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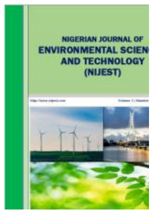

Cooling Effects of Common Tree Species in Jimeta, Adamawa State, Nigeria

[1]Dasin, M.S., [2]Usman, B.D., [1]Amos, J.K. and [1*]Zemba, A.A.
[1]Department of Geography, Faculty of Environmental Sciences, Modibbo Adama University, PMB, 2076, Yola, Nigeria
[2]Department of Operations Research, Faculty of Physical Sciences, Modibbo Adama University, PMB 2076, Yola, Nigeria
[*]Correspondent author, aa_zemba@mau.edu.ng

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ABSTRACT

Urban vegetation provides nature-based solutions for mitigating the Urban Heat Island (UHI) effect, particularly in rapidly urbanizing and climate-vulnerable regions such as Jimeta, Nigeria. This study assessed the cooling efficiency of 18 urban tree species over 18 days during the hot-dry season. Sub-canopy air temperature and relative humidity were recorded hourly with HOBO MX2301A data loggers at 1.5 m, complemented by Nigerian Meteorological Agency (NiMet) records. Tree traits including diameter at breast height (DBH), canopy size, height, and age were also measured. Cooling efficiency, computed as T_air – T_canopy, averaged 2.49 ± 0.73 °C. ANOVA revealed significant interspecific differences ($F = 11.54$, $p < 0.001$). The most effective cooling species were Gmelina arborea ($\Delta T = 3.8$ °C), Azadirachta indica (3.6 °C), Mangifera indica (3.3 °C), Khaya senegalensis (3.2 °C), and Delonix regia (3.0 °C), while Ficus macrocarpa (1.3 °C), Olea europaea (1.5 °C), and Vitis vinifera (1.6 °C) showed lower effects. A mixed-effects model confirmed significant influence of species and diurnal variation (R^2 marginal = 0.41; conditional $R^2 = 0.63$). Canopy size ($r = -0.62$, $p < 0.01$) and DBH ($r = -0.55$, $p < 0.05$) were negatively correlated with canopy temperatures, while humidity rose with crown spread. Regression showed every 10 m² canopy area reduced temperature by ~0.4 °C ($p < 0.01$). Results indicate that selective planting of species such as Gmelina arborea, Azadirachta indica, and Mangifera indica could lower urban microclimates by 2–3 °C, enhancing thermal comfort and resilience in semi-arid cities like Jimeta..

Keywords: Urban heat island; Urban trees; Cooling effect; Jimeta; Cooling efficiency; Nature-Based Solution

1.0. Introduction

The rapid expansion of cities across tropical regions has intensified the urban heat island (UHI) effect, a well-documented phenomenon in which built-up areas exhibit significantly higher temperatures than surrounding rural landscapes. This thermal imbalance arises from the replacement of natural vegetation with impervious surfaces such as asphalt, concrete, and rooftops, which absorb, store, and slowly release heat while restricting evapotranspiration. Elevated urban temperatures have multiple consequences, including aggravated thermal discomfort, increased electricity consumption for cooling, and heightened health risks such as heat stress and heat-related illnesses (Ogunleye et al., 2014; Feyisa et al., 2014). For rapidly urbanizing tropical cities, where climate vulnerability is already high, UHI mitigation is therefore critical to sustainable development and human well-being.

Urban trees provide one of the most effective, low-cost, and nature-based strategies for addressing UHI. Through shading and evapotranspiration, trees reduce both surface and near-surface air temperatures, thereby improving outdoor thermal comfort, reducing building energy demand, and enhancing resilience to extreme heat (Armson, et al., 2012; Speak et al., 2022). However, the magnitude of cooling benefits varies considerably across species. Differences in morphological and structural traits (canopy size, crown density, leaf morphology, DBH, height, and age) affect the degree of shading, evapotranspiration rates, and interactions with local microclimates (Gillner et al., 2015; Rahman et al., 2017a; Makido et al., 2016). For example, trees with large and dense canopies or broadleaf crowns tend to intercept more solar radiation and release more water vapor, leading to stronger cooling effects. Conversely, smaller or sparsely foliated species often provide limited benefits.

