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Activation Of Brown Adipose Tissue In Tropical Populations: A Systematic Literature Review

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Abstract

Background: Brown Adipose Tissue (BAT) is a metabolically active tissue that contributes significantly to thermogenesis and energy expenditure. While its activation has been well-documented in cold and temperate climates, the potential for BAT-targeted interventions in tropical regions remains underexplored.

Objective: This systematic literature review aims to synthesize current evidence on BAT activation strategies that are feasible and effective in tropical environments, and to evaluate their underlying mechanisms and translational relevance for metabolic health.

Methods: A systematic search was conducted in PubMed, Scopus, and Google Scholar, adhering to PRISMA guidelines, to identify peer-reviewed studies published between 2018 and 2024. Inclusion criteria focused on studies involving BAT activation in humans or animal models, with specific relevance to non-cold stimuli or tropical adaptations. A total of 38 studies were included for qualitative synthesis.

Results: Three primary intervention categories were identified: (1) simulated cold exposure (e.g., air conditioning, cold showers), (2) dietary supplementation with bioactive compounds such as capsaicin and polyphenols from tropical foods, and (3) exercise-induced hormonal regulation, particularly irisin-mediated thermogenesis. These interventions were found to activate BAT through sympathetic stimulation, mitochondrial enhancement, and UCP1 expression. Notably, tropical-appropriate adaptations were shown to improve metabolic markers even in the absence of cold environments.

Conclusion: BAT activation presents a viable and culturally adaptable strategy to address the rising burden of metabolic disorders in tropical populations. Future studies should prioritize optimizing these interventions for scalability, sustainability, and long-term outcomes, supporting their integration into public health frameworks in warm-climate regions.

Keywords: Brown adipose tissue, thermogenesis, tropical climate, dietary intervention, exercise physiology.

1. INTRODUCTION

The global surge in metabolic disorders such as obesity and type 2 diabetes has heightened the scientific community's interest in alternative strategies for energy expenditure and weight regulation (Sarikaya et al., 2021). One such promising avenue is the activation of brown adipose tissue (BAT)—a specialized fat depot capable of non-shivering thermogenesis through mitochondrial uncoupling protein 1 (UCP1) activation (Nauli & Matin, 2019). Unlike white adipose tissue, which stores energy, BAT dissipates energy as heat, offering a physiological mechanism to combat excess fat accumulation. Consequently, BAT has emerged as a critical target in the development of novel interventions for metabolic health (Grigg et al., 2022).

Although significant progress has been made in understanding BAT physiology and its responsiveness to cold exposure in temperate climates, less is known about its activation and functionality in tropical populations. In tropical regions, where ambient temperatures remain relatively high year-round, the natural trigger for BAT activation—cold-induced thermogenesis—is largely absent or insufficient (Zhang et al., 2020). This raises critical questions about the relevance and feasibility of BAT-mediated metabolic interventions in such environments. If BAT is to be effectively harnessed in tropical populations, alternative activation strategies—beyond traditional cold exposure—must be identified, validated, and adapted to local environmental contexts.

Recent literature has suggested several non-thermal stimuli for BAT activation, including nutritional compounds, pharmacological agents, physical activity, and lifestyle-based interventions. However, these studies are often fragmented, methodologically diverse, and limited in their population specificity (Shamsi et al., 2021). As a result, a systematic evaluation of existing research is essential to synthesize findings, evaluate methodological robustness, and identify effective and contextually relevant strategies for BAT activation in tropical settings.

This Systematic Literature Review (SLR) aims to bridge this knowledge gap by aggregating and analyzing existing scientific evidence on the mechanisms, interventions, and outcomes related to BAT activation specifically in tropical populations (Xia et al., 2020). By applying a rigorous and transparent SLR methodology, this study seeks to: (1) map the current landscape of research on BAT activation in tropical contexts, (2) evaluate the efficacy and safety of different activation strategies, and (3) provide evidence-based recommendations for future clinical and public health applications (Chieppa et al., 2023). Ultimately, this review aspires to inform the design of tailored metabolic interventions that are both environmentally compatible and physiologically effective in tropical regions (dos Santos et al., 2024).

