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The Unified Cycle from Stellar Nucleosynthesis to Food Crop Systems: Gratitude to Earth for Underground Tubers, Sweet Potato Leaves as Source of Energy-Nutrition

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Abstract

Solar energy not only supports primary productivity on Earth but also connects biological systems to the broader structure of the universe. This paper presents a scientific synthesis linking stellar nucleosynthesis, photosynthesis, trophic nutrition energy transfer, and ecological process, with a focus on food crop systems including tuber crops. We highlight how bio-essential elements, formed in celestial objects, are transformed through plant metabolism into edible nutritional energy and how this energy flows through food-nutrition webs, ultimately participating in Earth's geochemical and cosmic recycling. The interconnected role of sunlight, air, water, and food in sustaining metabolic function was systematically described in ancient Indian scientific scriptures over two millennia ago. They revealed in those ancient time the energy-matter continuum. That concept now boosting modern ecological science models through thermodynamic and biogeochemical principles. This energy-matter cycle underscores the systemic interdependence between agricultural products, food-nutrition cycle and cosmic processes. The energy and matter as well as food-nutrition cycle their inter dependence are common to food web including tuber crops grown underneath soil. In our life cycle, we all are dependent on different supportive components. We are born, grow and leave in due course of time. During this cycle we observed the integrated ecosystems for our existence governed by the "Mother Nature". Contribution of Mother Nature is enormous. We are fortunate for the opportunity to work directly with sub surface soil products of Mother Earth. Yes, we had worked on tropical root and tuber crops for their improvement. Among the various tropical tuber crops, cassava, sweet potato, taro and greater yam occupy special niche in fragile ecosystems to provide food energy (361 - 386 calories/100g) to millions across the world. Those are ancient, ethnic and life support crop species in distress across the world. With integrated knowledge on biotechnology and crop breeding, we developed the climate resilient nutritious field products of sweet potato, taro, greater yam etc. Those products are developed especially for the needy mass live in fragile ecosystems across the Nation and beyond. The first author (Archana Mukherjee) got the opportunity to express gratitude to our mother earth by adoring the good names to the improved varieties in sweet potato, taro, greater yam and so on. The valued products, their characteristics and popular names of sweet potato like "Bhu Sona", "Bhu Krishna"; in taro—"Bhu Kripa", "Bhu Sree" and so on are highlighted with gratitude to mother earth. Here "Bhu" signifies "Bhumi" the "earth (soil)" a part of cosmos as well as place of development the "Bhubaneswar" city in Odisha, India. Further, analysis of nutritional elements in purple, orange and white flesh sweet potato leaves indicate their potentials as leafy vegetables throughout the year. Good amount of lutein (5.17 to 14.83 mg/100g), Ze (0.72 to 2.6 mg/100g), Fe (0.97 to 2.93 mg/100g) in sweet potato leaves are as nutritious as water spinach and spinach. Let the healthy food-nutrition source and congenial environment of "Mother Nature" of unified cycle perpetuate towards sustenance of all in this planet.

Keywords

Unified Cycle, Nueleosynthesis, Food Crops, Gratitude, Underground Tubers, Sweet Potato Leaves, Nutrition

1. Introduction

The food and nutrition are the basics of human or living world's mobility. However the food, the calorie actually the edible energy comes from plant and animal kingdom. Plants are the efficient converter of solar energy into edible energy with the components of air and water [1]. We all know how plant synthesizes carbohydrate. To synthesis carbohydrate, plant cells' chlorophylls absorb light energy from sun then it is utilized to convert inorganic substances like CO_2, H_2O etc. into a complex carbohydrate [2]. This provides us with energy and makes us active to do various energy consuming works. Similarly animals do depend on plants and other animals for edible energy.

The biosphere, operates within a framework that is cosmically initiated and physically constrained. In agricultural systems, particularly in the cultivation of energy-dense food crops especially tuber crops. We observe a precise biochemical expression of universal cycle: one in which cosmic-originated elements and solar energy are systematically transformed into biological productivity and subsequently edible energy. Understanding this continuum is central in advancing sustainable crop science and systems-level ecological management. The elemental constituents of all terrestrial life—including carbon, nitrogen, phosphorus, potassium, and iron—originated not on Earth, but in the high-energy interiors of ancient stars [3]. These elements, synthesized via stellar nucleosynthesis and disseminated through supernova-driven mass ejection, became incorporated into the proto-planetary material that eventually formed Earth's crust, oceans, and atmosphere. As such, every atom forming plant tissue, soil minerals, and even enzymatic structures in human metabolism can be traced to cosmogenic processes.

