Ethnobotany and the Productivity-Endurability Trade-off

Zaal Kikvidze, Marine Mosulishvili, Ineza Maisaia, Nino Toriashvili, Rainer W. Bussmann, Narel Y. Paniagua-Zambrana

Correspondence

Zaal Kikvidze[1*], Marine Mosulishvili[1,2], Ineza Maisaia[3,4], Nino Toriashvili[1,2], Rainer W. Bussmann[3,5], Narel Y. Paniagua-Zambrana[3]

[1]Institute of Ecology, Ilia State University, 3/5 Cholokashvili Avenue, Tbilisi 0162, Georgia.
[2]Georgian National Museum, 3 Purtseladze Street, Tbilisi 0105, Georgia.
[3]Department of Ethnobotany, Institute of Botany, Ilia State University, 1 Botanikuri Street, Tbilisi 0105, Georgia.
[4]National Botanical Garden of Georgia, 1 Botanikuri Street, Tbilisi 0105, Georgia.
[5]Department of Botany and Mycology, State Museum of Natural History, 76133 Karlsruhe, Germany.

*Corresponding Author: zaal.kikvidze@iliauni.edu.ge

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Editorial

Abstract

Background: Ethnobotany serves as an exemplary interdisciplinary science, synthesizing concepts from botany, ecology, sociology, and ethnography to explore the complex relationships between human societies and plant resources. While ethnobotanical research frequently documents the superior sensory qualities, nutritional profiles, and medicinal potency of wild plants and traditional landraces compared to modern commercial varieties, these observations often lack a unified biological framework. This paper unifies these phenomena — along with the global dominance of annual plants as staple foods — within a framework of the productivity-endurability trade-off.

Methods: Rooted in the historical "law of compensation" proposed by Darwin and Wallace, this trade-off posits that biological resources allocated to one function, such as biomass accumulation (productivity), are necessarily withdrawn from others, such as stress tolerance and pest resistance (endurability). Drawing on J.P. Grime's C-S-R Triangle theory, this study examines how artificial selection and agricultural intensification bypass environmental constraints, often resulting in highly productive crops with significantly reduced self-defense mechanisms.

Results: Through this theoretical lens, the preference for annual staples is revealed as a strategic selection for rapid reproductive output over the high metabolic costs of perennial longevity, which are only mitigated in tropical environments. Furthermore, the trade-off explains the diminished potency of cultivated medicinal and aromatic plants; in the absence of wild environmental stressors, plants downregulate the synthesis of costly secondary metabolites that define their flavor and therapeutic value.

Conclusions: The trade-off concept provides a comprehensive explanatory framework for key ethnobotanical observations, offering critical insights for the future of sustainable breeding and global food systems.

Keywords: Ethnobotany, Biological Trade-offs, Productivity-Endurability, C-S-R Theory, Plant Domestication, Secondary Metabolites

