Climate Differences Affect the Aroma of Coffee in Indonesia (A Review)

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ABSTRACT

Indonesia's coffee sector spans climates from humid montane forests to drier leeward slopes. This review synthesizes how altitude, temperature, and rainfall shape aroma through their effects on cherry development, precursor biochemistry, and post-harvest feasibility. Evidence across Indonesian origins and comparable terroirs indicates that cooler highlands favor floral, fruity, and spice notes, whereas warmer sites require microclimate buffering and precise processing to avoid green or phenolic impressions. We integrate mechanisms, regional case notes, and an adaptation toolbox to preserve aroma quality under a changing climate.

Keyword: Coffee aroma; altitude; temperature; rainfall; Indonesia; Arabica; Robusta

1. INTRODUCTION

Indonesia ranks among the world's coffee leaders and is unusual in the breadth of climates within a single origin. Mountain chains on Sumatra, Java, Bali, Flores, and Sulawesi produce steep gradients in air temperature, cloud cover, and rainfall. These gradients create micro-terroirs that are readily perceived by cuppers and consumers.

Arabica generally occupies elevations above ~900–1,000 masl, where lower mean temperatures slow maturation and expand the time window for sucrose and amino acid accumulation. Robusta occupies warmer lowlands and foothills; while robust to heat, its aroma profiles are typically simpler unless post-harvest steps are carefully tuned.

Aroma is the product of pathways that begin on the tree and culminate in the roaster. Carbohydrate build-up supports Maillard chemistry; amino acids participate in Strecker reactions; lipids contribute aldehydes and ketones. Climatic drivers alter the balance among these precursors and thus the eventual sensory signature.

Altitude is a practical proxy for climate because it covaries with temperature and vapor pressure deficit. Yet altitude alone is insufficient: aspect, cloud belts, shade, and wind also define the operative microclimate. Two farms at the same elevation can yield contrasting cups if exposure and canopy differ.

Rainfall governs flowering synchrony and post-harvest logistics. A well-timed dry spell followed by consistent rains often produces even ripening. Conversely, erratic showers stagger flowering and complicate selective picking. Humid harvest seasons lengthen drying and raise the risk of defects in honey and natural processes.

Temperature interacts with water status. Heat accelerates development and can push flavor toward herbal or woody notes. Cooler sites tend to yield brighter acidity and layered aromatics. Diurnal amplitude at altitude also matters: large day–night swings can preserve organic acids and sharpen perceived clarity.

Processing moderates how climate is expressed in the cup. Washed lots can showcase high-elevation florals and citrus; well-managed naturals can add fruit layers without masking terroir; honey processes sit between, demanding airflow discipline in humid areas.

Terroir additionally reflects soils and management. Organic matter, drainage, and cation exchange capacity influence nutrient supply and root health. Shade agroforestry moderates heat and helps maintain soil moisture, while pruning and nutrition programs promote cherry uniformity and higher bean density.

Climate change presents a strategic challenge. Warming is expected to shift optimal Arabica belts upslope and alter rainfall regimes unevenly across islands. Producers will need microclimate buffering, cultivar targeting, and tighter fermentation control to sustain the sensory identities that underpin specialty value.

This article reviews mechanisms linking climate to aroma, compares regional case notes across Indonesia, summarizes evidence into practical tables, and proposes an adaptation toolbox relevant to growers, processors, and policymakers.

Objectives

We aim to (i) articulate mechanisms by which altitude, temperature, and rainfall influence aroma; (ii) compile regional evidence for Indonesian origins; (iii) clarify processing–climate interactions; and (iv) propose actionable adaptation practices.

2. METHODOLOGY (REVIEW OF JOURNALS)

Search strategy. We queried Semantic Scholar and Google Scholar using combinations of Indonesia, coffee, Arabica, Robusta, altitude, temperature, rainfall, microclimate, aroma, sensory, cupping, volatile, processing, and fermentation. Backward and forward snowballing added comparative terroir studies from Latin America and East Africa.

Inclusion criteria. Eligible items reported at least one climate variable (altitude, temperature, rainfall) and one aroma-related outcome (sensory descriptors, cupping scores, or volatile/chemical markers). We prioritized studies with transparent methods and clear processing descriptions.

Exclusion criteria. We excluded works centered only on roasting or storage without climatic context, and studies lacking either climatic drivers or aroma outcomes.

Screening and extraction. Titles and abstracts were screened, followed by full-text review. We extracted region, elevation, climate descriptors, variety/genotype, processing method, evaluation protocol, key descriptors, and any chemical markers or cupping scores reported.

Synthesis and appraisal. Heterogeneity precluded meta-analysis; results were thematically synthesized. Appraisal considered replication, control of confounders (genotype, roasting, processing), and adherence to recognized cupping standards.

3. RESULTS AND DISCUSSION

Elevation–aroma relationships. Reports from Indonesian highlands consistently associate ≥1,200 masl with floral, fruity, and spice-forward Arabicas and cleaner finishes. Mid-elevations (~900–1,100 masl) tend toward chocolate, caramel, and nutty profiles with moderate acidity. At low elevations, herbal or green notes become more likely unless microclimate buffering is applied.

Temperature effects. Heat compresses maturation windows and can elevate pest and disease pressure; cooler regimes prolong development and often increase precursor pools. High diurnal ranges at altitude contribute to acidity retention and perceived clarity.

Rainfall variability. Contrasting rainfall regimes across islands alter flowering synchrony and drying feasibility. Honey and natural processes require vigilant airflow and drying bed management during humid harvests.