Evidence from temperate regions underscores the importance of species identity. Gillner et al. (2015) demonstrated in Dresden, Germany, that species with broader crowns and larger DBH provided consistently stronger cooling effects while Tsoka *et al* (2020) reported that urban street trees have significant effects on building cooling in Thessaloniki, Greece. Similarly, Monteiro et al. (2019) found that native broadleaf species were particularly effective in mitigating extreme summer heat in Lisbon. Studies have also shown that the diurnal cycle matters: shading during daytime reduces direct heat exposure, while nighttime canopy cover can influence whether trees trap or dissipate stored heat (Lin et al., 2017). These dynamics highlight the need for species-specific assessments rather than generalized assumptions about tree performance.

In tropical cities, emerging evidence points to similar patterns, although research remains limited compared to temperate contexts. Nwokoro and Okonkwo (2021), for instance, studied street trees in Lagos, Nigeria, and found significant cooling benefits but also considerable variation between species. Makido et al. (2016) and Rahman et al. (2017a) further emphasized that morphological characteristics are strong determinants of cooling intensity in tropical parks. Yet, unlike temperate cities, tropical urban environments experience higher solar radiation, distinct rainfall regimes, and different urban forms, meaning that direct extrapolation from temperate studies may not be valid. This underlines the importance of localized, context-specific research.

Despite the recognized benefits of trees, urban forestry planning in many African cities remains fragmented. In numerous cases, decisions about species selection are driven more by aesthetics, availability, or immediate shade needs than by scientific evidence (Adegun, 2018). This often leads to underutilization of the capacity of urban vegetation to mitigate UHI and regulate microclimates. In Jimeta, Adamawa State, this challenge is particularly acute. Rapid urbanization, loss of riparian vegetation, and weak integration of green infrastructure into planning have all contributed to increasing thermal stress (Zemba et al., 2010). The city hosts a rich diversity of urban tree species; however, a systematic assessment of their relative contributions to cooling remains scarce. Preliminary findings suggested a positive relationship between tree size-related traits and cooling performance, but the specific structural and morphological factors driving variation across species has not fully explored.

This knowledge gap has practical consequences. Without empirical evidence, city planners and residents may inadvertently favour tree species with limited cooling potential, missing opportunities to maximize the benefits of urban greening. Conversely, identifying species that reliably reduce local temperatures by 2–3 °C or more could significantly improve outdoor thermal comfort, reduce heat-related health risks, and contribute to climate-resilient urban design.

The present study addresses these gaps by systematically examining the cooling efficiency of 18 common tree species in Jimeta during the hot-dry season (April - May 2025). It combines biometric measurements, including DBH, canopy size, tree height, and age, with hourly microclimatic observations of temperature and relative humidity under tree canopies. These were complemented by ambient climatic records from the Nigerian Meteorological Agency (NiMet) at Yola International Airport, located within 5 km of the study site. A total of 54 individual trees were evaluated using statistical approaches such as ANOVA, linear mixed-effects models, correlation analysis, and regression.

By integrating field-based microclimatic monitoring with trait-based assessments, this study provides robust empirical evidence on species-specific cooling performance in a tropical semi-arid setting. The results not only validate global findings regarding the importance of canopy traits but also provide locally relevant insights for West African cities. Ultimately, the study contributes to evidence-based urban forestry and offers guidance for integrating trees into climate-adaptive planning in rapidly urbanizing regions such as Jimeta.

2.0 Methodology

2.1. The Study Site

Jimeta, the administrative and commercial hub of Yola North Local Government Area and Adamawa State, Nigeria, is located between 9°13'–9°19' N and 12°20'–12°30' E (Figure 1). The area lies within the Sudan Savanna ecological zone and experiences a tropical wet-and-dry climate. Mean annual rainfall is about 980 mm, concentrated between May and October. The dry season (November–April) is typically hot, with daily maximum temperatures exceeding 40 °C in March and April. Relative humidity ranges from about 20% during the dry season to over 80% at the peak of the rainy season.

In recent years, notable shifts in local weather patterns have been observed in Yola, including changes in the onset and cessation of rainfall, as well as extreme temperatures exceeding 43 °C between March and early May. Rapid urbanization, driven by population growth and migration, has accelerated the conversion of natural vegetation into built-up areas, thereby heightening exposure to heat stress (Zemba, 2010). While trees are planted along streets, within residential neighborhoods, and in institutional compounds, systematic selection of species for climate resilience remains limited. The combination of intense solar radiation, sparse vegetation cover, and unplanned urban expansion makes Jimeta a suitable site for evaluating the cooling performance of urban tree species.

