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SHORT RESEARCH ARTICLE

Assessing heat tolerance in groundnut (*Arachis hypogaea* L.) through the MGIDI approach

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Abstract

Groundnut (*Arachis hypogaea* L.) productivity is constrained by high temperature and drought stress. The present study used the multi-trait genotype-ideotype distance index (MGIDI) to evaluate genotypes under post-rainy conditions and identify heat-tolerant lines. Four superior genotypes (ICGV 07222, ICGV 03043, ICGV 13312, ICGV 03042) were selected with 86.66% success at 15% selection intensity. High selection gains for traits such as pod yield per plant, heat use efficiency, photothermal use efficiency, heliothermal use efficiency, shelling percentage, test weight, canopy temperature, haulm weight and SPAD chlorophyll meter reading highlighted their role as key indicators of heat tolerance.

Keywords: Groundnut, heat-stress tolerance, Multi-trait Genotype Ideotype Distance Index (MGIDI), selection gain, superior genotype, selection.

Groundnut (*Arachis hypogaea* L.) is a vital oilseed crop cultivated across semi-arid tropics, often facing drought and heat stresses that severely affect yield and quality (Puppala et al. 2023; Raza et al. 2024). With the global mean temperature projected to rise by 1.5°C by 2040 (IPCC, https://www.ipcc.ch/report/ar6/syr/), the development of heat-tolerant groundnut cultivars is crucial. Temperature exceeding 35°C during the reproductive stage severely affects pollen viability and pod set in groundnut, ultimately reducing productivity and posing a threat to food security (Aravind et al. 2022). A total of 30 groundnut genotypes, comprising recombinant inbred lines (RILs) for heat tolerance and their parents, elite cultivars, advanced breeding lines from ICRISAT were evaluated during the post-rainy seasons of 2022-23 (PR 2022) and 2023-24 (PR 2023) at University of Agricultural Sciences (UAS), Dharwad in a Randomized Block Design with two replications. The highest temperatures recorded at the experimental site were 40.97°C in April 2023 and 42.97°C in May 2024, coinciding with the flowering and reproductive stages of the groundnut crop during the post-rainy season. These conditions provided a suitable environment for evaluating the genotypes under natural high-temperature stress. Two plants per genotype were tagged for recording morpho-physiological observations like plant height (PH in cm), days to flower initiation (DFI), days to 50% flowering (DFF), SPAD chlorophyll meter reading (SCMR), canopy temperature (CT, °C) and agronomic traits like number of pods per plant (NPPP), pod yield per plant (PYPP, g), haulm weight (HW, g), seed weight (SW, g), test weight (TW, g), shelling percentage (SP, %), biological yield (BY, g/plant), harvest index (HI, %) were recorded. Weather data from GKMS, UAS, Dharwad, were used to compute thermal indices like, growing degree days (GDD, °C day), GDD for flower initiation (GDDFI), GDD for fifty percent flowering (GDDFF), heat use efficiency (HUE, kg ha^{-1} °C day), helio-thermal unit

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(HTU, ℃ days-[1] hrs[-1]), helio-thermal use efficiency (HTUE, g °C days^{-1} hrs^{-1}), photothermal unit (PTU, °C days^{-1} hrs^{-1}), photothermal use efficiency (PTUE, g °C days^{-1} hrs^{-1}) to assess heat response. The Multi-Trait Genotype-Ideotype Distance Index (MGIDI) approach was used to rank genotypes based on multiple traits, which were rescaled for desired positive gains (PYPP, HW, NPPP, SP, TW, HI, SCMR, HUE, PTUE, HTUE) and negative gains (PH, CT, SLA, GDDFI, GDDFF), with the ideal genotype scoring 100 for all traits. Exploratory Factor Analysis (EFA) was used to reduce the data dimensionality and to address multicollinearity. Selection differentials and selection gains were estimated at 15% selection intensity, adjusting gains for heritability. All analyses were conducted in R Studio (v4.4.1) using the 'metan' package (Olivoto and Lúcio 2020) to identify superior heat-tolerant genotypes.

