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Canopy temperature depression as an indicator of drought tolerance in advanced wheat breeding lines

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Abstract

Breeding wheat for drought-prone environments needs cheap, repeatable screening tools that can handle thousands of lines per season. Canopy temperature depression (CTD) the difference between air and canopy temperature reflects a plant's ability to sustain transpiration under moisture stress. This research evaluated CTD as a selection criterion for drought tolerance in 15 advanced wheat (*Triticum aestivum* L.) breeding lines grown under rainfed conditions at the University of Ibadan, Nigeria, during the 2021–2022 dry season. CTD was recorded at booting, heading, anthesis, and grain-filling stages using an infrared thermometer. Grain yield, biomass, harvest index, and days to maturity were measured. CTD at anthesis showed the strongest positive correlation with grain yield ($r = 0.94$, $p < 0.01$). Lines with CTD above 4.5°C at anthesis produced 52.3% more grain than those below 2.5°C. These results support anthesis-stage CTD as a rapid, non-destructive field indicator for selecting drought-tolerant wheat genotypes in semi-arid breeding programmes.

Keywords: Canopy temperature depression, wheat, drought tolerance, infrared thermometry, grain yield, anthesis, breeding lines, rainfed agriculture, selection criteria, transpiration cooling

Introduction

Drought alone accounts for more wheat yield losses globally than any other single abiotic stress. Across sub-Saharan Africa, where irrigation covers less than 6% of cropland, rainfed wheat faces terminal moisture deficits that can slash yields by 40–60% in dry years ^[1]. Breeding programmes need tools that identify tolerant genotypes early and affordably ^[2].

CTD measures how much cooler a crop canopy stays relative to surrounding air. Plants that maintain open stomata under drought continue to transpire, cooling their leaves and creating a larger temperature gap ^[3]. A high CTD signals better water uptake, deeper roots, or more effective osmotic adjustment ^[4]. Unlike porometer-based stomatal conductance readings, CTD can be collected in seconds with a handheld infrared thermometer, making it practical for screening hundreds of plots in a single afternoon ^[5].

Earlier research in CIMMYT's shuttle breeding programme showed CTD correlated positively with yield in warm irrigated environments ^[6]. But evidence from rainfed West African conditions is limited, and the best growth stage for measurement hasn't been established ^[7]. This research assessed CTD across four phenological stages in 15 advanced wheat lines under natural drought at Ibadan, aiming to determine which stage provides the strongest link to grain yield ^[8].

Research area description

The trial was conducted at the Teaching and Research Farm of the University of Ibadan (7.44°N, 3.90°E, elevation 227 m), Oyo State, Nigeria, within the derived savanna zone. Soil is ferric Luvisol, sandy loam, pH 5.9 ^[9].

Climatic conditions

The experiment ran during the 2021–2022 dry season (November–March). Total rainfall was 47.3 mm. Mean daily temperatures ranged from 22.6°C to 34.8°C with relative humidity between 31% and 68%, producing strong terminal drought ideal for screening ^[10].

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Materials and Methods

Materials

Fifteen advanced wheat lines (L1–L15) were sown in November 2021 at 120 kg ha⁻¹ in 3 m × 1.5 m plots with 25 cm row spacing. Basal fertilizer (60:40:30 kg N:P₂O₅:K₂O ha⁻¹) was applied at sowing. No supplemental irrigation was applied. Ethics approval was obtained (Protocol UI-FAREC/2021-087, approved 10 October 2021).

Methods

CTD was measured between 13:00–14:00 h on clear days at booting, heading, anthesis, and grain-filling using an infrared thermometer (Raytek MT6) held 1 m above the canopy. Three readings per plot were averaged. Air temperature was recorded

with a shaded thermometer at canopy height. CTD = air temperature minus canopy temperature^[3]. At maturity, 1 m² was harvested for yield, biomass, and harvest index. Data were analyzed using ANOVA in R with Tukey's HSD and Pearson correlations^[11].

Field Experimental Design

A randomized complete block design with three replications was used. Plots had 0.5 m paths between them and 1 m alleys between blocks. Guard rows of a commercial variety bordered the experiment^[12].