However, material availability is not equivalent to biological function. The activation of matter into life-supporting systems requires a persistent energy input—fulfilled by solar radiation. The Sun, a middle-aged main-sequence star, emits electromagnetic radiation across the visible and near-infrared spectrum. Within the photo synthetically active radiation (PAR) range, photons are absorbed by chlorophyll molecules in autotrophic organisms. This initiates the photochemical conversion of atmospheric CO_2 and water into carbohydrates, with oxygen as a by-product [4]. In tuber crops, this energy is stored primarily in the form of starch within subterranean storage organs, serving as a direct reservoir of transformed solar energy. Tuber crops such as potato, cassava, sweet potato and yam represent efficient biological endpoints in this solar-to-biomass conversion. Their role in global food security is inseparable from their ecological function as energy storage hubs. Once harvested and consumed, the energy contained in their starch molecules enters the heterotrophic domain of the food web. Across each trophic level, metabolic processes convert stored chemical energy into mechanical, thermal, and biochemical forms [4]. However, a large fraction of energy is lost as heat at each transfer step, consistent with the constraints imposed by the "Second Law of Thermodynamics". Thus, energy within food webs flows directionally—from high-order chemical potential to dispersed entropy—marking ecosystems as fundamentally open, dissipative systems. Beyond trophic exchange, all food crops including tuber crops systems actively participate in the modulation of Earth system processes, through plant respiration, microbial decomposition, and nutrient cycling. Hence, agricultural landscapes interact with atmospheric gas dynamics, soil structure, and hydrological feedbacks.

These interactions regulate carbon and nitrogen fluxes, affect greenhouse gas balances, and modulate planetary albedo, especially in intensively managed crops lands [5]. As such, food production is not an isolated biological process, it is a planetary-scale geophysical phenomenon. Over deeper temporal scales, the residues of biological activity undergo geochemical assimilation. Decomposed organic matter may be mineralized and reincorporated into pedogenic processes or buried within sedimentary sequences [6] [7]. Through tectonic subduction, erosion, or even extraterrestrial ejection events, these materials are redistributed across Earth's geo spheres. "In rare instances, may exit the planetary system entirely. This closes the energy–matter loop between food systems and the cosmos as a physically governed cycle of transformation and reintegration".

As noted in the *Charaka Saṁhitā* (Sūtrasthāna 1.69 [8]), quoting Maharsi Bharadvāja, the cyclic exchange of "light, wind, water, and food" is described as a balanced system where "*Tejas* (*radiation*) *transforms into Anna* (*nourishment*), *sustaining all motion and metabolism*" [9]. Another Ancient scripture, such as the *Suśruta Saṁhitā* (ca. 1000-500 BCE [10]), documented the fundamental role of sunlight, air, and water in the generation of food-bearing plant structures [11]. This early explanation parallels the modern understanding of solar energy conversion into biochemical energy via photosynthesis and its role in sustaining ecological and physiological function. This paper aligning and explaining the scientific basis of this continuum, focusing on the conversion of cosmic matter into biologically useful energy within the context of food webs, with tuber crops as a representative model with the help of ancient Indian scriptures and modern observations. By unifying the trajectory from stellar synthesis to agricultural metabolism and planetary recycling, we aim to provide a systems-level framework that positions crop science within a broader cosmological narrative. This perspective not only deepens our understanding of food-energy systems but also reinforces the interconnection of agricultural sustainability and planetary function. Among the various tuber crops, participating in nutrition cycle continuum, sweet potato is the third most important tuber crops grown in wide agro-climatic conditions. It is an important component in food web especially in the conditions of despair. Hence considered as "life support" crop. In India at ICAR-CTCRI, sweet potato breeders worked further to enhance its adaptability and nutritional quality [12]. Irrespective of the food crops, leaves are the source sites to absorb solar radiation. Leafy, vegetables directly transform the absorbed energy into edible energy unlike other vegetables. However, in case of sweet potato, we reveal here the nutritional elements of its leaves as food-nutritional source. Thus sweet potato can offer food-energy nutrition throughout the year both through tubers and its leaves. We are indebted to this universe for our sustenance through nourishment from the unified cycle of cosmos. The gratitude expressed to Earth (soil) for underground tuberous food, nutrition through adorable names is highlighted here.