Trait clustering and identification of heat tolerance indicators in groundnut based on selection gain

The first three factors (FA1, FA2, and FA3) with eigenvalues greater than one explained 43.5, 24.6, and 8.2% of the variance, respectively, cumulatively accounting for 76.3% of the total variance and effectively grouping the traits into three major components under high temperature conditions. FA1 included PYPP, HUE, PTUE, HTUE, NPPP, and HI, representing yield and thermal indices critical for heat tolerance and productivity. FA2 comprised HW, SP, TW, CT, SLA, and GDDFI, reflecting reproductive and thermal adaptation traits related to biomass, partitioning, and flowering. FA3 included SCMR, PH, and GDDFF, representing physiological efficiency and maturity traits. Most traits showed communalities close to 1, indicating that the extracted factors effectively captured the trait variability (Table 1). High selection gains highlighted FA1 traits, PYPP (13.42), HUE (9.15), PTUE (9.14), HTUE (9.05), and HI (2.34) as primary indicators for improving productivity and heat tolerance. In FA2, TW (16.94), SP (8.63), CT (5.03) and HW (3.70) showed moderate to high gains, emphasizing their importance in reproductive efficiency and canopy temperature regulation, while negative gains for SLA (-0.40) and GDDFI (-8.60) suggest refinement is needed in leaf architecture and phenology. FA3 traits had lower gains, with slight improvement in SCMR (1.56) but negative gains for PH (-7.63) and GDDFF (-4.05), suggesting shorter and early flowering plants enhance stress adaptation (Table 1). Overall, PYPP, HUE, PTUE, HTUE, TW, SP, CT, HW and SCMR emerged as reliable selection targets for heat-tolerant groundnut genotypes, consistent with previous studies (Akbar et al. 2017; Sharma et al. 2023; Aravind et al. 2024).

MGIDI-based genotype selection and strengths–weaknesses analysis

Based on MGIDI rankings, the top 15% of genotypes were identified as superior performers. The pooled analysis across PR 2022 and PR 2023 identified ICGV 07222 (G1; 2.09), ICGV 03043 (G5; 2.12), ICGV 13312 (G2; 2.52) and ICGV 03042 (G7; 2.66) as the most promising genotypes, having the lowest MGIDI scores, which indicate their close resemblance to the ideal ideotype. Girnar 5 (G20; 2.86) and ICGV 181031 (G3; 2.87) also performed well, with MGIDI values near the selection threshold. In contrast, ICGR

Table 1. Factor loadings, communality, heritability, and selection gains of traits at high temperature condition

Traits	Factor	Factor loading	Communality	Xo	Xs	SD %	h^2	SG %
PYPP	FA1	0.97	0.976	17.52	20.58	17.51	0.77	13.42
NPPP	FA1	0.86	0.863	16.36	16.01	-2.11	0.82	-1.72
HI	FA1	0.80	0.812	37.31	38.62	3.51	0.67	2.34
HUE	FA1	0.94	0.738	6.91	7.80	12.84	0.71	9.15
PTUE	FA1	0.94	0.645	0.06	0.07	12.84	0.71	9.14
HTUE	FA1	0.93	0.929	0.08	0.09	12.83	0.71	9.05
HW	FA2	0.74	0.482	28.79	30.65	6.49	0.57	3.70
SP	FA2	0.82	0.987	76.58	83.99	9.68	0.89	8.63
TW	FA2	0.70	0.987	39.76	47.79	20.21	0.84	16.94
CT	FA2	0.85	0.983	33.50	35.91	7.18	0.70	5.03
SLA	FA2	0.46	0.506	64.10	63.66	-0.70	0.58	-0.40
GDDFI	FA2	0.66	0.791	420.95	378.05	-10.19	0.84	-8.60
SCMR	FA3	0.67	0.350	41.91	42.96	2.51	0.62	1.56
PH	FA3	0.51	0.815	25.89	22.96	-11.32	0.67	-7.63
GDDFF	FA3	0.70	0.588	591.08	562.86	-4.78	0.85	-4.05

$\mathbf{X_0}$ = Overall mean; $\mathbf{X_S}$ = Mean of selected genotypes; **SD = S**election differential; **h²** = Broad-sense heritability and **SG** = Selection gain

Table 2. MGIDI scores and factor values for groundnut genotypes evaluated under post-rainy seasons