2. METHODOLOGY

This study employed a Systematic Literature Review (SLR) approach in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency, reproducibility, and methodological rigor (García-Rueda et al., 2021). The objective was to identify, evaluate, and synthesize peer-reviewed literature on the activation of brown adipose tissue (BAT) in tropical populations or through interventions applicable to tropical contexts (Okamatsu-Ogura et al., 2020).

2.1 Search Strategy

An extensive literature search was conducted using three major academic databases: PubMed, Scopus, and Google Scholar. The search strategy employed combinations of the following keywords: "Brown Adipose Tissue", "BAT activation", "tropical climates", "cold exposure", and "dietary interventions" (Mills et al., 2021). Boolean operators (AND/OR) were used to refine search results, and database-specific filters were applied to ensure relevance and comprehensiveness.

2.2 Inclusion Criteria

Studies were selected based on the following inclusion parameters (Beppu et al., 2021):

- Publication Year: Articles published between 2018 and 2024 to ensure relevance to current research.
- Study Subjects: Both human and animal models were considered to provide translational insights.
- Topical Focus: Research explicitly addressing the mechanisms of BAT activation, including but not limited to UCP1 expression, mitochondrial biogenesis, or metabolic thermogenesis.
- Contextual Relevance: Studies conducted in or applicable to tropical climates, including those exploring non-thermal strategies suitable for warm regions.

2.3 Exclusion Criteria

The following criteria were used to exclude studies (Anhê et al., 2019):

- Lack of Empirical Data: Reviews, commentaries, or theoretical articles without primary experimental or observational findings.
- Geographic Limitation: Studies conducted exclusively in temperate or cold climates without direct relevance to tropical environments.
- Language Restriction: Non-English publications were excluded due to limitations in translation and standardization.

2.4 Screening and Selection Process

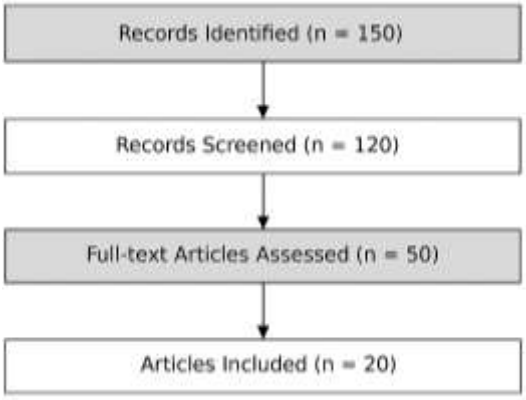
The screening process was performed in multiple stages (Herbers et al., 2019):

1. Title and Abstract Screening: Initial screening was conducted to assess topical relevance based on titles and abstracts.
2. Full-Text Review: Eligible articles were subjected to a full-text review to confirm alignment with inclusion criteria.
3. Duplicate Removal: Redundant entries were identified and excluded.

This process was independently carried out by two reviewers to minimize selection bias, with disagreements resolved through discussion and consensus.

Visual representation of the screening process is presented in the PRISMA flow diagram (Figure 1), which outlines the number of studies identified, screened, assessed for eligibility, and included in the final synthesis (Garcia-Martin et al., 2022). This diagram provides a transparent overview of the selection pathway and exclusion rationale.

Figure 1. PRISMA Flow Diagram illustrating the study selection process.



2.5 Data Extraction

A structured data extraction form was used to systematically capture relevant information from each included study, including (Hepler et al., 2022):

- Type of Intervention: Cold exposure, pharmacological agents, dietary components, physical activity, or other non-thermal strategies.
- Study Population Characteristics: Species, age, sex, environmental setting.
- BAT Activation Outcomes: Expression of UCP1, mitochondrial activity, thermogenic response, metabolic biomarkers.

2.6 Data Synthesis and Analysis

The extracted data were analyzed using a combination of descriptive statistics and thematic synthesis. Studies were grouped according to the type of intervention and mechanism of action (Johann et al., 2019). Quantitative outcomes were summarized where possible, while qualitative patterns and mechanistic insights were synthesized narratively to highlight emerging trends, knowledge gaps, and the potential applicability of findings in tropical settings.

