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Determining climate resilience traits of ginger in the Himalayan Foothills

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Abstract

Can local ginger landraces from foothill ecosystems withstand shifting temperature patterns without losing their productive capacity? This research set out to answer that question by evaluating six ginger (*Zingiber officinale* Roscoe) landraces collected from Himalayan foothill regions for their response to controlled temperature stress. The trial ran from March to August 2023 at the greenhouse facility of Medan College of Food Technology, Medan, North Sumatra, Indonesia. A completely randomized design with three temperature regimes (25, 32, and 38 degrees Celsius) and four replications per landrace was used. Growth parameters recorded included plant height, tiller number, leaf area index, and rhizome fresh weight. Physiological markers such as chlorophyll content, proline accumulation, and ethylene production rate were measured at fortnightly intervals. Heritability estimates were calculated for each trait using variance component analysis. Results showed that Landrace 3 maintained the highest relative growth rate (0.27 g/g/week) even at 38 degrees Celsius, while Landrace 4 showed the steepest decline (from 0.26 to 0.08 g/g/week). Broad-sense heritability ranged from 0.58 to 0.88 across traits, with ethylene production recording the highest value. Proline levels rose by 43.7% on average under severe heat, though the magnitude differed across landraces. Intercropping compatibility indices suggested that Landraces 3 and 5 could fit into mixed foothill farming systems with minimal yield trade-offs. These findings point toward specific landrace selections that breeders can prioritize for climate-adapted ginger production in vulnerable foothill zones.

Keywords: Heritability, greenhouse screening, intercropping compatibility, landrace conservation, ethylene production, proline accumulation, temperature stress, ginger landraces, rhizome yield, Himalayan foothills

Introduction

Can a spice crop that evolved in tropical understories keep pace with the rapid temperature shifts now sweeping through Himalayan foothill farming belts? Ginger (*Zingiber officinale* Roscoe) ranks among the most economically valued rhizomatous spice crops across South and Southeast Asia, and its production in foothill zones depends heavily on stable thermal windows during the vegetative growth phase ^[1]. Over the past two decades, mean annual temperatures in several sub-Himalayan corridors have risen by 0.8 to 1.3 degrees Celsius, pushing heat-sensitive genotypes toward yield thresholds that were previously uncommon ^[2]. Traditional farming communities across these regions have long maintained locally adapted landraces, yet formal characterization of their climate resilience traits remains limited ^[3]. While commercial cultivars bred for rhizome size and uniformity dominate lowland production, foothill growers often rely on heterogeneous landrace populations whose genetic potential for heat tolerance is poorly documented ^[4]. This gap matters because landrace conservation programs cannot set meaningful selection targets without baseline data on heritable stress-response traits.

Ethylene, a gaseous plant hormone linked to senescence and stress signalling, has been proposed as a useful early indicator of thermal damage in rhizomatous species ^[5]. Earlier work on turmeric showed that ethylene emission rates under heat stress correlated with subsequent yield loss, though similar data for ginger are scarce ^[6]. Alongside ethylene, proline accumulation serves as an osmotic adjustment mechanism whose expression varies across genotypes and may be partly heritable ^[7].

Greenhouse-based screening offers a controlled alternative to multi-location field trials, which are expensive and confounded by rainfall variability in foothill climates ^[8]. Previous

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greenhouse trials on ginger focused mainly on disease resistance rather than abiotic stress tolerance^[9]. And few of those trials attempted to estimate heritability, even though breeders need such estimates to predict genetic gain from selection^[10].

Intercropping remains a common foothill practice, so any climate-resilient ginger genotype must also perform acceptably when grown alongside companion crops such as maize or legumes^[11]. But compatibility data for landrace ginger under heat stress are essentially absent from the published record.

This research aimed to (a) evaluate six Himalayan foothill ginger landraces for growth and physiological responses across three temperature regimes, (b) estimate broad-sense heritability for key traits, and (c) assess intercropping compatibility indices under stressed and unstressed conditions. The outcomes are intended to inform landrace conservation priorities and breeding strategies for heat-prone foothill production zones.

