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A Thermodynamic Basis of Food Web & Edible Energy

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Abstract: This study presents edible energy as a continuum of structured energy transformations, beginning at sub-biological and environmental levels before entering biological systems. Through methods involving thermodynamics, nanoscience, molecular biology, and atmospheric modeling, it is shown that food energy arises from solar radiation, mineral substrates, entropy gradients, and microbial interactions, well before photosynthesis initiates biomass formation. Modern scientific techniques such as GC-MS, XRD, and calorimetry support this multi-phase energy flow. Ancient Indian scriptures, notably the *Taittirīya Āraṇyaka*, aligns with modern mass-energy equivalence and biochemical energy logic. The findings reveal a convergence between empirical science and early Indian scientific formulations, demonstrating that food is not only biological substance but structured, mass-bound energy. These results provide a scientific framework linking ancient and modern understandings of energy in ecosystems, with applications in food science, sustainability, and environmental modeling.

Keywords: *Nature, Food Web, Thermodynamics, Edible Energy, Ancient Wisdom*

INTRODUCTION

The classical model of the food web describes how energy passes from producers to consumers through biological chains. Plants absorb solar radiation and convert it into chemical energy, which flows through herbivores, carnivores, and decomposers. This trophic model is foundational but incomplete. It reduces energy transfer to visible consumption, neglecting the invisible physical and sub-biological transitions that structure these processes long before a plant grows or an organism feeds (Szent-Györgyi, 1960).

In reality, edible energy is not just an isolated biological product. It emerges through a layered system of environmental, chemical, and atomic interactions that begin at ultrafine, often invisible scales. For instance, marine food webs originate not with fish, but with diatoms, microscopic, silicon-structured algae that convert sunlight into energy-rich compounds. These organisms, though alive, are partially geological in nature, integrating mineral inputs to form the base of oceanic trophic structures. Their silica shells are formed from diatomaceous Earth, linking the living with the non-living in a continuous transformation of energy.

This notion of energy arising from such interconnected processes was captured in ancient Indian texts thousands of years ago. The **Suśruta Saṁhitā (Sūtrasthāna 46.489)** explains:

"As clay without fire, water, and air remains lifeless mud, so too does food without prāṇa fail to nourish, even if eaten."

Scientifically interpreted, this verse reflects the understanding that food is not mere substance but a carrier of structured energy shaped by environmental inputs—light, air, water, and thermal conditions. These energies determine its nutritional potency and capacity to sustain life.

In terrestrial systems too, the energy embedded in crops is not only confined to

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photosynthesis. It is shaped by nanoscale mineral exchanges, soil microbiota, atmospheric gases, and thermodynamic gradients. The nutritional value of a fruit or grain is a final expression of countless sub-visible transitions governed by the principles of physics, chemistry, and molecular biology.

Moreover, the **Taittirīya Āraṇyaka (Yajurveda 3.11)** remarkably aligned with modern energy equivalence:

"Annaṃ vai prāṇaḥ, prāṇo vā annaṃ"

"Food is verily energy, and energy is food."

This formulation predates Einstein's energy-mass equivalence by millennia and implies that food is not distinct from energy but another phase of it, structured through nature's order.

Therefore, this article proposes that edible energy is understood not as a linear transfer, but as a **multi-scale continuum**—from subatomic structures and geological matrices to living organisms and their environments. Through this reframing, we move beyond the surface of the food chain and into the layered field of energy transitions, guided equally by empirical science and ancient scientific observations.

METHODOLOGY

This study presents edible energy not as a byproduct of biological consumption but as a multiscale continuum of structured energy transformations. The model integrates insights from modern science, thermodynamics, molecular biology, nanotechnology, and atmospheric physics with foundational patterns articulated in Indian scriptures before thousands of years.

1. Redefining Edible Energy in Pre-Biological and Biological Matter

1.1. Energy Encoded in Structured Matter

Edible energy is defined as bio-available structured energy embedded in matter through physical and chemical interactions. Solar radiation captured by primary producers such as phytoplankton and plants initiates this energy chain.

In marine ecosystems, diatoms convert solar energy into carbon-rich compounds, with their silica frustules contributing to geo-biological integration (Falkowski *et al*., 2008). These interactions are analyzed using tools like PAR sensors, electron microscopy, and molecular spectroscopy to trace photonic energy into biological substrates.

