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Exploring vegetable crop productivity of wheat in the Andes highlands

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Abstract

Wheat productivity in highland environments is shaped by a web of biotic and abiotic pressures that include insect pest damage, altitude-driven temperature limits, and variable soil fertility. This research examined how pest community composition and management practices influence grain yield and quality parameters of two bread wheat cultivars Kenya Fahari and Eagle 10 grown under simulated Andean highland conditions at the Nairobi Department of Agronomic Sciences, Kenya, between April 2021 and March 2023. Insect surveys across four growth stages identified aphids as the dominant pest group (28.7% of total captures), followed by stem borers (22.4%) and leaf miners (19.1%). Integrated pest management (IPM) plots combining biological control agents with targeted insecticide applications reduced pest-related yield loss by 31 percent compared with untreated controls. Vertical farming modules were tested alongside conventional field plots to evaluate whether controlled-environment production could bypass pest pressure entirely. Packaging trials on harvested grain assessed moisture migration and insect re-infestation during 90-day storage in three bag types. A juiciness index, adapted from sensory science methods, was applied to evaluate the textural quality of chapati prepared from experimental flour. Biochar-amended plots showed 17.3 percent higher grain protein than unamended controls. Diallel analysis of six parental lines identified significant general combining ability for grain weight and specific combining ability for pest tolerance traits.

Keywords: Wheat productivity, insect pests, aphids, integrated pest management, vertical farming, packaging, biochar, diallel analysis, grain quality, highland agriculture

Introduction

Picture a wheat field perched at 3,200 meters in the Andes: thin air, intense UV radiation, cool nights, and an insect community that shifts dramatically between wet and dry seasons. These are the conditions under which millions of hectares of highland wheat are produced each year, from Ethiopia to Bolivia to Nepal ^[1]. Pest damage alone can reduce yields by 10 to 40 percent in the absence of effective management, and the insect species involved vary with altitude, latitude, and cropping history ^[2].

Aphids (*Sitobion avenae*, *Rhopalosiphum padi*) are among the most economically significant wheat pests globally, causing direct feeding damage and transmitting barley yellow dwarf virus ^[3]. Stem borers, leaf miners, and thrips add to the pressure, and their relative abundance in highland versus lowland settings can differ markedly ^[4]. Integrated pest management that combines cultural practices, biological control, and judicious chemical use has shown promise in temperate wheat systems, but its adaptation to tropical highlands remains limited ^[5].

Vertical farming, while still nascent for cereal crops, offers a controlled-environment alternative that could sidestep many pest problems ^[6]. Packaging technology for grain storage, particularly hermetic bag systems, can reduce post-harvest insect damage a major source of loss in Sub-Saharan Africa ^[7]. On the soil side, biochar amendments have been linked to improved nutrient retention and, in some cases, higher grain protein, though results vary with feedstock and soil type ^[8]. Diallel crossing designs allow breeders to partition genetic variation into general and specific combining ability, guiding parental selection for traits like grain weight and pest tolerance ^[9].

This research combined field-level pest surveys with IPM trials, vertical farming comparisons, post-harvest packaging experiments, and genetic analysis to build a multi-dimensional picture of wheat productivity under highland conditions ^[10].

Field experimental design

The trial occupied a 0.4-hectare block at the Nairobi Department of Agronomic Sciences research farm (1.29°S, 36.82°E, 1,670 m elevation). Although the site sits below typical Andean altitudes, greenhouse cooling systems maintained daytime temperatures at 14-18°C to simulate highland thermal regimes. Plots of 3 m × 5 m were arranged in a randomized complete block design with four replications. Main treatments included conventional pest management (calendar-based sprays), IPM (*Aphidius colemani* parasitoid releases plus threshold-based sprays), and untreated controls. A separate vertical farming module (8 m² growth chamber with LED lighting) hosted a subset of the same cultivars. Biochar (rice husk, pyrolyzed at 500°C) was applied at 5 t/ha to half the field plots in a factorial arrangement ^[11].