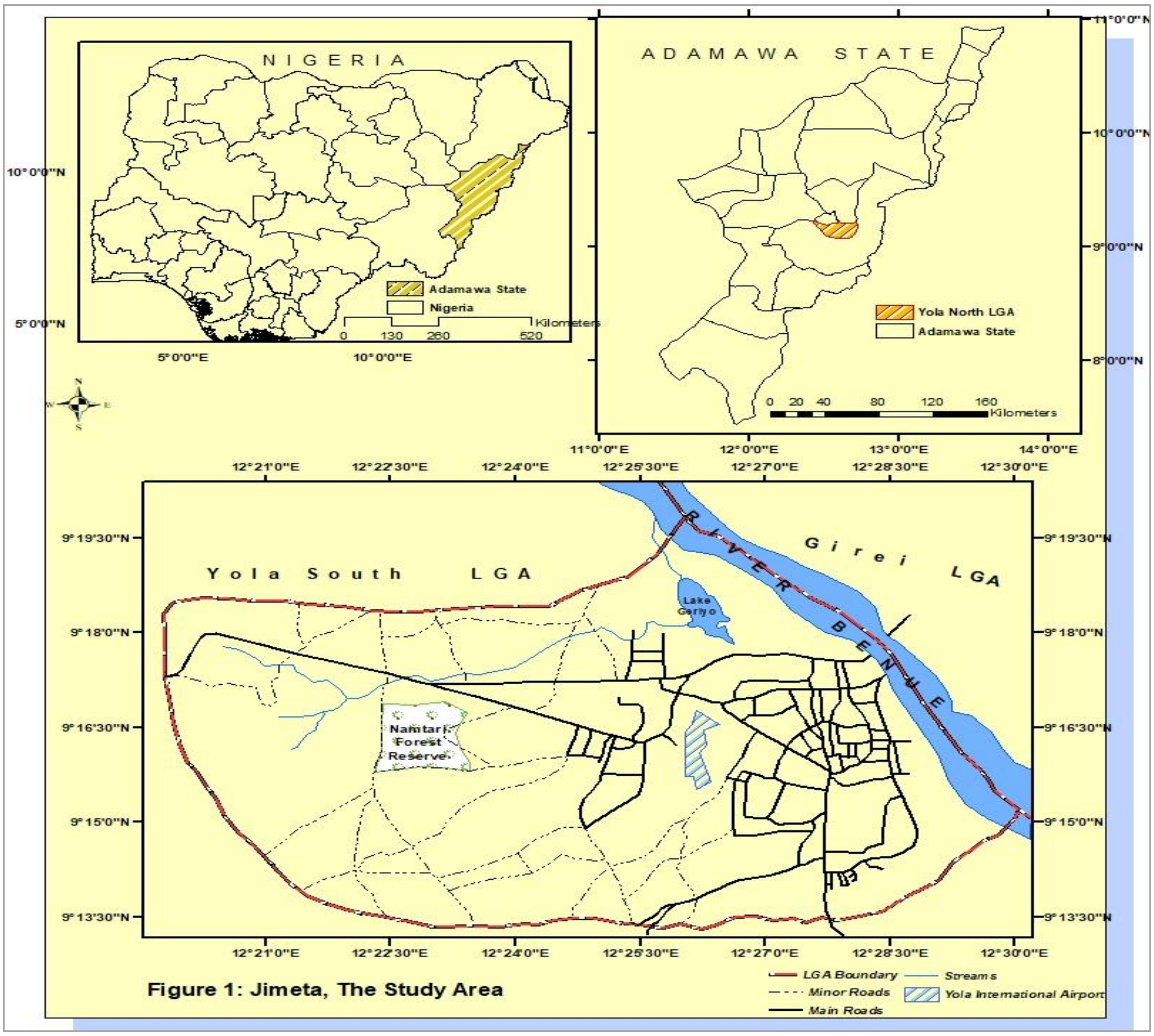

Figure 1: The Study Area

2.2 Data Collection

This section presents a description of field work undertaken and data collection procedures as well as an examinations of analytical techniques adopted in the research.