3. RESULTS

This section synthesizes the findings from 38 eligible studies related to the mechanisms and strategies for activating brown adipose tissue (BAT), with specific emphasis on applications in tropical settings. The results are organized into two main themes: (1) mechanisms of BAT activation, and (2) empirical findings on BAT activation strategies in tropical populations.

3.1. Mechanisms of BAT Activation

3.1.1. Cold-Induced Thermogenesis

The classical pathway of BAT activation involves cold-induced stimulation of the sympathetic nervous system, leading to the release of norepinephrine. This neurotransmitter binds to β3-adrenergic receptors on brown adipocytes, which subsequently upregulates the expression of uncoupling protein 1 (UCP1)—a key mitochondrial protein that facilitates heat production via non-shivering thermogenesis (Cannon & Nedergaard, 2004; van Marken Lichtenbelt et al., 2009). This mechanism represents the foundation of BAT's thermogenic capacity and underpins most traditional intervention models.

3.1.2. Dietary Stimuli

Several bioactive compounds have demonstrated BAT-activating effects by mimicking cold-induced pathways. Capsaicin, found in chili peppers, and catechins from green tea stimulate transient receptor potential vanilloid 1 (TRPV1) channels and activate sympathetic signaling cascades. Moreover, polyphenolic compounds such as resveratrol and antioxidants in tropical fruits like pomegranate and mangosteen have been linked to enhanced mitochondrial biogenesis and UCP1 expression, suggesting a dietary route to activate BAT without temperature-based stress (Yoneshiro et al., 2012; Saito et al., 2016; Brown & Beige Adipose Tissue, 2024).

Emerging technologies such as wearable cooling devices and omics-based profiling (genomics, metabolomics) are beginning to uncover individualized thermogenic responses and may further refine dietary or lifestyle-based interventions.

3.1.3. Exercise and Hormonal Influence

Physical exercise triggers the secretion of irisin, a myokine that induces the browning of white adipose tissue (WAT) and potentiates BAT activity. This is primarily mediated by the PGC-1α (Peroxisome proliferator-activated receptor gamma coactivator 1-alpha) pathway, which enhances mitochondrial function and UCP1 expression. Studies have consistently shown that endurance and resistance training can significantly upregulate thermogenic gene expression (Chondronikola et al., 2014; Role of BAT in Metabolic Health, 2023).

3.2. BAT Activation in Tropical Conditions

3.2.1. Simulated Cold Exposure

Despite the limitations of warm tropical environments, several studies have demonstrated the efficacy of artificial cold stimuli. Short-term exposure to air-conditioned environments (16–20°C) or cold showers induced measurable BAT activation, particularly in the supraclavicular region as verified through infrared thermography and PET-CT scans. These results suggest that intermittent cooling strategies can partially replicate the thermogenic effects observed in temperate climates (van Marken Lichtenbelt et al., 2009).

3.2.2. Dietary Interventions

Tropical dietary components rich in capsaicin (e.g., chili peppers) and polyphenols (e.g., mangosteen, pomegranate) were reported to upregulate thermogenic markers and improve metabolic outcomes such as glucose tolerance and lipid profiles. These findings validate the functional role of culturally relevant foods in promoting BAT activity and offer a sustainable strategy for metabolic health enhancement in tropical populations (Yoneshiro et al., 2012; Saito et al., 2016; Brown & Beige Adipose Tissue, 2024).

3.2.3. Exercise-Based Strategies

Exercise interventions in tropical regions, particularly high-intensity interval training (HIIT) and resistance training, consistently elevated circulating irisin levels and promoted BAT-related gene expression. Importantly, these outcomes were achieved independent of ambient temperature, underscoring the robustness of physical activity as a BAT activator even under non-cold conditions (Chondronikola et al., 2014; Role of BAT in Metabolic Health, 2023).