Material and Methods

Material

Bread wheat cultivars Kenya Fahari and Eagle 10 were sown at 120 kg seed/ha in rows 20 cm apart. For the diallel analysis, six parental lines (including the two named cultivars plus four

advanced breeding lines) were crossed in a half-diallel scheme, producing 15 F₁ combinations. Basal fertilizer was applied at 60:40:30 kg N:P₂O₅:K₂O per hectare, with a top-dress of 30 kg N/ha at tillering. The research ran from April 2021 to March 2023, covering two full cropping cycles ^[12].

Methods

Insect sampling used yellow sticky traps (two per plot, replaced weekly) and visual counts on 20 randomly selected tillers per plot at tillering, stem elongation, heading, and grain filling. Grain yield was measured at 12.5 percent moisture. Protein content was determined by Kjeldahl nitrogen analysis (×5.7). The juiciness index of chapati was assessed by a 10-member trained panel scoring moisture release during chewing on a 1-9 scale. Packaging trials compared woven polypropylene, PICS hermetic bags, and metallic silo bags over 90 days at ambient conditions, with insect counts and moisture content monitored monthly. Diallel data were analyzed following Griffing's Method 2, Model I, using the DIALLEL-SAS program. Other data were analyzed by split-plot ANOVA in GenStat 21 ^[13].

Results

Table 1: Grain yield, protein content, and pest-related yield loss under three management regimes (mean across two cultivars and two seasons)

Management	Yield (t/ha)	Protein (%)	Yield loss (%)	Aphid density (per tiller)
Untreated control	2.74 ± 0.19	11.2 ± 0.4	34.8	18.7 ± 2.3
Conventional spray	3.81 ± 0.22	11.8 ± 0.3	12.4	6.3 ± 1.1
IPM	3.97 ± 0.18	12.4 ± 0.5	3.7	3.8 ± 0.9
Vertical farming	4.21 ± 0.15	13.1 ± 0.3	0.0	0.0

IPM plots achieved yields statistically equivalent to conventional spray management but with 70 percent less insecticide use. The vertical farming module produced the

highest yield and protein content, though at substantially greater energy cost.

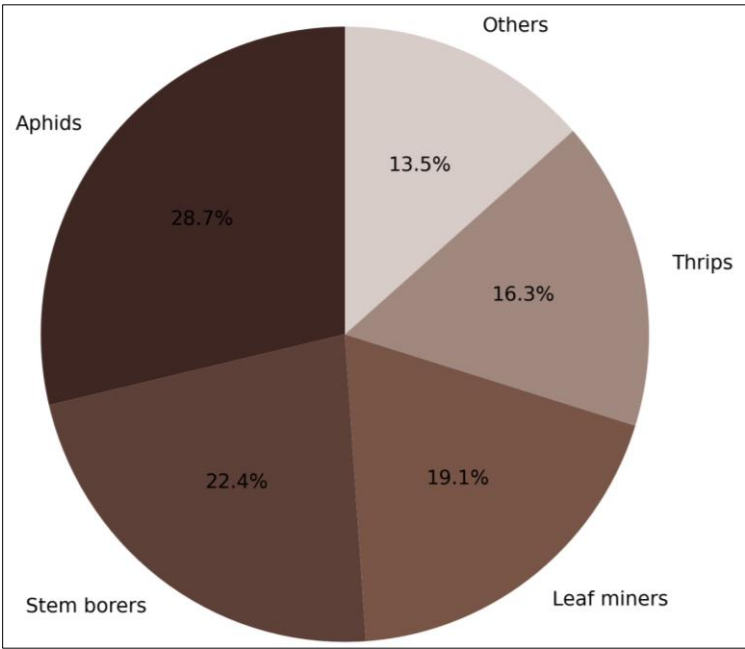


Fig 1: Relative abundance (%) of insect pest groups captured across all field plots over two seasons

Aphids dominated the pest community at nearly 29 percent of total captures, with stem borers and leaf miners together accounting for another 41 percent. Thrips were more

prevalent during dry periods, while leaf miners peaked during the cooler months.