Prior to the ground agro-products, steps of stellar nucleosynthesis are presented as follows:

1.1. The Steps Involved from Cosmos to Earth Terrestrial System

This study investigates the interconnection between the terrestrial food web. Here we specifically focusing on tuber crop system sand broader cosmic and planetary processes. The framework synthesizes approaches from crop physiology, ecological energetics, biochemical modeling, and astrophysical element tracking. Our objective is to trace the continuum from stellar-origin elements through photosynthetic energy assimilation in tuber crops to trophic transfer, environmental regulation, and long-term geophysical recycling.

1.1.1. Origin of Bio-Essential Elements in the Cosmos

Bio-essential elements such as carbon, nitrogen, oxygen, phosphorus, potassium, and iron—fundamental to plant nutrition and crop productivity—originate from stellar nucleosynthesis. These elements are formed in the cores of massive stars and distributed through the galaxy by supernova explosions and stellar winds [13]. Upon the formation of planetary systems, including Earth, these elements were incorporated into the lithosphere, hydrosphere, and atmosphere, becoming the chemical foundation for terrestrial ecosystems. In agricultural soils, particularly those supporting tuber crops. The presence and availability of these elements are direct results of planetary geological evolution. Their relative abundances in soil and plant tissues reflect not only the parent rock material but also long-term biogeochemical cycling shaped by both cosmic input and terrestrial weathering processes. Analytical techniques, including stable isotope ratio analysis (e.g., 13C/12C, 15N/14N), are used to identify the signatures of these elements and trace their transformation across systems.

In such study, geochemical profiles of soils supporting food crops including cassava, sweet potato, and potato crops were examined across contrasting climatic zones. These profiles help to establish a direct link between cosmic elemental synthesis and biological nutrient availability. By situating agricultural systems within this broader elemental cycle, crop science is repositioned within the continuity of planetary and cosmic matter flow. The understanding of this connection provides a foundation for viewing soil fertility and crop productivity not in isolation but as outcomes of long-duration cosmic and geophysical processes.

1.1.2. Solar Radiation and Biological Energy

Solar radiation is the primary driver of energy flow in terrestrial ecosystems. Photosynthesis serves as the mechanism through which autotrophic organisms convert solar electromagnetic energy into chemical energy, initiating the biological energy cascade. In tuber crops, light energy within the photo synthetically active radiation (PAR) range is absorbed by chlorophyll molecules and utilized to fix atmospheric carbon dioxide into organic compounds, primarily carbohydrates. These carbohydrates are then stored in underground storage organs, forming a significant reserve of edible energy.

Measurements of photosynthetic rates, light-use efficiency, and biomass accumulation provide insight into the energy assimilation capacity of different tuber crops [14]. Parameters such as net primary productivity (NPP) and photosynthetic efficiency (η) quantify the energy retained in plant tissues relative to the incident solar energy. Starch accumulation in tubers is a key indicator of this conversion process, representing a stable form of energy accessible to consumers.

"A detailed observation of how plants use sunlight to produce food is found in the SuśrutaSaṁhitā, an ancient medical scripture written over 2000 years ago.

"Tejo ambu vāyubhir hīnāḥ paṅkajāḥ prāṇinām hitāḥ |

Āhāra-sambhavāḥ śākhā mūlāni ca phalāni ca ||" (*Suśruta Saṁhitā*, *Sūtrasthāna 46.489*)

Translation: "With the help of sunlight (Tejas), water (Ambu), and air (Vāyu), plants synthesize structures beneficial to living beings. From these arise edible forms—branches, roots, and fruits." [11].

This ancient biochemical transformation establishes the foundation of the food web. The energy captured by plants is transferred through herbivores and omnivores, forming a hierarchical structure of energy flow. At each level, energy is degraded, primarily as metabolic heat, consistent with thermodynamic laws [15]. The initial photosynthetic capture thus not only supports plant growth but enables the functioning of entire food systems.