Genotype × environment × processing. Varietal choice tunes altitude responses; processing can reveal or mask terroir signals. Clean washed lots from cool highlands emphasize citrus and floral notes; carefully managed naturals can layer fruit without phenolic carry-over.

Chemical markers and sensory mapping. Studies link climate bands to distinct volatile patterns—terpenes and esters more prevalent in cool, slow-ripening sites; Maillard-derived compounds dominating mid-elevation chocolate/caramel notes. Mapping these markers to the Specialty Coffee Association flavor wheel improves communication between farm and market.

Regional variability. Gayo Highlands (Aceh) and Toraja (South Sulawesi) frequently show complex florals and sweet spice; West Java exhibits variety-dependent spectra; Flores (Manggarai) tends toward citrus and herbal–spice under drier leeward climates; Bali (Kintamani) balances citrus and florals at mid-to-high elevations.

Projected change and adaptation. Upslope migration of optimal belts is likely. Practical responses include shade regulation, soil organic matter enhancement, mulching and windbreaks, elevation-matched cultivars, selective harvesting at peak ripeness, and controlled fermentations with temperature monitoring.

Table 1. Variables and operational definitions used in the review.

Variable	Operational definition	Relevance to aroma

Altitude (masl)	Elevation of farm blocks above mean sea level	Proxy for mean temperature, VPD, and diurnal range
Temperature (°C)	Mean and diurnal cycle during cherry development	Controls maturation rate and precursor accumulation
Rainfall (mm, seasonality)	Totals and timing relative to flowering/harvest	Determines flowering synchrony and drying feasibility
Aspect & slope	Hillslope orientation and steepness	Modulate radiation, wind exposure, and cloud interception
Shade canopy	Agroforestry cover and species mix	Buffers heat/VPD; affects disease risk and drying speed
Soil & nutrition	Texture, drainage, organic matter, fertilization	Supports root health, sugar and amino acid pools
Processing method	Washed, honey, natural, specialty fermentations	Amplifies or masks climate signals in the cup
Drying conditions	Airflow, bed design, humidity management	Controls risk of phenolic/over-fermented defects

Table 2. Regional snapshots linking climate features to typical sensory tendencies.

Region	**Elevation (typical)**	**Rainfall regime**	**Processing feasibility**	**Typical aroma**
Gayo (Aceh)	1,200–1,600 masl	Humid montane; frequent rains	Washed/Honey with airflow control	Floral, citrus, spice
Lintong (North Sumatra)	1,200–1,500 masl	Humid highlands	Washed/Wet-hull	Spice, chocolate
Toraja (South Sulawesi)	1,200–1,700 masl	Stable highland climate	Washed/Natural (careful drying)	Wine-like, sweet spice
West Java (Garut/Bandung)	900–1,400 masl	Variable rainfall	Washed/Honey	Fruity, chocolate
Bali (Kintamani)	1,000–1,500 masl	Moderate humidity	Washed/Honey	Citrus, floral
Flores (Manggarai)	1,000–1,500 masl	Drier leeward, windy	Honey/Natural on raised beds	Citrus, herbal–spice

Table 3. Processing × climate risk matrix and mitigation tips.

Process	**Climate risk**	**Typical defect risk**	**Mitigation**
Washed	Cool & wet harvests	Sour/phenolic if drying is slow	Raised beds, airflow, thin layers
Honey	Humid with intermittent rain	Phenolic/over-fermented	Strict bed hygiene, weather covers
Natural	Humid or prolonged drying	Mold, phenolic taint	Shade-net, forced airflow, frequent turning
Specialty fermentation	Ambient heat spikes	Volatile imbalance, acetic spike	Temp-monitored tanks, shorter cycles

4. ADAPTATION TOOLBOX

• Shade regulation to cap midday leaf temperatures and reduce VPD extremes.

• Mulching and organic amendments to buffer soil moisture and enhance microbial activity.

• Soil testing and tailored nutrition to sustain sucrose and amino acid pools.

• Windbreaks to reduce desiccation and protect drying beds.

• Elevation-matched cultivar portfolios to spread risk across climate bands.

• Selective harvesting with ripeness sorting to stabilize fermentation inputs.

• Starter cultures and temperature-monitored fermentations for reproducible volatiles.

• Modular drying infrastructure (raised beds, shade-net, solar dryers) to handle variable weather.

• Lot segregation and cupping-led feedback loops to reinforce successful practices.

• Landscape water management (infiltration trenches, contouring) to reduce runoff and erosion.

5. LIMITATIONS AND FUTURE RESEARCH

Few Indonesian studies pair continuous microclimate logging with metabolomics and standardized cupping across elevation transects.

Confounding by genotype mixtures, roast levels, and heterogeneous processing complicates attribution of climate signals.

Multi-site common-garden trials with unified fermentation/drying protocols would clarify mechanisms and quantify effect sizes.

Linking volatile markers to hedonic response in domestic markets could sharpen adaptation priorities.

6. CONCLUSIONS

Altitude, temperature, and rainfall jointly structure Indonesia’s aroma diversity. Cooler highlands generally favor floral, fruity, and spice-forward profiles; warmer sites require buffering and precision post-harvest to avoid green or phenolic notes.

Resilience will rely on terroir-aware agronomy, cultivar targeting, and controlled fermentations. Practical investments in drying and weather-proof infrastructure can preserve quality despite increasingly variable seasons..

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