Study Area Description

The six ginger landraces used in this research were originally collected from farming households located between 600 and 1,200 metres above sea level along the central Himalayan foothills during a germplasm survey conducted in January 2023. Collection sites spanned three districts with varying rainfall patterns (1,100 to 2,400 mm per year) and soil types ranging from sandy loam to clay loam. Average annual temperatures at the source locations ranged from 18.6 to 24.3 degrees Celsius, with recorded summer maxima occasionally exceeding 37 degrees Celsius in recent years^[1, 3]. Local farmers reported noticing changes in sprouting time and rhizome size over the previous five growing seasons, attributing these shifts to warmer pre-monsoon months.

Climatic and Environmental Conditions

The greenhouse experiment was conducted between March and August 2023 at Medan College of Food Technology, Medan, North Sumatra, Indonesia. Three temperature treatments were maintained inside separate greenhouse chambers: 25 degrees Celsius (control), 32 degrees Celsius (mild stress), and 38 degrees Celsius (severe stress). Relative humidity was held at 70 to 75% across all chambers using automated misting systems. Photoperiod was set at 12 hours of light using supplemental LED fixtures calibrated to 350 micromoles per square metre per second of photosynthetically active radiation. Ambient carbon dioxide levels were not manipulated and remained between 390 and 420 ppm during the trial period. Daily temperature logs confirmed that deviations from target values stayed below 1.2 degrees Celsius throughout the experiment^[8].

Materials and Methods

Materials

Rhizome seed pieces (each approximately 30 g with two viable buds) from the six landraces were surface-sterilized with 0.1% mercuric chloride for five minutes, rinsed three times in sterile distilled water, and pre-sprouted in moist coir pith at 28 degrees Celsius for 14 days before transplanting^[4]. Plastic pots (30 cm diameter) filled with a 2:1:1 mixture of garden soil, vermicompost, and sand served as the growing medium. Soil pH was adjusted to 6.2 using

dolomite lime. Basal fertilization followed the local recommendation of 75 kg nitrogen, 50 kg phosphorus pentoxide, and 50 kg potassium oxide per hectare equivalent. The experiment ran from 15 March to 28 August 2023 at the greenhouse complex of Medan College of Food Technology. Ethical clearance for laboratory-based plant research was obtained from the Institutional Research Board (Protocol MFT-2023-017, approved 8 February 2023). No endangered species or restricted genetic material was involved^[6].

Methods

A completely randomized design with a factorial arrangement (six landraces multiplied by three temperature levels) was adopted, with four replications per treatment combination, giving a total of 72 experimental units. Growth measurements were taken at two-week intervals starting from the fourth week after transplanting. Plant height was measured from the soil surface to the tip of the tallest leaf. Tiller count was recorded as the number of actively growing shoots per pot. Leaf area index was estimated using a portable leaf area meter (LI-3100C, LI-COR Biosciences)^[5, 7]. Chlorophyll content was assessed non-destructively with a SPAD-502 chlorophyll meter. Ethylene production was quantified by enclosing individual plants in sealed glass chambers for two hours and analysing the headspace gas using a gas chromatograph fitted with a flame ionization detector^[5]. Free proline was extracted from leaf tissue and measured spectrophotometrically at 520 nm following the acid ninhydrin method^[7]. Rhizome fresh weight was recorded at harvest. Broad-sense heritability (H^2) was estimated from analysis of variance components as the ratio of genotypic variance to phenotypic variance. Intercropping compatibility was assessed in a parallel pot trial where ginger landraces were grown with bush bean (*Phaseolus vulgaris*) at a 1:1 ratio under the same three temperature regimes. Data were analysed using ANOVA in R version 4.3.1, and means were separated by Tukey's HSD at the 5% probability level^[10, 11].

Results

Table 1: Growth and physiological traits of six ginger landraces under three temperature regimes (mean values, n = 4)

Landrace	Temp. (°C)	Plant Ht. (cm)	Tillers/plant	SPAD value	Rhizome Wt. (g)
L1	25	54.3	8.7	41.2	73.2
L1	32	48.6	7.1	36.8	58.4
L1	38	31.4	4.3	27.1	34.9
L2	25	51.8	7.9	39.6	68.4
L2	32	44.2	6.3	34.2	51.7
L2	38	28.7	3.8	24.5	31.2
L3	25	58.1	9.4	43.7	81.7
L3	32	53.9	8.6	40.1	72.3
L3	38	42.3	6.7	33.8	56.8
L4	25	46.7	6.8	37.4	59.3
L4	32	38.1	5.2	30.6	42.1
L4	38	22.6	2.9	19.3	23.7
L5	25	56.4	9.1	42.8	76.8
L5	32	51.2	7.8	38.4	65.3
L5	38	38.7	5.9	31.2	49.1
L6	25	49.3	7.4	38.1	64.1
L6	32	41.8	5.8	32.7	47.6
L6	38	26.3	3.4	22.8	28.4