1.1.3. Energy Flow through Ecosystems and Food Webs

Within agricultural landscapes, the energy fixed by food crops propagates through ecological systems via feeding interactions. These food webs transfer chemical energy from primary producers to higher trophic levels, including herbivores, carnivores, and decomposers. Each step is governed by metabolic constraints and thermodynamic efficiency, with a substantial proportion of energy dissipated as heat.

Energy flow through food webs is modelled using ecological pyramids and transfer efficiency estimates. Empirical data from caloric content analyses of crops and trophic consumption rates allow for the construction of energy budgets. Typically, only about 10% of the energy is transferred between successive trophic levels, with the remaining energy being lost to respiration and entropy.

The detrital pathway also plays a central role. Plant residues, root exudates, and un-harvested biomass undergo microbial decomposition, returning nutrients to the soil and releasing energy through respiration [16]. Soil microbial activity is a key driver in this phase of the cycle, facilitating the breakdown of complex organic matter into simpler forms that re-enter the biological system. The trophic and detrital pathways together sustain both productivity and stability in food systems. In crops-based agro ecosystems, these flows determine not only yield outcomes but also resilience and sustainability. By quantifying energy degradation and nutrient recycling within these systems, it becomes possible to evaluate their efficiency and ecological balance within the broader biosphere.

1.1.4. Environmental Interactions and Planetary Recycling

The interaction between food systems and Earth’s environment extends beyond local fields and farms. Various crops including tuber crop production influences atmospheric gas composition, soil nutrient profiles, water availability, and sediment movement. These interactions link food energy dynamics to larger planetary processes. Carbon and nitrogen fluxes are central indicators of these interactions. Agricultural activities contribute to greenhouse gas emissions through plant and soil respiration, microbial nitrification, and decomposition. Measuring carbon dioxide, methane, and nitrous oxide emissions from various cropping systems including tuber crops provides insight into their role in the Earth's climate system [17]. Nutrient cycling measurements, such as soil nitrogen mineralization and phosphate availability, reflect how biological activity modulates elemental availability.

Water movement through various cropping systems also shapes environmental outcomes. Evapotranspiration, infiltration, and runoff affect both on crop productivity and hydrological balance. Nutrient leaching during rainfall events can influence downstream water quality. Erosion from cultivated slopes can mobilize soil-bound carbon and minerals, contributing to sediment fluxes that eventually reintegrate into geological reservoirs [18].

On geological timescales, these materials may be mineralized, or sub-ducted into deeper layers of the Earth's crust. This geophysical recycling of matter links the end-point of agricultural systems to planetary-scale element cycles. When visualized as part of a larger energy and matter system, food production is not an endpoint but a node within a continuous exchange that extends from stellar events to planetary systems. This explanation supports a systems-based approach to agriculture, where food, energy, and planetary stability are deeply intertwined.

The cycle (Figure 1) representing the formation of bio-essential elements via stellar nucleosynthesis, their assimilation into terrestrial biomass through photosynthesis, transfer through food energy networks, regulation within ecological systems, and long-term reintegration into Earth's geophysical and planetary cycling processes.

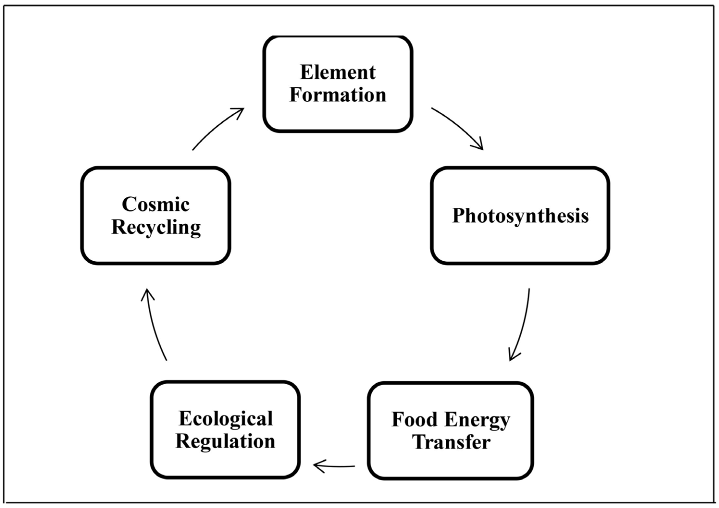


Figure 1. Cycle of energy flow from cosmic synthesis to terrestrial recycling.