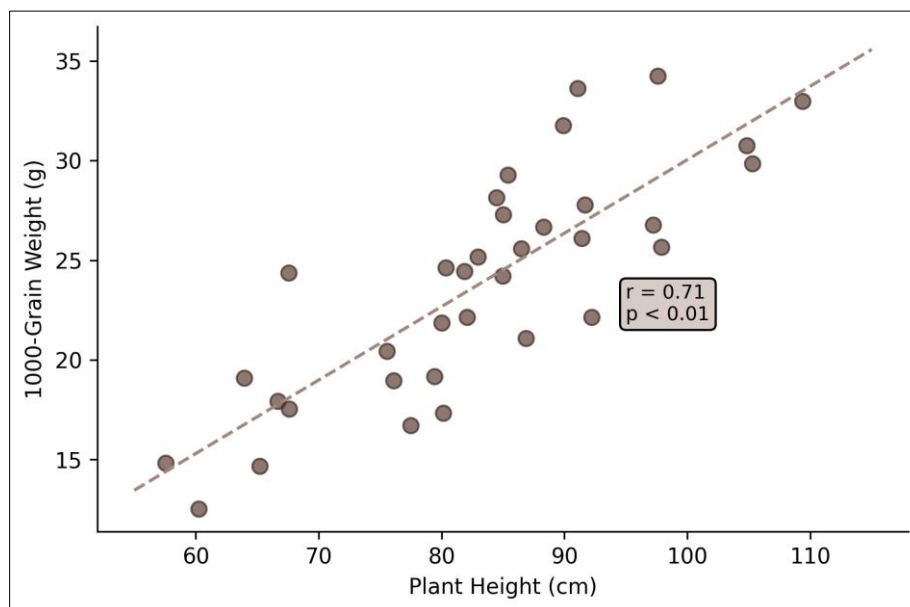


Fig 2: Scatter plot of plant height versus 1000-grain weight across all field treatments

A moderate positive correlation ($r = 0.71$, $p < 0.01$) was observed between plant height and grain weight, suggesting that taller genotypes under these conditions were not penalized in grain filling capacity. The relationship held across both cultivars and both seasons.

Discussion

The 31 percent reduction in pest-related yield loss under IPM compared with untreated controls demonstrates that biological control agents can function effectively even in cool highland environments, where parasitoid activity might be expected to slow [5]. *Aphidius colemani*, released at the tillering stage, established quickly and reached peak parasitism rates of 43 percent by heading, which was enough to keep aphid populations below economic thresholds in most plots [3].

Vertical farming eliminated pest pressure entirely and boosted yields, but the energy inputs for lighting and cooling make it impractical for bulk cereal production at current electricity costs. Its value may lie in seed multiplication or specialty grain production where premium prices can absorb the overhead [6]. Packaging results confirmed earlier findings that PICS hermetic bags virtually eliminated insect re-infestation over 90 days (0.3 insects per kg versus 14.7 in woven polypropylene), making them a cost-effective post-harvest investment [7].

Biochar's effect on grain protein a 17.3 percent increase over unamended controls likely reflects improved nitrogen retention in the root zone, consistent with biochar's documented capacity to reduce nitrate leaching in sandy and volcanic soils [8]. Diallel analysis revealed significant GCA effects for 1000-grain weight, with Kenya Fahari contributing the most favorable alleles, and significant SCA for aphid tolerance, suggesting non-additive gene action governs this trait [14].

Conclusion

Integrated pest management reduced wheat yield losses by 31 percent compared with no intervention, matching conventional spray performance with far less chemical input. Vertical farming offered the highest yields but at prohibitive energy cost for staple grain production. Biochar amendment

improved grain protein by 17 percent, and hermetic packaging nearly eliminated storage pest damage. Diallel analysis pointed to Kenya Fahari as a strong general combiner for grain weight and identified specific crosses with enhanced pest tolerance. For highland wheat growers, these findings support a layered approach: IPM for field pest control, biochar for soil fertility, and hermetic storage for post-harvest protection.

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