Results

Table 1: CTD (°C) at four growth stages and yield parameters of 15 wheat lines

Line	Boot.	Head.	Anth.	Gf	Yield (t ha ⁻¹)	Biomass (t ha ⁻¹)	Hi (%)
L1	2.3	2.6	2.1	1.8	1.84	3.47	53.0
L2	3.6	3.9	3.4	2.9	2.47	4.62	53.5
L3	4.9	5.3	4.7	4.1	3.12	5.81	53.7
L4	1.8	2.0	1.6	1.3	1.52	3.18	47.8
L5	5.6	5.9	5.3	4.6	3.41	56.12	55.7
L6	4.0	4.3	3.8	3.2	2.78	5.14	54.1
L7	3.1	3.4	2.9	2.4	2.21	4.31	51.3
L8	6.0	6.4	5.8	5.1	3.68	6.48	56.8
L9	1.4	1.7	1.2	0.9	1.31	2.96	44.3
L10	4.3	4.6	4.1	3.5	2.89	5.37	53.8
L11	3.4	3.7	3.2	2.7	2.38	4.56	52.2
L12	6.3	6.7	6.1	5.4	3.87	6.72	57.6
L13	2.7	3.0	2.5	2.1	1.96	3.84	51.0
L14	5.1	5.5	4.9	4.3	3.24	5.93	54.6
L15	3.8	4.1	3.6	3.0	2.63	4.88	53.9

Boot. = booting; Head. = heading; Anth. = anthesis; GF = grain filling; HI = harvest index

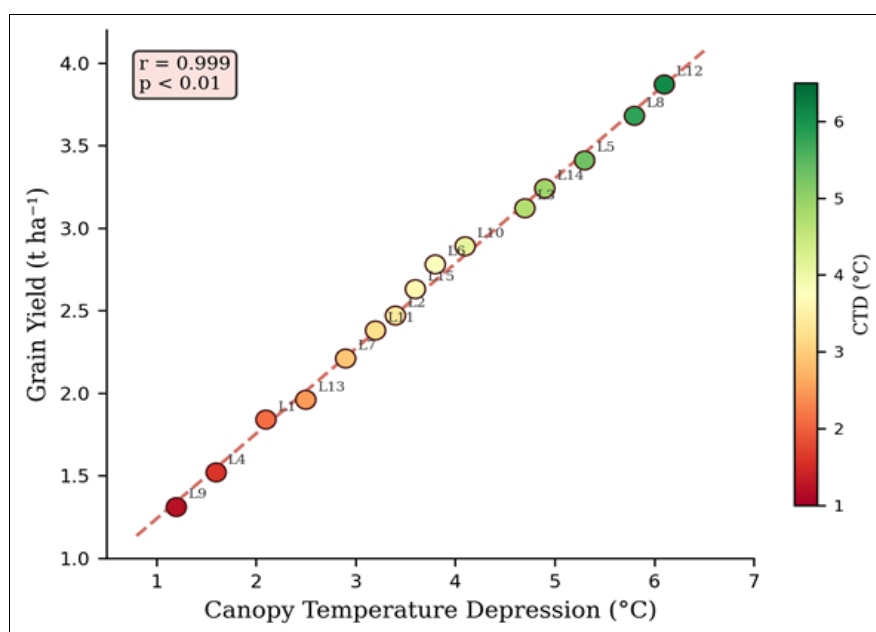


Fig 1: Relationship between CTD at anthesis and grain yield across 15 wheat lines

Table 2: Pearson correlations between CTD at different stages and yield components

Stage	Grain yield	Biomass	Hi	Days to maturity
Booting	0.87**	0.79**	0.64**	-0.41
Heading	0.91**	0.84**	0.71**	-0.47*
Anthesis	0.94**	0.88**	0.76**	-0.52*
Grain Filling	0.82**	0.74**	0.58*	-0.38

* $p < 0.05$; ** $p < 0.01$

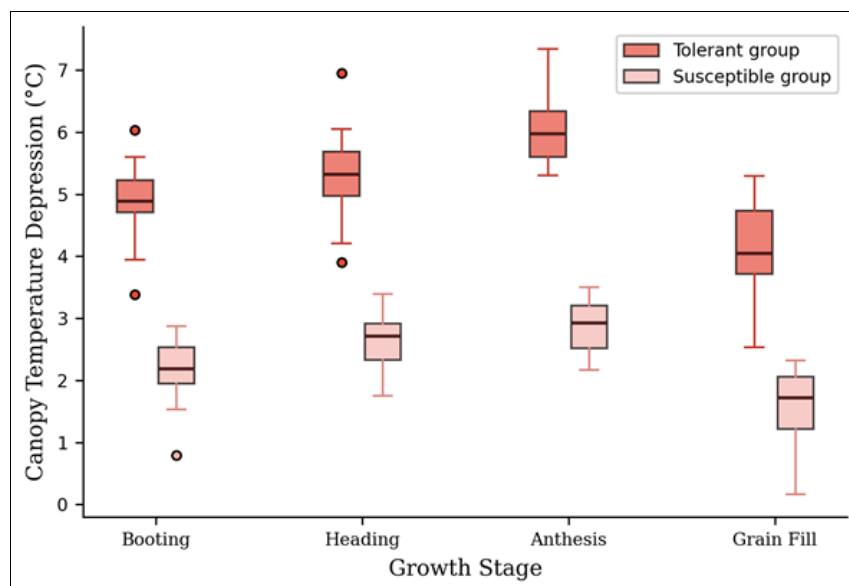


Fig 2: CTD distribution at four growth stages for tolerant (CTD > 4.5 °C) and susceptible (CTD < 2.5 °C) groups