This diagram outlines the closed-loop progression of elemental and energy exchange across five interconnected stages, beginning with stellar nucleosynthesis and continuing through plant productivity, food energy distribution, ecosystem regulation, and planetary matter recycling.

1) Element Formation: It refers to the generation of life-supporting elements—carbon, nitrogen, oxygen, phosphorus, potassium, sulphur, and others—within stellar interiors. These elements are released during stellar collapse or supernova events and incorporated into protoplanetary matter. Their presence in Earth's crust and biosphere provides the material base for biological and agricultural systems.

2) Photosynthesis: It represents the primary entry point of solar radiation into the biosphere. Autotrophic organisms. The green of earth including tuber crops, use chlorophyll to absorb photons within the photosynthetically active radiation range and convert carbon dioxide and water into carbohydrates. This conversion forms the initial biochemical input for energy flow through terrestrial ecosystems.

3) Food Energy Transfer: It includes the movement of this chemical energy through trophic interactions. As primary producers are consumed, energy is transferred through herbivores, omnivores, and decomposers, with a proportion of energy lost at each stage due to metabolic inefficiencies. This flow is governed by thermodynamic principles, particularly entropy generation.

4) Ecological Regulation: It includes the biological and physical processes that influence nutrient availability, greenhouse gas flux, water cycling, and soil function. The energy stored and mobilized in agricultural systems directly contributes to carbon and nitrogen turnover and supports system-level equilibrium in managed ecosystems.

5) Cosmic Recycling: It describes the long-term reintegration of biological and geochemical materials into larger Earth systems. Through erosion, sedimentation, lithospheric cycling, and subduction, elements from biological residues return to geologic reservoirs, maintaining continuity in the planetary matter cycle.

This cyclic framework contextualizes food systems within the broader physics of planetary, tropical and cosmological processes.

1.1.5. Cosmic Elements to Terrestrial Food-Nutrition

The results of present study reveal a structured continuity between cosmic element synthesis and terrestrial food systems. Across the selected agro-ecological zones, the observed elemental compositions of soils and plant tissues aligned with globally modeled stellar nucleosynthesis outputs [3] [13]. The presence of stable isotopes of carbon, nitrogen, and oxygen in food crop biomass confirmed the long-term geophysical retention and biological assimilation of elements with astrophysical origins.

Further, food energy transfer modeling showed that, despite efficient primary productivity, only a fraction of captured energy reached higher trophic levels. Measured trophic efficiency values across modeled food webs remained within the expected ecological range (8% - 12%), with a majority of energy dissipated as heat or recycled through detrital pathways. This aligns with the principles of thermodynamic degradation and energy dissipation [4], reinforcing that biological systems are constrained by entropy even under optimal metabolic conditions.

Microbial respiration and decomposition rates from post-harvest residues and root biomass contributed significantly to soil carbon turnover. The highest respiration fluxes were recorded during early decomposition phases, with microbial CO_2 emissions accounting for 35% - 45% of measured soil CO_2 flux post-harvest. These values illustrate the role of detrital energy recycling in maintaining nutrient pools and closing short-term biogeochemical loops [6].

1.1.6. Between Planetary Process, Geo Physical Retention and Short Term Bio Geo Chemicals Loops. Food Crops Play Pivotal Role in Energy Assimilation to Recycling

In all three crop systems studied—cassava in tropical humid, sweet potato in semi-arid subtropical, and potato in temperate highland regions—photosynthetic parameters demonstrated consistent light-use efficiency under comparable solar radiation inputs [2]. Chlorophyll concentrations, net CO_2 assimilation rates, and carbohydrate accumulation profiles indicated high efficiency of light energy capture and conversion into starch-rich biomass [14]. Across sites, starch content in mature tubers constituted 62% - 70% of dry weight, underscoring the energetic density and caloric potential of these crops [1].