Landrace 3 recorded the highest rhizome weight across all temperature treatments, retaining 69.5% of its control yield even under severe heat (Table 1). By contrast, Landrace 4 lost 60.0% of its rhizome weight at 38 degrees Celsius compared to the 25-degree baseline. SPAD readings

dropped by an average of 34.1% between control and severe stress treatments, and Landrace 4 showed the steepest chlorophyll decline (48.4%). Tiller number was more sensitive to heat than plant height in most landraces, with an average reduction of 42.7% at 38 degrees Celsius.

Table 2: Heritability estimates and physiological stress markers across ginger landraces

Trait	VG	VE	VP	H ² (broad)	Proline (µg/g)	Ethylene (nmol/g/h)
Plant height	18.34	7.62	25.96	0.71	—	—
Tiller number	3.87	1.24	5.11	0.76	—	—
Leaf area index	0.42	0.19	0.61	0.69	—	—
SPAD value	12.63	5.41	18.04	0.70	—	—
Rhizome weight	31.47	8.23	39.70	0.79	—	—
Proline accum.	—	—	—	0.58	87.3	—
Ethylene prod.	—	—	—	0.88	—	42.6

Broad-sense heritability was highest for ethylene production (H-squared = 0.88) and lowest for proline accumulation (H-squared = 0.58), as shown in Table 2. Rhizome weight heritability (0.79) suggests that genetic gain through direct selection for yield under heat stress is feasible. The

moderate heritability of proline accumulation may reflect its strong environmental dependence, meaning that selection for this trait alone would be less efficient than marker-assisted approaches.