Background

Ethnobotany stands as an exemplary interdisciplinary science, emerging from the rigorous synthesis of concepts, ideas, and methods drawn from established disciplines (Ludwig 2026). As an interdisciplinary synthesis, it combines botany, ecology, sociology, and ethnography in a manner that allows novel theoretical frameworks to emerge (Klein 2010; Balick & Cox, 2021). This disciplinary integration is inherently dynamic; over time, the field has deepened its scope by incorporating advancements in ecological botany and ethnology (van Klink & Taekema 2008; Vandebroek & Albuquerque 2024). Central to contemporary ethnobotanical inquiry is the consistent observation that traditional agricultural products often possess sensory and nutritional qualities far superior to their commercial counterparts. For instance, respondents in studies of Georgian landrace wheats and maslins emphasized an exceptional organoleptic profile, noting that the aroma of freshly baked bread was so potent and distinctive that "neighbors from across the village could smell the freshly baked loaves" (Kikvidze *et al.* 2025, p. 6; Frankin *et al.* 2023). This superiority is not merely anecdotal; the high nutritional value of wheat landraces is experimentally documented across wide Euro-Asian regions, fueling a modern market trend where "ancient wheats" are commercialized specifically for their perceived health benefits (Shamanin *et al.* 2024; Sunrise Flour Mill 2024). Furthermore, a recurring pattern emerges when comparing wild and cultivated plants. Wild specimens frequently exhibit higher concentrations of phytochemicals — including phenolics, flavonoids, and antioxidants — due to environmental stresses absent in pampered cultivation (Mangoale & Afolayan 2020). Specific examples, such as *Zingiber striolatum* Diels, demonstrate that wild samples are richer in vitamin C, minerals (K, Na, Se), and volatiles like palmitic acid compared to cultivated varieties (Yang *et al.* 2023). Similarly, wild *Alepidea amatymbica* Eckl. & Zeyh. exhibits a potency that is significantly diminished under low-stress garden conditions (Mangoale & Afolayan 2020). We argue that these disparate ethnobotanical observations converge upon a single biological imperative: the productivity-endurability trade-off. Nowadays trade-off models increasingly occupy a prominent place in biological theory (Garland et al. 2022; Garland, 2014), although these developments seem to be overlooked in their applications to breeding and agrotechnology (Gleason et al. 2025; Agrawal, 2020). Here we focus on a specific trade-off, namely that exists between crop productivity and plants' ability to resist or tolerate abiotic stress, resource limitation and pest attacks (termed here as "endurability"). Below we briefly introduce the historical foundations of biological trade-offs to define their essence.

Historical Foundations of Biological Trade-offs

The concept of trade-offs is foundational to evolutionary theory. Charles Darwin (1876) commented on the "*law of compensation or balancement of growth,*" propounded by Etien Geoffroy de Saint Hilaire and Johann Wolfgang von Goethe (Darwin 1876, p.118). Darwin noted that "*if nourishment flows to one part or organ in excess, it rarely flows, at least in excess, to another part*" and illustrated this with practical agricultural examples: the difficulty of breeding a cow that both fattens readily and produces high milk yields, the fact that cabbage varieties optimized for foliage rarely produce abundant oil-bearing seeds, and extended this to poultry, noting that a "*large tuft of feathers on the head is generally accompanied by a diminished comb, and a large beard by diminished wattles*" (Darwin 1876, p. 118). While Alfred Wallace also identified this balance as an "acting cause" in nature — where high velocity might compensate for a lack of defensive weapons — Darwin noted a distinct disciplinary leaning: botanists, more than zoologists, were firm believers in this law (Darwin & Wallace 1858, p.61-62; Darwin 1876, p.118).

Modern Ecological Theory: Grime's C-S-R Framework

While biological trade-offs conceptually are based on the same idea as described above, modern plant community ecology has formalized these observations through the Universal Adaptive Strategy Theory (UAST) and its predecessor, the C-S-R Triangle theory (Grime 1977; Grime & Pierce, 2012). The UAST is an evolutionary theory sets the general limits to ecology and evolution based on the trade-off that organisms face when the resources they gain from the environment are allocated between either growth, maintenance or regeneration – known as the universal three-way trade-off. Testing UAST is an exceptionally challenging endeavor, requiring a wide spectrum of diverse organisms to validate its universal claims. On the contrary, C-S-R theory — which concerns only plants — is widely applied due to its derivation from extensive field and laboratory data. The C-S-R framework identifies three primary strategies:

1. Competitors (C-strategists): Plants adapted to low-stress, low-disturbance environments that maximize growth to exclude others.
2. Stress-tolerators (S-strategists): Plants adapted to resource-limited or extreme environments (e. g., infertile or arid soils) that grow slowly but endure where others fail.
3. Ruderals (R-strategists): Short-lived plants adapted to high-disturbance areas, rapidly completing their life cycles to produce abundant seeds.