Genotypes	Code	MGIDI Score	FA1	FA2	FA3
ICGV 07222	G1	2.09	68.00	11.85	20.15
ICGV 13312	G2	2.52	79.81	0.71	19.47
ICGV 181031	G3	2.87	80.97	11.85	7.19
ICGV 16553	G4	2.88	86.63	4.20	9.17
ICGV 03043	G5	2.12	39.72	23.06	37.22
ICGV 181023	G6	3.21	64.66	4.21	31.13
ICGV 03042	G7	2.66	67.32	13.17	19.52
ICGV 11380	G8	3.41	42.66	17.34	40.00
ICGV 13189	G9	3.03	36.11	24.53	39.36
ICGR 152007	G10	4.34	46.30	2.03	51.68
ICGR 152014	G11	4.33	49.06	8.37	42.58
ICGR 151998	G12	4.50	47.01	6.53	46.46
ICGR 152134	G13	4.51	42.12	5.55	52.33
ICGR 152090	G14	5.90	53.01	2.23	44.77
ICGR 152040	G15	4.36	70.45	3.57	25.99
ICGR 151956	G16	4.39	52.82	4.21	42.97
JL 24	G17	3.91	42.40	19.92	37.68
55-437	G18	3.04	33.35	26.73	39.92
Dh 86	G19	3.57	31.95	12.24	55.81
Girnar 5	G20	2.86	8.44	22.10	69.46
K 1574	G21	3.42	48.39	24.07	27.54
R 9227	G22	4.75	45.66	26.31	28.02
G 2-52	G23	4.23	51.61	16.65	31.75
Dh 232	G24	2.97	23.48	31.54	44.98
Dh 245	G25	3.56	38.30	30.33	31.38
Dh 256	G26	3.21	22.64	32.82	44.54
Dh 257	G27	3.45	46.55	40.56	12.89
JSP 39	G28	4.22	42.29	23.96	33.75
KDG 123	G29	3.46	41.09	22.85	36.06
ICG 875	G30	4.78	63.98	30.78	5.24

152090 (G14; 5.90) and ICG 875 (G30; 4.78) exhibited higher MGIDI scores, reflecting greater sensitivity to heat stress (Table 2 and Fig. 1a). The strengths–weaknesses analysis indicated that among the top-performing genotypes (G1, G5, G2 and G7), the higher contribution of FA1 suggests that yield-related and thermal efficiency traits remain primary targets for genetic improvement, whereas physiological and reproductive attributes represented by FA2 and FA3 exhibited performance closer to the ideotype (Table 2 and Fig. 1b). Overall, the selected genotypes exhibited a superior integration of morpho-physiological and yield-related traits,

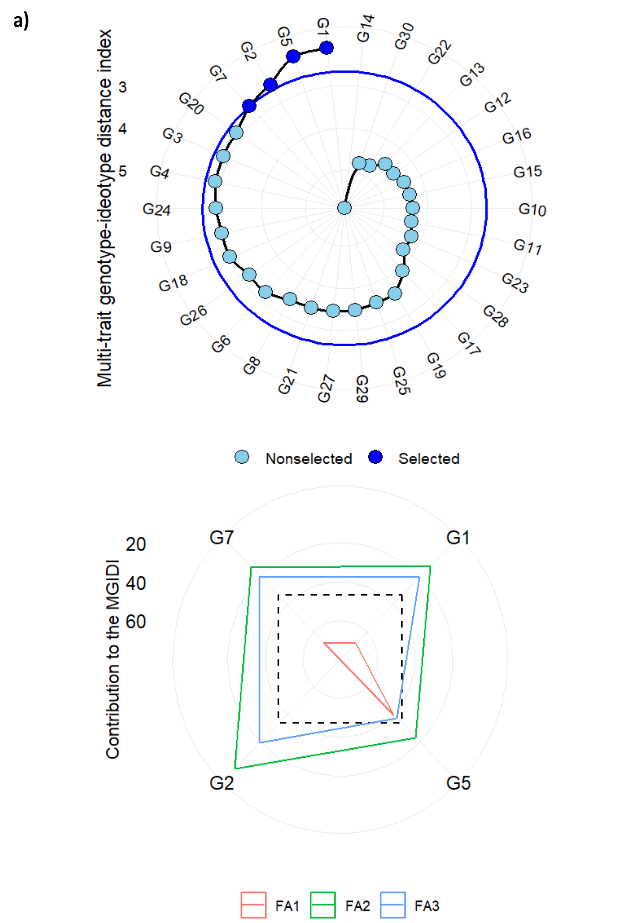

Fig. 1. MGIDI-based ranking and trait contributions for selected genotypes a) MGIDI radar plot showing overall genotype performance b) Strengths and weaknesses profile highlighting factor-wise contribution for selected genotypes

defining them as heat-tolerant ideotypes. With further multi-environment evaluation, these genotypes hold strong potential for deployment in breeding programs aimed at developing climate-resilient groundnut cultivars.

Authors' contribution

Conceptualization of research (SNN); Designing of the experiments (SNN, BNM, RSB, PSK); Contribution of experimental materials (PJ, BNM); Execution of field/lab experiments and data collection (RJS); Analysis of data and interpretation (RJS, SNN); Preparation of the manuscript (RJS, SNN).

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