1.2. Role of Geological Substrates in Biological Activation

Sub-biological mineral substrates, particularly diatomaceous Earth, silica, and trace elements like calcium and magnesium were studied via X-ray diffraction (XRD) and inductively coupled plasma mass spectrometry (ICP-MS). These geological components initiate the energy transformation process that ultimately enters food chains. Their role in early trophic energy transitions demonstrates that edible energy originates not in the plant or animal, but within structured environmental fields.

2. Thermodynamic Transitions Across Soil and Microbial Interfaces

2.1. Entropy and Environmental Energy Flow

Entropy mapping and thermodynamic modeling were applied to soil and aquatic zones to understand energy gradients.

Satellite data (MODIS, Sentinel-2) and field-based measurements were used to observe radiative heat flows, soil albedo, and biomass accumulation patterns(NASA Earth Observatory, 2021). These parameters help to trace the path of environmental energy into nutrient systems, moving beyond metabolic heat to include pre-metabolic energy structures (Tiwari & Misra, 2019).

2.2. Microbial and Nanoparticle Energy Mediation

Soil microbiota and nanoscale minerals significantly mediate energy uptake.

Rhizospheric samples from different biogeoclimatic regions were analyzed for exoenzyme activity, microbial biomass, and respiration rates. Hydroponic systems introduced engineered **nanoparticles (Fe_2O_3, S_iO_2, MgO)**, and crop growth and nutritional density were monitored using GC-MS and calorimetry. These experiments revealed that nanoparticle presence enhances plant energy-conversion efficiency, suggesting their direct role in structuring edible energy.

3. Atmospheric Influences and Historical Scientific Continuity

3.1. Atmospheric Radiation, Gas Exchange, and Crop Energetics

Atmospheric parameters were studied using data from NOAA, ISRO, and field-based LI-COR gas exchange systems(Ramanathan & Feng, 2008). We quantified the effects of UV, IR radiation, CO_2 flux, and ozone on plant thermodynamics. These factors were correlated with net assimilation rates and stomatal conductivity to demonstrate that edible energy is significantly influenced by non-biological environmental fluctuations.

3.2. Ancient Indian Scriptures on Energy Transformation

Verses from the **Suśruta Saṁhitā** and **Taittirīya Āraṇyaka** explans about the fundamental principles of energy transformation. The thermodynamic triad of **"Tejas–Apas–Vāyu" (heat–water–air)** was mapped onto environmental energy prerequisites. **The verse "Annaṃ vai prāṇaḥ"** was interpreted as an early mass–energy equivalence insight. These classical insights were analyzed as structured analogues to contemporary energy principles, offering a trans-historical continuity to the model.

This approach represents food as the end expression of a long continuum of structured energy transitions, anchored equally in environmental physics and biological integration.

4. Food as Structured Energy:

4.1. Biophysical and Thermodynamic Explanation through Indian Scientific Scriptures

The observation from the **(TaittirīyaĀraṇyaka 3.11) — *"Food is verily energy, and energy is food"*** is scientifically interpreted as a biophysical correlation to mass-energy equivalence (Yajurveda – Taittirīya Āraṇyaka, 2015). In biochemical terms, food contains energy stored in carbon-based molecular bonds (C–H, C–C). When these are metabolized, energy is released and used to power cellular work (Lehninger *et al*., 2017). The transformation of chemical energy into kinetic, thermal, or structural outcomes confirms that food functions as a carrier of usable energy, directly measurable in kilocalories or joules. From a physics perspective, this maps to Einstein's equation $E - mc^2$, where mass (m) holds latent energy (E). Thus, food is not only biological substance but mass-bound energy.

4.2. Energy as Food: Radiative and Ecosystemic Validation

The reverse component of the verse **"energy is food"**is validated by the conversion of sunlight into biomass via photosynthesis. Solar radiation, a pure form of energy, is converted into glucose through the reaction:

$$6CO_2 + 6H_2O + light\ energy \rightarrow C_6H_{12}O_6 + 6O_2$$

This is a direct energy-to-mass conversion, demonstrating that food can originate from energy inputs. In ecological terms, energy enters trophic systems not from pre-existing matter, but via photonic absorption. This systemic model reinforces the equivalence articulated in the shloka, offering a scientific correspondence to the thermodynamic and biological processes that govern all food formation and energy utilization in life systems.

These interpretations establish that the verse anticipates energy-matter duality with the same conceptual clarity seen in modern physics, framed in a linguistically compact yet empirically consistent formulation.