1.2. Terrestrial Sub Surface Soil Grown Tuberous Food Source

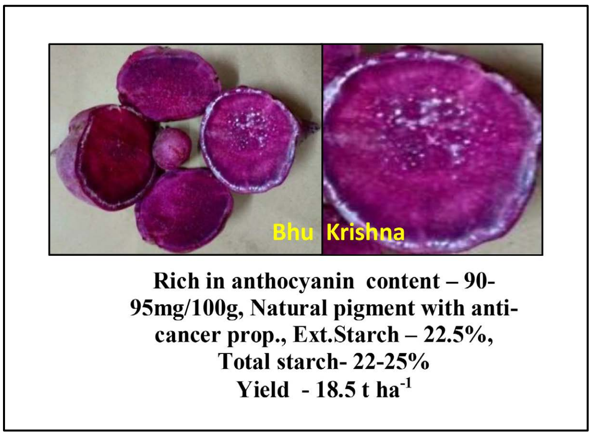
The title of the present communication also reflects the tuber crops-based food sources which are grown underground need to be cared for survival of living world. The root and tuber crops whether temperate potato or tropical tuber crops all are grown underground. Among these, tropical tuber crops viz. Cassava (*Manihot esculenta*), Sweet potato (*Ipomoea batatas*), Taro (*Colocasia esculenta* (L.)), Greater yam (*Dioscorea alata*), Elephant foot yam (*Amorphophallus paeoniifolius*) and other minor tuber crops occupy special "Niche" as rescue or life saving crops.

Since ancient time these crops got integrated with livelihood and ethnic culture. However, progressive diversifications in food have squeezed the demand for these type food crops. Irrespective of this issue, these crops especially sweet potato (*Ipomoea batatas*) found to save the lives of many as "saviour crops" across the world in distress. We got the opportunity to work on these crops for their further improvement to cope with changing environment as well as for higher nutritional values [12]. With these objectives, we have worked hard on sweet potato, taro, greater yam and yam bean (*Pachyrhizus erosus*). During our scientific career we have worked with senior crop breeders' viz. Dr. S.K Naskar, Dr. B. Vimala and followed their path to develop farmers' friendly, Nation friendly varieties.

The actual crop breeding work takes minimum 10 - 12 years to identify desirable traits and then to stabilize the marketable traits by testing trials in different agro climatic zones across the nation. Valued traits of a particular crops are being selected through progressive breeding and recurrent selection. Thereafter, initial evaluations are conducted in Institute farms at least for three years for the valued traits. Subsequently, the best performers are them inducted in All India Coordinated Research Project Trials (AICRP) of respective crops. In case of tropical tuber crops we had validated the desirable traits through AICRP-Tuber crops (TC) trials in different agro climatic zones. The best performing nutrition enriched, stress tolerant tuber crops varieties (products) developed were recommended for release by panel of experts for multi stake holders. The coloured flesh nutrient enriched stress tolerant sweet potato, nutrition enriched taro and greater yam released during 2017 still gaining popularity are briefed with their good names and special attributes.

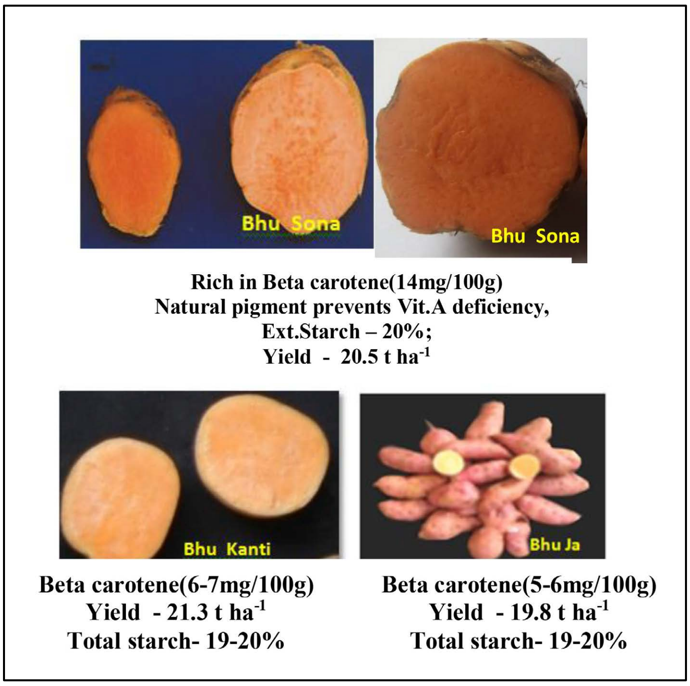
2. The Improved Different Tuber Crops with Good Names