2.2.1 Tree Species Selection

An inventory of tree species was carried out in urban Jimeta. A purposive sampling method was employed to select commonly planted urban tree species. Selection was guided by availability (at least three replicates) and maturity (diameter at breast height, DBH ≥ 35 cm). The sampled species included *Azadirachta indica, Gmelina arborea, Mangifera indica, Ficus macrocarpa, Delonix regia, Terminalia catappa, Palaquium gutta, Albizia julibrissin, Psidium guajava, Khaya senegalensis, Vitis vinifera, Olea europaea, Albizia lebbeck, Dalbergia sisoo, Terminalia mentali, Eucalyptus camaldulensis, Ximenia americana,* and *Cassia fistula*. Three replicates were taken for each of the 18 species, giving a total of 54 individual trees studied. Biometric traits including DBH, canopy spread, tree height, and estimated age were measured following standard forestry procedures (Nowak et al., 2008). The procedure prescribes that in the absence of dendrochronological tools, tree age can be estimated through participatory engagement with community elders, an approach also validated in tropical settings where growth rings are often indistinct (Kling *et al.,* 2022).

2.2.2 Air Temperatures under Tree Canopies

Microclimatic data were recorded from April 19 to May 6, 2025, during the hottest period of the year. Sub-canopy temperatures and relative humidity were measured using HOBO MX2301A data loggers. Measurements were taken from three individuals of the same species per day, covering 18 days for the 18 species. The loggers were mounted at the base of tree canopies at a height of about 1.5 m above the ground. Due to high costs, only three loggers were available; they were rotated across species daily. The instruments were programmed to record air temperature and relative humidity at 1-hour intervals, with an accuracy of ±0.2 °C and ±2% RH. Each logger is waterproof and shielded against sunshine. Measurements were carried out for 22 hours per day (0900 to 0600 hours the following morning), while the period 0601–0859 hours was used for resetting and transferring loggers to other trees. Logger accuracy was cross validated with data from the nearest weather station.

2.2.3 Climate Data Collection

The Nigerian Meteorological Agency’s (NiMet) Station (09°15′27″N, 12°25′49″E), located at Yola International Airport within 5 km of the study area, provided reference (ambient) data. Hourly ambient air temperature and relative humidity corresponding to the sub-canopy measurement days were sourced from this station. Although the absence of instruments at open, non-canopy sites is a limitation, the relatively small study area and the availability of high-resolution meteorological data from NiMet provide a viable alternative for estimating background conditions.

2.2.4 Morphological Trait Measurements

DBH was measured at 1.3 m above ground level following standard dendrometric practices (Pauleit et al., 2002; McPherson et al., 2016). Canopy size was determined from the average spread along north–south and east–west axes. Both DBH and canopy size were determined using a measuring tape. Tree height was estimated using trigonometric calculations combined with visual calibration, a method commonly used in rapid urban forest assessments (Rahman et al., 2015). Tree age was estimated with the assistance of community elders, due to the absence of dendrochronological tools.

2.3 Data Analysis

Data analysis involved descriptive statistics (mean and standard deviation), one-way ANOVA to compare species’ cooling effects, Pearson correlation to evaluate relationships between tree traits and microclimatic conditions, and simple linear regression to quantify the influence of traits on cooling efficiency. The following equations guided the analyses.

2.3.1 Computation of Cooling Efficiency

This was done using the formula in equation 1:

$$\mathbf{\Delta T} = T_{air} - T_{Canopy} \quad (1)$$

Where:

ΔT = Cooling efficiency (^{0}C)
T_{air} = Air temperature
T_{canopy} = Temperature under tree canopy

2.3.2 One-way ANOVA

One-way ANOVA was used to test whether mean cooling effects differed significantly among tree species. Equation 2 (Fisher, 1925) provided a guide for the computation.

$$F = \frac{MS_{between}}{MS_{within}} = \frac{SS_{between}/df_{between}}{SS_{within}/df_{within}} \quad (2)$$

Where:
$SS_{between}$= Sum of squares between groups
SS_{within}= Sum of squares within groups
$df_{between}$= degree of freedom between groups
df_{within}= degree of freedom within groups

2.3.3 Pearson Correlation Coefficient (r)

Correlation was used to measure the strength of association between tree traits and microclimatic conditions (Equation 3) (Pearson, 1896).