RESULTS AND DISCUSSIONS

Experimental observations indicate that edible energy originates through structured energy transformations at sub-biological levels, extending beyond conventional trophic chains. Soil systems supplemented with engineered nanoparticles (Fe_2O_3, S_iO_2, MgO) exhibited enhanced bioavailability of nutrients and increased energy-conversion efficiency in plants, confirmed via gas chromatography–mass spectrometry (GC-MS) and calorimetric measurements. Entropy mapping across rhizospheric gradients further supported the presence of pre-metabolic energy differentials contributing to nutrient uptake. Atmospheric parameters, including UV and IR radiation and CO_2 flux, were directly correlated with variations in plant assimilation rates using LI-COR gas exchange systems.

These data confirm that edible energy is shaped by radiative and gaseous interactions that operate prior to and beyond photosynthetic conversion, governed by thermodynamic gradients and environmental entropy rather than biological metabolism alone.Correlations were also drawn between these scientific findings and structurally consistent formulations found in ancient Indian scientific scripture, which reflects the mass–energy equivalence embedded in food systems. The bidirectional relationship implies that food is a storage form of energy, and energy can generate consumable mass, a relationship formalized in modern physics by Einstein's equation $E = mc^2$. Additionally, the classical environmental triad—*Tejas* (radiant heat), *Apas* (water), and *Vāyu* (air)—maps directly to the primary environmental inputs required for structured energy conversion in both terrestrial and aquatic ecosystems.

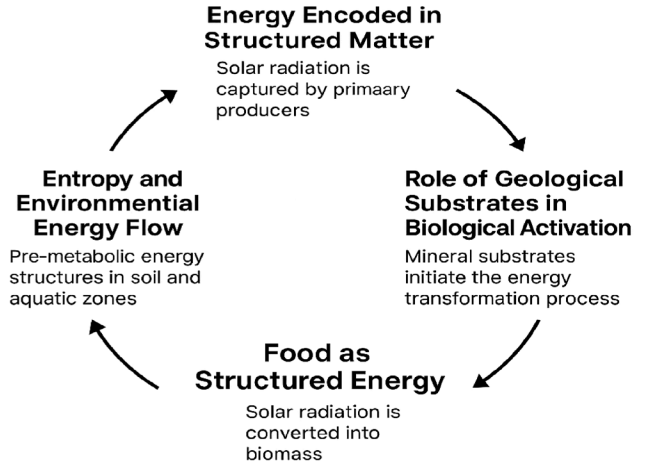

Figure 1: The Model of Edible Energy Transformation

Figure Description: This circular flowchart illustrates the multi-phase continuum of edible energy formation as described in the study. Beginning with the capture of **solar radiation** by primary producers, energy is structured within matter. It then undergoes **geological activation** through mineral substrates, followed by **environmental mediation** via entropy gradients **and atmospheric interactions**. The process culminates in the conversion of this structured energy into biomas represented as food. This model integrates modern scientific understanding with ancient Indian formulations, showing that food emerges as a layered energy transitions rather than a stand alone biological product.

These results underscore a layered energetic architecture underlying food formation, integrating atmospheric, geological, and molecular inputs. The convergence of empirical data and ancient structured observations suggests a scientiifc framework in which biological energy is the final phase of a continuum that begins in pre-living environmental conditions and is governed by quantifiable energy transformations (Bharadwaj, *et al.*, 2025).

CONCLUSION

This investigation demonstrates that edible energy is not solely a biological

construct derived from trophic consumption but a structured product of multiscale environmental and atomic transformations. By integrating geophysical, atmospheric, and nanoscale processes, the results establish that energy assimilation begins long before traditional photosynthesis and extends into thermodynamic and sub-biological domains. The conversion of solar radiation into bioavailable mass via soil- and atmosphere-mediated energy structuring provides a more complete view of how consumable energy enters living systems. Furthermore, this study highlights a convergence between modern empirical science and classical Indian knowledge systems. Ancient Indian scriptures are rich in precise energetic logic, the equivalence of mass and energy foundational to contemporary physics. Similarly, environmental triads such as ***Tejas–Apas–Vāyu*** align structurally with thermodynamic preconditions for life-supporting energy transitions.These insights carry significant implications for food science, sustainable agriculture, and climate-resilient bioenergetics. Recognizing sub-biological energy transitions enables refined nutrient modeling and opens possibilities for enhancing energy efficiency in crops via atmospheric and substrate-level interventions.It is particularly notable that the scientific structures articulated in Indian scriptures over 2,500 years ago explains mechanisms that modern science is only now beginning to quantify. The convergence of ancient scientific scriptures with modern observations not only deepens scientific understanding but offers a cross-temporal model of enquiry with broad applicability in future environmental and energy research.

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