection through to publication. Finally, all authors have read and approved the manuscript for submission and consideration for publication.

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Data Availability

Original research data will be available upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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