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y^2 - (\sum y)^2]}} \quad (3)$$

Where:
r = correlation coefficient
x, y = individual samples for two variables
n = number of data pairs
∑ = summation operator

2.3.4 Simple Linear Regression Equation

Simple linear regression was used to model the relationship between diameter at breast height, canopy size, height of tree, age (predictor) and temperature reduction (response variable). Galton (1886) method (equation 4) was used to model the relationship.

$$\hat{y} = \beta_0 + \beta_1 x \quad (4)$$

Where:
$\hat{y}$ = predicted value (eg temperature reduction)
x = independent variable (e.g.) DBH)
β_0 = intercept
β_1 = slope (rate of change)

The slope β_1 and intercept $\beta_0$were calculated as presented in equation 5 & 6:

$$\beta_1 = \frac{\sum(x_1 - \bar{x})(y_1 - \bar{y})}{\sum(x_1 - \bar{x})^2} \quad (5)$$

$$\beta_0 = \bar{y} - \beta_1 \bar{x} \quad (6)$$

2.3.5 Coefficient of determination (R^2)

The goodness of fit of the regression model was evaluated using equation 7.

$$R^2 = 1 - \frac{\Sigma(y-\hat{y})^2}{\Sigma(y-\bar{y})^2} \quad (7)$$

Where:
y = observed value
$\hat{y}$ = predicted value
$\bar{y}$ = mean of observed values

3.0 Results and Discussion

3.1 Variations in Cooling Efficiencies Among Tree Species

The comparative analysis of canopy–ambient temperature differences (ΔT) revealed substantial variability among the 18 tree species investigated in Jimeta. The one-way ANOVA confirmed that these differences were statistically significant (F = 11.52, p < 0.001), underscoring that tree species do not contribute equally to microclimatic cooling. The overall mean cooling efficiency across species was 2.6 °C, with values ranging from as low as 1.3 °C in *Ficus macrocarpa* to as high as 3.8 °C in *Gmelina arborea*. This widespread illustrates that tree species selection is crucial in urban climate regulation strategies.

Within-species variability was generally low, with standard deviations of ±0.2–0.6 °C, indicating relatively stable cooling contributions across replicates. This consistency strengthens the evidence that observed differences reflect genuine species-level effects rather than random variation. Relative humidity also exhibited species-dependent differences: while ambient humidity averaged 48.7%, sub-canopy humidity was consistently higher, ranging from 53% in *Olea europaea* to 78.5% in *Dalbergia sissoo*. These increases ranged between 4% (*Palaquium gutta*) and 15% (*Psidium guajava* and *Azadirachta indica*), demonstrating that cooling is often accompanied by enhanced atmospheric moisture, likely due to evapotranspiration.

Post-hoc comparisons using Tukey's HSD test showed that *Gmelina arborea* (mean ΔT = 3.8 °C), *Azadirachta indica* (3.6 ^{0}C), *Mangifera indica* (3.3 °C), *Khaya senegalensis* (3.2 ^{0}C), and *Delonix regia* (3.0 °C), provided significantly greater cooling than species such as *Vitis vinifera* (1.6 °C), *Albizia julibrissin* (1.8 °C), and *Ficus macrocarpa* (1.3 °C). Mid-performing species such as *Eucalyptus camaldulensis (2.9* °C), *Dalbergia sissoo* (2.8 ^{0}C), *Terminalia cappa* (2.7 ^{0}C), *Palaquium gutta* (2.6 ^{0}C), *Cassia fistula* (2.4 ^{0}C) also offered measurable benefits, though not statistically different from each other at the 95% confidence level.
A linear mixed-effects model (cooling ~ species + time of day + (1/treeID)) showed that species identity explained a large portion of variance (R^2 marginal = 0.41, conditional R^2 = 0.63). Time of day was also significant (t = –4.23, p < 0.001), confirming that cooling effects were most pronounced during peak afternoon hours (1200–1600 h), when ambient temperatures exceeded 35 °C.

Correlation analysis further revealed that microclimatic conditions were significantly associated with tree morphological traits. Canopy spread showed the strongest relationship with cooling efficiency (r = –0.62, p < 0.01), followed by DBH (r = –0.55, p < 0.05). Larger and more expansive canopies created deeper shaded zones and supported greater leaf area for evapotranspiration, which in turn lowered under-canopy temperatures. Height and estimated age also correlated with cooling efficiency but weaklier, suggesting that while mature and taller trees contribute meaningfully, their effect is mediated primarily through canopy spread and DBH. Regression analysis confirmed that every 10 m^2 increase in canopy area reduced under-canopy temperature by approximately 0.4 °C (p < 0.01).