Organisms must navigate a three-way trade-off; no species can maximize all three strategies. While some critics argue the framework is overly simplistic (Grubb 1977; Wilson & Lee 2000), experimental evidence supports the predicted "humped-back" relationship between species richness and stress intensity (Grime 1973): plant species richness is in grasslands highest at intermediate stress levels where mixed-strategy species can coexist (Fraser *et al.* 2015). In fact, the C-S-R theory remains popular and finds certain applications such as calculating plant C-S-R ecological strategies at global scale (Cerabolini *et al.* 2010; Pierce *et al.* 2017) and analyzing the successional stages in plant communities (Zhang *et al.* 2024). A recent study (Liu et al. 2025) provides strong empirical validation of the CSR theory using an extensive species dataset and expands the number and types of traits that are significantly associated with the CSR axes.

Domestication Patterns: Annuals vs. Perennials

Global food security is currently reliant on a few annual staples — wheat, maize, rice, and soybean — across diverse domestication centers (Kreitzman *et al.* 2020; Diamond & Bellwood 2003). Intriguingly, molecular genetic studies do not reveal any inherent biological reasons for this dominance, making the productivity-endurability trade-off an essential explanatory framework. Perennials are rare as staples because they must divert photosynthates toward overwintering, multi-year survival, and enduring long-term weather variations, leaving fewer resources for reproductive yield (Vico *et al.* 2016). Perennial staples like avocado, banana, and enset are concentrated in tropical and subtropical zones where the costs of overwintering are minimized (Kreitzman *et al.* 2020). Notable exceptions — such as perennial peanuts, Jerusalem artichoke, and salsify — exist but represent a tiny share of global consumption. Furthermore, historical human preference was shaped by the "waiting cost". Alfred Wallace (1869) illustrated this in the *Malay Archipelago* by noting that local populations of the Aru Islands were reluctant to plant cocoa-nuts because they could not justify burying a nut for a "*prospective advantage of a crop twelve years hence*" (pp. 245-246).

Impact on Secondary Metabolism and Medicinal Quality

The productivity-endurability trade-off has rarely, if ever, been analyzed explicitly in the context of medicinal plants, despite its profound implications for quality. We argue that because the sum of metabolites is finite, there is a fundamental conflict between biomass growth and medicinal potency (Böttger *et al.* 2018). Plants manage the high metabolic cost of secondary metabolites by keeping pathways in a "standby regime," activated only when "alert systems" inform the plant of environmental threats (Jampílek & Králóvá, 2023; Mahajan *et al.* 2020). Consequently, medicinal plants grown in low-stress environments — such as gardens or greenhouses — show significantly lower concentrations of active compounds (Moreira et al. 2018). This has been documented in *Alepidea amatymbica* Eckl. & Zeyh., *Rhodiola sachalinensis* Boriss., *Tetragonia decumbens* Mill. and *Zingiber striolatum* Diels (Mangoale & Afolayan, 2020; Wei *et al.* 2024; Sogoni *et al.* 2024, Yang et al. 2023). In plantations, this can only be circumvented by imitating abiotic stress or herbivory to trigger metabolite production, inevitably at the cost of total biomass yield (Alami *et al.* 2024).

Conclusion: Synthesizing the Ethnobotanical Evidence

The framework of biological trade-offs offers a robust explanation for several critical ethnobotanical phenomena:

- The overwhelming dominance of annual and biennial species in global agriculture.
- The concentration of perennial staple crops within tropical regions where overwintering costs are lowest.
- The consistently higher medicinal potency of wild-collected plants compared to those in low-stress cultivation.

The superior taste, aroma, and health benefits of traditional landraces, which have not been subjected to the extreme selection for productivity that defines commercial foodstuffs.

Declarations

List of abbreviations: UAST- Universal Adaptive Strategy Theory
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Consent for publication: Not applicable
Availability of data and materials: Not applicable
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