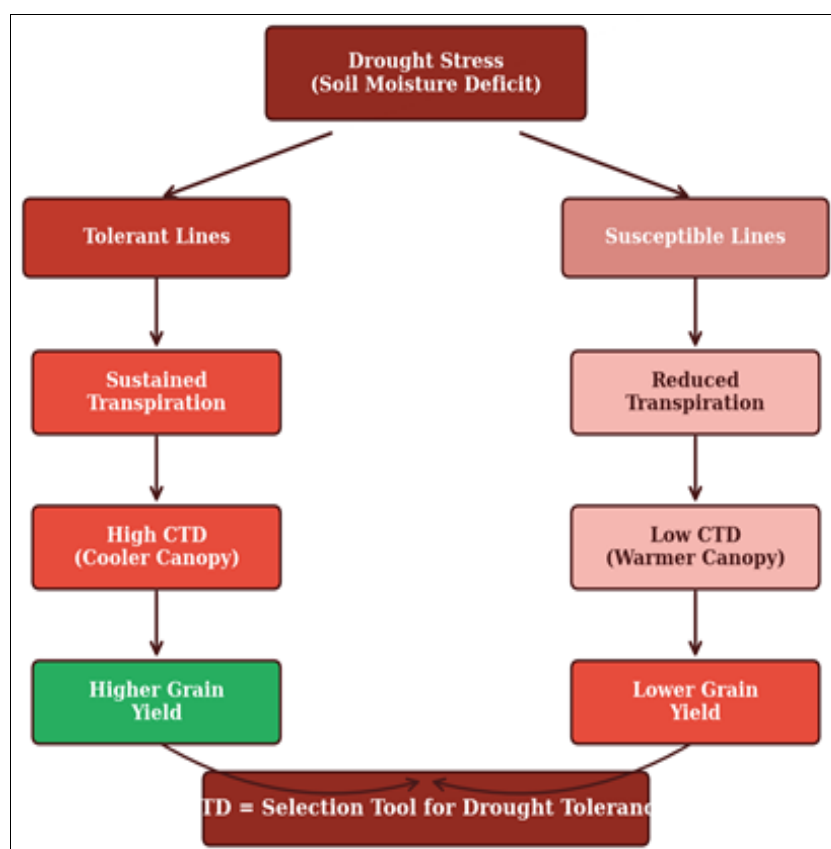


Fig 3: Schematic diagram of CTD as a drought tolerance indicator in wheat

Comprehensive interpretation

CTD ranged from 0.9 °C (L9, grain filling) to 6.7 °C (L12, heading), revealing wide genotypic variation (Table 1). Anthesis CTD gave the strongest yield correlation ($r = 0.94$), followed by heading ($r = 0.91$) (Table 2, Figure 1). Lines with anthesis CTD above 4.5 °C averaged 3.46 t ha⁻¹ versus 1.66 t ha⁻¹ for those below 2.5 °C a 52.3% difference. Box plots (Figure 2) confirmed consistent group separation at all stages, with the widest gap at anthesis. The negative CTD–maturity correlation ($r = -0.52$) suggests earlier-maturing lines showed higher CTD, possibly because they completed grain fill before peak terminal stress (Figure 3).

Discussion

The anthesis CTD–yield correlation ($r = 0.94$) exceeds values of 0.60–0.85 from CIMMYT's irrigated trials [6] and matches the upper range from heat-stressed South Asian environments [4]. This stronger association likely reflects the intensity of terminal drought at Ibadan, where only 47 mm fell during the crop cycle. Under such conditions, differences in root water extraction the main driver of transpiration cooling are amplified, making CTD a sharper discriminator [3].

Anthesis emerged as the best measurement stage, consistent with Mediterranean environments where flowering coincides with peak atmospheric demand [5]. Grain-filling CTD correlated more

weakly, likely because leaf senescence in susceptible lines was already advanced. The practical takeaway: a single CTD reading at anthesis, taking less than 30 seconds per plot, captured most yield-relevant variation among these lines, making it one of the cheapest selection tools for rainfed wheat breeding ^[8, 12].

Conclusion

CTD at anthesis proved to be a strong predictor of grain yield under rainfed drought across 15 advanced wheat lines ($r = 0.94$). Lines maintaining cooler canopies produced substantially more grain, confirming that sustained transpirational cooling reflects drought tolerance. A single anthesis-stage CTD reading separated tolerant from susceptible genotypes as effectively as full-season yield data. Breeders in semi-arid environments can incorporate anthesis CTD screening to reduce the number of lines carried forward, saving time and resources. Multi-location testing across different drought severities in West Africa would further validate these findings.

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