The salt, midseason drought tolerant, weevil resistant purple flesh (Bhu Krishna), orange flesh (Bhu Sona, Bhu Kanti, Bhu Ja) and white flesh (Bhu Swami) sweet potato developed through progressive breeding and selection are presented with major characteristics in **Figures 2-4**. The yield performance of all those varieties across Odisha, India have already shown in our previous communication in detail [12]. Their nutritional composition has also been discussed.



Rich in anthocyanin content – 90-95mg/100g, Natural pigment with anti-cancer prop., Ext.Starch – 22.5%,
Total starch- 22-25%
Yield - 18.5 t ha^{-1}

Figure 2. The salt tolerant (6 - 8 $dS\cdot m^{-1}$) weevil resistant purple flesh sweet potato (Bhu Krishna).



Rich in Beta carotene(14mg/100g)
Natural pigment prevents Vit.A deficiency,
Ext.Starch – 20%;
Yield - 20.5 t ha^{-1}

Beta carotene(6-7mg/100g)
Yield - 21.3 t ha^{-1}
Total starch- 19-20%

Beta carotene(5-6mg/100g)
Yield - 19.8 t ha^{-1}
Total starch- 19-20%

Figure 3. Salt tolerant (6 - 8 $dS\cdot m^{-1}$) orange flesh sweet potatoes (Bhu Sona, Bhu Kanti, Bhu Ja).

The leaf blight resistant, salt tolerant taro varieties (Bhu Kripa and Bhu Sree) developed through breeding and subsequent evaluation is presented in **Figure 5**. Yield and nutritional attributes of those varieties have been discussed earlier [12].

Yield -24.5 t ha^{-1}
Extractable Starch-22-23%, Total starch-24-28%

Figure 4. Midseason drought tolerant, high starch with excellent processing quality sweet potato (Bhu Swami).

Yield : 15-20 t ha^{-1}
Dry matter (%) : 23.5 to 24.6
Starch (%) : 12.3-14.2
Total sugar (%) : 1.3-1.7
Cooking quality : Good

Yield : 15-20 t ha^{-1}
Dry matter (%) : 23.0 to 24.8
Starch (%) : 15.6-17.3
Total sugar (%) : 1.2-1.5
Cooking quality: Good

- **Taro tubers good source of Zn & Fe**
- **100g of taro fresh leaves can supplement 4825 IU or 161% of RDA of Vit. A**
- **100g tubers provide 11% daily requirement of dietary fibre**

Figure 5. Salt tolerant (4 - 6 dS·m^{-1}), Blight resistant taro (Bhu Kripa, Bhu Sree).

Similarly the short duration greater yam variety (Bhu Swar) developed and notified is presented in Figure 6. Yield performance of "Bhu swar" presented in Table 1. Average yield of Bhu Swar (DA-25) under different schemes observed to be 22.47 t/ha recorded after 6 - 7 months of harvest compared to the yield of checks (15.58 to 16.05 t·ha^{-1}). It has excellent cooking quality. The palatability, yield and shorter duration (6 months) are the special attributes of this variety.

Table 1. Pooled analysis of yield of greater yam varieties across Odisha, India.

Varieties	Tuber yield (t/ha)
Bhu Swar (DA-25)	22.47
Sree Karthika	16.05
Sree Roopa	15.58
CD at 5%	4.215

Yield :22-5 t ha^{-1}
Maturity :6-7 months
Dry matter (%) : 32-33
Starch (%) :20-22.5
Total sugar (%) : 1-1.5
Cooking quality: Excellent

Figure 6. Short duration greater yam (Bhu Swar).