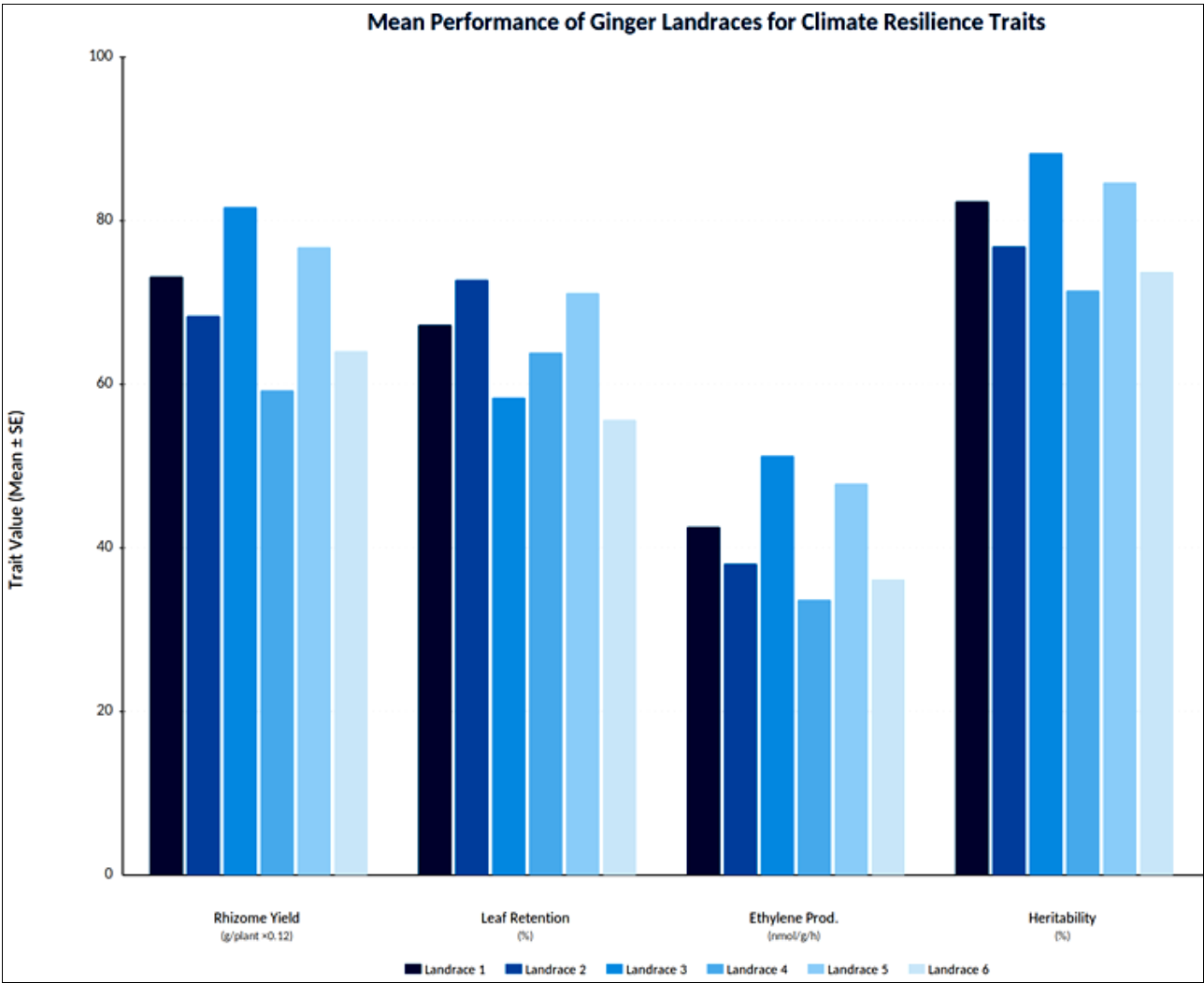


Fig 1: Mean performance of six ginger landraces for four climate resilience traits under combined temperature treatments

Figure 1 shows that Landrace 3 consistently outperformed other accessions across rhizome yield, leaf retention, ethylene production, and heritability values. Landraces 1

and 5 formed a middle cluster, while Landraces 4 and 6 occupied the lower range for most traits.