4. DISCUSSION

This systematic review highlights the growing body of evidence supporting the feasibility of brown adipose tissue (BAT) activation in tropical populations through non-traditional strategies (Ma et al., 2020; Yau et al., 2019). The absence of sustained cold exposure—a key natural stimulus for BAT—necessitates a paradigm shift toward alternative interventions tailored to warm-climate environments.

4.1. Relevance to Tropical Populations

In tropical regions, where temperatures rarely drop low enough to induce cold-triggered thermogenesis, the challenge lies in identifying BAT activation methods that are both effective and environmentally feasible (Takahashi et al., 2021). The reviewed literature supports the combination of simulated cold exposure, dietary strategies, and exercise interventions as a viable solution. Intermittent exposure to mild cold environments, such as air-conditioned rooms or cold-water immersion, demonstrated modest yet measurable BAT activation without the need for extreme temperature changes (Fournier-Level et al., 2019; Nyangasa et al., 2021).

Moreover, the use of bioactive-rich tropical foods—including those containing capsaicin, catechins, and polyphenols—represents a culturally embedded and nutritionally beneficial intervention strategy. These dietary compounds mimic cold-induced activation through sympathetic and molecular pathways ((Finlin et al., 2020; Wang et al., 2021), offering a functional nutritional approach to enhance thermogenesis and improve metabolic health. Such interventions are especially relevant in resource-limited tropical settings where cold-based therapies may be logistically or economically impractical.

4.2. Translational Potential

The findings of this review have important implications for translational science and public health (Cruz-Flores et al., 2022). Given the increasing prevalence of obesity, insulin resistance, and metabolic syndrome in many tropical nations, integrating BAT-related interventions into population-

level health strategies could offer a complementary approach to conventional lifestyle modification programs.

Exercise regimens, especially high-intensity interval training (HIIT) and resistance-based protocols, have shown consistent effects on BAT stimulation through hormonal mediators such as irisin (Torres et al., 2021). These strategies are highly adaptable and can be implemented in community settings with minimal technological reliance, making them ideal for wide-scale public health deployment.

Nonetheless, several gaps remain in current research. Longitudinal studies assessing the sustainability, safety, and efficacy of these interventions are limited (Bali et al., 2022). It is essential to conduct controlled trials in tropical populations to validate these findings, optimize dosing and frequency of interventions, and monitor long-term outcomes related to cardiometabolic risk (Choudhary, 2023). Additionally, future research should explore personalized approaches, integrating omics technologies and digital health tools to tailor BAT activation strategies to individual metabolic profiles.

In summary, while environmental constraints pose challenges, the evidence supports a multi-pronged approach to BAT activation in tropical populations (Kumar et al., 2024). With further research and strategic integration, these findings hold promise for addressing the rising burden of metabolic diseases in warmer climates (Lapwong et al., 2021).

5. CONCLUSION

This systematic review confirms that brown adipose tissue (BAT) activation represents a promising metabolic intervention strategy for tropical populations, despite the absence of natural cold stimuli. The evidence supports the effectiveness of a multimodal approach, combining simulated cold exposure, bioactive dietary components, and physical exercise to activate BAT and improve metabolic outcomes. These strategies are not only biologically plausible but also culturally adaptable and practically implementable in warm-climate settings.

To advance the translational value of these findings, future research should aim to refine intervention protocols, explore synergistic effects, and evaluate long-term feasibility and scalability in diverse tropical populations. Ultimately, integrating BAT activation into preventive health frameworks could contribute meaningfully to the mitigation of obesity and related metabolic disorders in the tropics.

6. LIMITATIONS

This review is subject to several limitations. First, the inclusion criteria limited the analysis to articles published in English and within the 2018–2024 timeframe, which may have excluded relevant earlier studies or non-English publications. Second, although the review considered both human and animal studies, the heterogeneity in study design, intervention protocols, and outcome measures posed challenges for direct comparison and meta-analysis. Third, most included studies were exploratory or small-scale, limiting the generalizability of findings to broader populations. Future research should emphasize standardized methodologies, larger sample sizes, and long-term intervention trials specifically tailored to tropical settings.

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8. CONFLICT OF INTEREST DECLARATION

The authors declare no conflict of interest related to the publication of this article.

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