These findings are consistent with earlier reports by Armson et al. (2012), who observed that larger crowns are associated with lower surface and air temperatures in urban England, and by Rahman et al. (2017b) in Germany, where cooling intensity was positively correlated with tree crown dimensions. Comparable patterns have also been reported in tropical contexts. For example, Feyisa et al. (2014) in Addis Ababa found that tree-rich parks reduced local air temperatures by up to 2.8 °C compared to surrounding built-up areas, a cooling margin close to the mean value observed in Jimeta. Similarly, Speak et al. (2022) in Malaysia reported that tree canopy density explained more than half the variation in observed cooling, highlighting the ecological universality of this relationship.

Taken together, these results emphasize that cooling efficiency is a species-dependent phenomenon strongly mediated by tree size and structural traits. The implication for urban forestry is that careful matching of tree species to site conditions can optimize microclimatic benefits, particularly in hot, rapidly urbanizing cities such as Jimeta.

3.2 Performance of Tree Species in Cooling Efficiency

The ranking of tree species by mean cooling efficiency (Table 1) provides a clear performance hierarchy, enabling evidence-based recommendations for urban planting schemes. *Gmelina arborea* emerged as the top performer, delivering an average cooling efficiency of 3.8 °C. This was followed by *Azadirachta indica* (3.6 0C), *Mangifera indica* (3.3 0C), *Khaya senegalensis* (3.2 °C) and *Delonix regia* (3.0 °C). Together, these five species represent the most promising candidates for mitigating thermal stress in Jimeta's dense urban spaces. Their strong performance can be attributed to a combination of wide canopy spread, tall stature, and relatively large DBH, which maximize both shading and transpiration cooling.

Moderately performing species included *Eucalyptus camaldulensis, Dalbergia sisso, Termanalia cappa, Palaquium gutta, Cassia fistula, Terminalia mentali, Ximania americana,* and *Psidium guajava* (cooling range: 2.0–2.9 °C). These species are notable because they also provide ecosystem services beyond cooling. For instance, *Eucalyptus camaldulensis* offers medicinal and pesticidal benefits, while *Psidium guajava indica* supplies fruit, linking microclimatic regulation to livelihood support. Their integration into multifunctional green infrastructure projects therefore delivers co-benefits beyond thermal comfort.
On the other hand, species such as *Albizia lebbeck, Albizia julibrissin, Vitis vinifera, Olea europaea* and *Ficus macrocarpa* were the least effective, cooling by less than 2.0 °C on average. Their smaller canopy spreads and relatively lower DBH likely constrained their shading potential and transpiration capacity. Although such species may have aesthetic or cultural value, their limited contribution to thermal regulation suggests that they should not be prioritized where cooling is the main objective.

Interestingly, *Terminalia catappa* and *Cassia fistula* fell within the moderate range despite relatively smaller DBH values. This points to the role of canopy architecture, that is, species with horizontally spreading crowns may provide effective shading despite not being the largest in girth. This aligns with findings by Gillner et al. (2015) in Berlin, where horizontally layered canopies were shown to intercept more solar radiation and deliver higher cooling efficiency compared to tall but narrow crowns.

It is important to reemphasize that *Gmelina arborea* exhibited the strongest cooling effect (3.8°C), followed closely by *Azadirachta indica* (3.6 ^{0}C), *Mangifera indica* (3.3 ^{0}C), *Khaya senegalensis* (3.2°C), and *Delonix regia* (3.0°C). These species consistently produced canopy microclimates at least 80% as effective as the best performer (Table 1). Conversely, species such as *Ficus macrocarpa* (1.3 ^{0}C), *Olea europaea* (1.5 ^{0}C), *Vitis vinifera* (1.6 ^{0}C), and *Albizia julibrissin* (1.8°C) exhibited comparatively weaker cooling functions (<50% as the best performer).

The performance ranking also resonates with tropical case studies. In India, Shashua-Bar et al. (2010) reported that *Delonix regia* reduced street-level air temperatures by over 3.0 °C, closely matching the value obtained in Jimeta. Similarly, McPherson et al. (2016) in California highlighted *Khaya senegalensis* as a high-performing shade species with strong evapotranspiration rates, supporting its top-tier ranking in this study. The convergence of findings across diverse ecological contexts suggests that certain tree traits, particularly wide, dense canopies, consistently drive microclimatic cooling regardless of location.

Therefore, the hierarchy presented in Table 1 provides a practical framework for urban planners and environmental managers. Species in the top performance category should be prioritized for avenues, public parks, and heat-vulnerable neighborhoods, while moderate performers can be used strategically in mixed plantings that balance ecological, social, and economic functions.