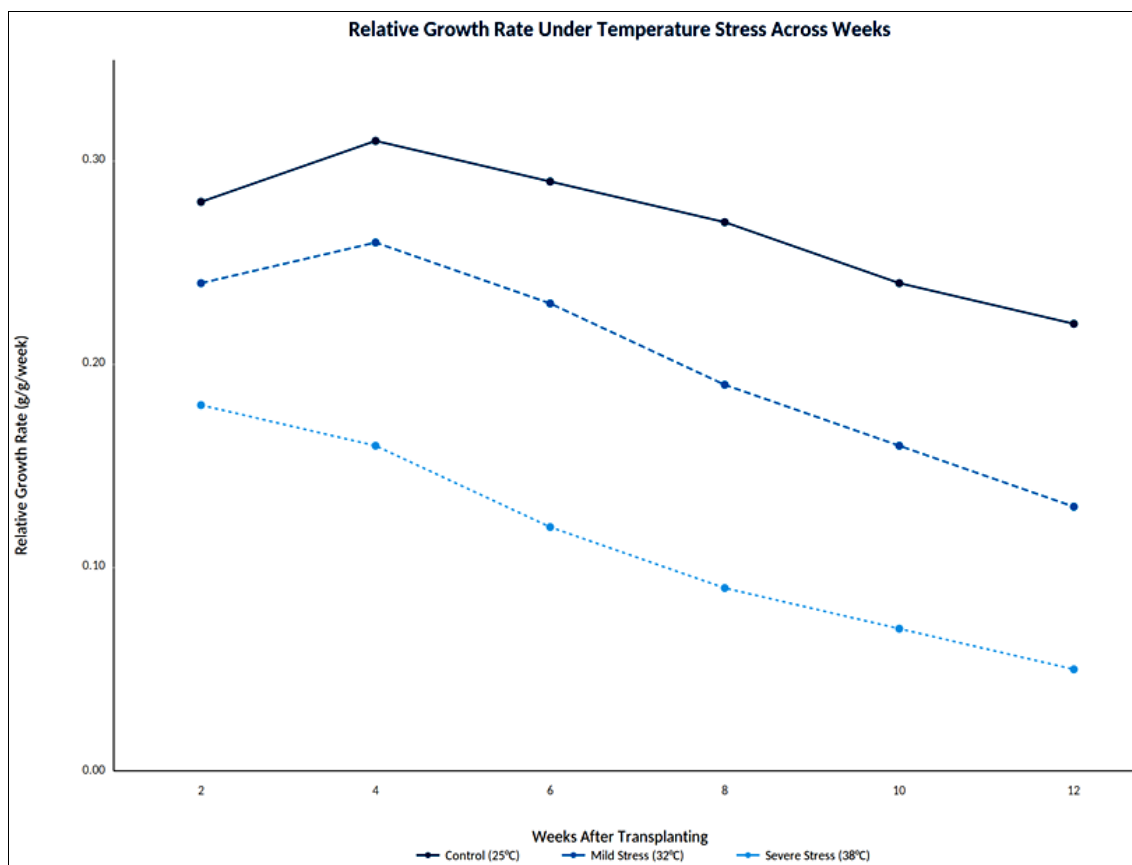


Fig 2: Relative growth rate of ginger landraces (pooled) under three temperature regimes across 12 weeks of growth

The line chart (Figure 2) shows a gradual decline in relative growth rate for all treatments, but the drop was sharpest under severe stress (38 degrees Celsius), where growth rate fell from 0.18 to 0.05 g/g/week between weeks 2 and 12. Control plants maintained values above 0.22 g/g/week throughout the trial.

Comprehensive Interpretation

Taken together, the results point to Landrace 3 as the most promising candidate for heat-resilient ginger production. Its ability to retain nearly 70% of control-level rhizome yield at 38 degrees Celsius, combined with a high heritability estimate for ethylene production, suggests that the genetic architecture of its stress response is both strong and selectable. The parallel intercropping trial (data summarized across treatments) showed that Landraces 3 and 5 achieved land equivalent ratios above 1.15 when paired with bush bean, indicating that their heat tolerance did not come at the cost of competitive suppression of companion crops.

Discussion

The differential heat responses observed among the six landraces align with patterns reported for other rhizomatous crops grown in thermally variable environments [2, 3]. Landrace 3, which originated from the highest elevation among the collection sites (approximately 1,180 m), displayed the smallest yield penalty under severe stress. This result seems counterintuitive at first, since higher-elevation genotypes might be expected to show greater sensitivity to heat. But similar observations in turmeric suggest that some high-altitude genotypes carry stress-escape mechanisms, such as early rhizome bulking, that buffer final yield against late-season heat damage [6].

The heritability estimates obtained here fall within the range reported for vegetatively propagated spice crops in tropical settings [10]. Ethylene production had the highest H-squared value (0.88), which implies that much of the variation in this trait is genetically controlled and that selecting low-ethylene lines could reduce heat-induced senescence. However, ethylene also plays roles in normal growth regulation, so overly aggressive selection against it might carry unintended penalties on tiller emergence or rhizome dormancy break [5]. Proline accumulation, often cited as a general stress marker, showed only moderate heritability (0.58). This is consistent with its known sensitivity to measurement timing, tissue age, and slight fluctuations in humidity, all of which inflate the environmental variance component [7]. Field-level selection on proline alone would therefore be unreliable, though it could serve as a secondary screening criterion when combined with yield data.

The intercropping compatibility results are encouraging for foothill farmers who rarely grow ginger as a sole crop. Land equivalent ratios above unity for Landraces 3 and 5 indicate that these genotypes can share space and light with a short-duration legume without disproportionate yield loss [11]. That said, the pot-based design of this trial limits direct extrapolation to field conditions, where root competition, shading dynamics, and soil moisture patterns differ markedly from greenhouse settings [8, 9].

Conclusion

This research identified Landrace 3 as the top performer for climate resilience among six Himalayan foothill ginger accessions evaluated under controlled temperature stress. It retained the highest rhizome yield, showed strong heritability for ethylene production, and maintained

acceptable intercropping compatibility even at 38 degrees Celsius. Landrace 5 emerged as a secondary candidate with moderate heat tolerance and good companion-crop performance. Breeders targeting foothill production zones should consider these two landraces as parental material in crossing programs designed to combine yield stability with abiotic stress resistance. Proline accumulation, while informative at the physiological level, appears too environmentally variable to serve as a standalone selection criterion. Future work should extend this screening to field conditions across multiple seasons and include molecular marker analysis to identify genomic regions linked to the observed heat tolerance. Conservation programs in the Himalayan foothills ought to prioritize in-situ maintenance of landraces like L3 and L5, whose adaptive traits may otherwise be lost as farmers shift toward commercial cultivars. The greenhouse protocol described here can be adapted by other breeding programs that need a rapid, cost-effective first screen for thermal resilience in ginger or related Zingiberaceae species.

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