Table 1: Ranking of tree species by mean cooling efficiency

S/N	Species	Tree Count	Mean Cooling Efficiency (°C)	Relative Cooling Efficiency (%)
1	*Gmelina arborea*	3	3.8	100
2	*Azadirachta indica*	3	3.6	95
3	*Mangifera indica*	3	3.3	87
4	*Khaya senegalensis*	3	3.2	84
5	*Delonix regia*	3	3.0	80
6	*Eucalyptus camaldulensis*	3	2.9	76
7	*Dalbergia sissoo*	3	2.8	74
8	*Terminalia catappa*	3	2.7	71
9	*Palaquium gutta*	3	2.6	68
10	*Cassia fistula*	3	2.4	63
11	*Terminalia mantaly*	3	2.3	61
12	*Ximania americana*	3	2.1	55
13	*Psidium guajava*	3	2.0	53
14	*Albizia lebbeck*	3	1.9	50
15	*Albizia julibrissin*	3	1.8	47
16	*Vitis vinfera*	3	1.6	42
17	*Olea europaea*	3	1.5	40
18	*Ficus macrocarpa*	3	1.3	34

The implications of these results are significant for urban sustainability in Jimeta and other tropical cities facing similar climatic pressures. The demonstrated variation in cooling efficiency confirms that tree planting cannot be treated as a one-size-fits-all solution; instead, strategic species selection is essential to maximize climate adaptation benefits. For instance, planting species such as *Gmelina arborea*, *Azadirachta indica*, *Mangifera indica*, *Khaya senegalensis*, and *Delonix regia* in busy roads, markets, and densely populated residential zones could provide temperature reductions of up to 3.0–3.8 °C. This margin represents a substantial improvement in outdoor thermal comfort. The World Health Organization (WHO) has emphasized that even a 1 °C reduction in peak urban temperatures can significantly lower heat-related morbidity and mortality risks, underscoring the health relevance of these findings.

Equally important is the correlation observed between canopy traits and cooling performance, which highlights the value of long-term investment in tree growth. Urban forestry policies that prioritize the protection of mature trees and allocate adequate space for canopy expansion are more likely to deliver sustained microclimatic benefits, given that younger or narrowly structured trees provide considerably less cooling.

Beyond this, the study provides an empirical basis for evidence-driven greening strategies in rapidly urbanizing contexts such as Jimeta. Incorporating high-performing tree species into city development plans could help counter the urban heat island effect while also generating multiple co-benefits, including pedestrian shade, reduced household and commercial energy demand for cooling, and improved air quality.

Ultimately, the findings reinforce a broader narrative that urban forestry is not simply ornamental but a critical climate adaptation tool. By quantifying the species-specific contributions to temperature regulation, this study strengthens the link between ecological evidence and actionable urban planning, offering a pathway toward more climate-resilient and livable tropical cities.

4.0 Conclusion

This study assessed the cooling efficiency of urban tree species in Jimeta, Nigeria, and demonstrated that species differ significantly in their capacity to regulate canopy temperature. High-performing shade trees such as *Gmelina arborea*, *Azadirachta indica*, *Mangifera indica*, *Khaya senegalensis*, and *Delonix regia* consistently achieved greater temperature reductions compared to species with narrower or less dense crowns. These results confirm that cooling benefits in tropical urban environments are strongly linked to morphological traits such as canopy spread, DBH, and crown density, underscoring the need for deliberate species-specific selection in urban forestry.

The findings have important implications for urban sustainability planning in tropical cities facing rapid urbanization and heat stress. Beyond their ecological value, shade trees should be strategically integrated into public landscapes, streets, and institutional grounds to optimize thermal comfort. An integrative planting strategy that blends climate-resilient shade trees with multipurpose species, including fruit trees, would further enhance ecosystem services while supporting local livelihoods. To ensure long-term effectiveness, urban forestry policies should develop local guidelines for species selection grounded in microclimatic performance and resilience rather than arbitrary planting choices.

Community engagement also emerges as a critical pathway for expanding canopy cover in residential neighbourhoods, fostering stewardship and sustainability of tree resources. Finally, establishing a monitoring framework to track tree growth, cooling performance, and survival under changing climatic conditions will provide the empirical feedback needed to refine planting strategies over time.

By linking species-specific evidence with practical recommendations, this study not only highlights the role of trees as nature-based solutions to the urban heat island effect but also provides actionable guidance for building climate-resilient and liveable tropical cities.

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