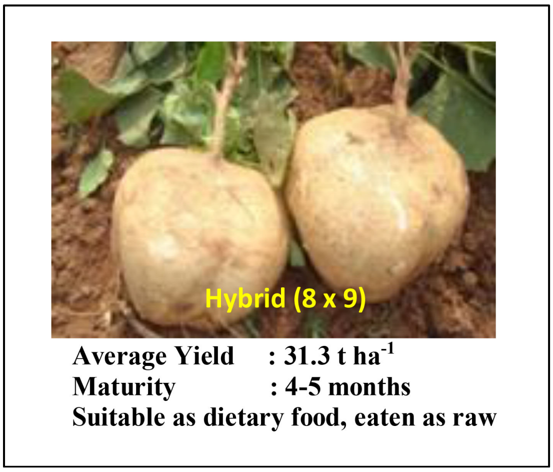
The yam bean hybrid (8 × 9), developed is found to give better yield (31.1 t/ha) as compared to the others. Fruits are palatable. Hence was inducted in progressive AICRP-TC trial to validate the traits prior to release. Yield performance of this hybrid was found to be superior among the tested entries (Table 2).

Table 2. Tuber yield (t/ha) and harvest index (%) of yam bean at Institute farm, Odisha, India.

Sl. No	Accession	Yield (t/ha)	HARVEST INDEX (%)
1	L-19	30.51	77.67
2	L No.3	29.35	72.33
3	8 × 9	31.1	84.67
4	ECI00546	23.95	75.33
5	DPH-9	19.9	70.33
6	DPH-58	21.56	73.33
7	DPH-70	19.98	78
8	DPH-88	20.37	79.33
9	BCYB-1	18.91	72.33
10	BCYB-2	21.86	72.33
	CD (0.05)	2.6	3.5

N.B: 8 × 9 hybrid developed by Dr. S.K. Naskar and Dr. Archana Mukherjee.

The selected yam bean hybrid line is presented in Figure 7 with features. Archana Mukherjee had decided its good name as "Bhu Madhura" means the sweet fruit of earth. Though it is grown as vegetable but is eaten as fruit or salads like cucumber.



Average Yield : 31.3 t ha^{-1}
Maturity : 4-5 months
Suitable as dietary food, eaten as raw

Figure 7. Yam bean hybrid (8 × 9) with good yield and palatability.

3. Expression of Gratitude through Good Names of Each Improved Variety of Tuber Crops

When we release a variety, a crop breeder gets an opportunity to give a good name to the developed variety. Usually the names are selected to reflect the attractive traits as well as the region or place of its development. In case of developed sweet potato, taro and greater yam; First author (Archana Mukherjee) got just one day time for proposing the good names of the improved ones. She met Shri S. Prusty, the then Director, Dir. of Hort., Odisha, India (2016-17) and had submitted the good names for discussion with him. She did so prior to presentation the release proposals of the developed improved tuber crops varieties before the "Expert Team" to release for Odisha, India and beyond. Shri S. Prusty (IFS, Director, Dir. of Hort., Odisha, India) said her to justify the names proposed by her for the different tuber crops.

She had explained him as follows—"Bhu" the first name means "Bhumi" the "Earth" (soil) the part of cosmos as well as "Bhu" stands for Bhubaneswar city, Odisha, India—the place of its development. It will be better understood with each variety along with full name as given below.

1) Bhu Sona-Bhu ("Bhumi"-"Earth" and also Bhubaneswar city, Odisha, India);

Sona (Precious gold type food from soil "earth" as its flesh colour is pure gold colour, dark orange owing to high beta carotene 14 - 16 mg/100g).

2) Bhu Krishna-Bhu as previous

Krishna (The saviour in distress as well as purplish black flesh colour owing to high anthocyanin 90 - 95 mg/100g with total starch—22% - 25%).

3) Bhu Kanti-Bhu as previous

Kanti (Glow of earth as its flesh colour is orange with beta carotene 7 - 8 mg/100g).

4) Bhu Ja-Bhu as previous

Ja (Originated from earth as hand hold food support with beta carotene 6 - 7 mg/100g).

5) Bhu Swami-Bhu as previous

Swami (Pure, soft product of earth as its flesh colour is milky white owing to high extractable starch—23% and total starch 24% - 28%).

6) Bhu Kripa-Bhu as previous

Kripa (Kind gesture of mother earth "soil" in the form of healthy food values like Ca; 30 - 32 mg/100g; Zn; 0.7 - 0.8 mg/100g; Fe; 0.6 - 0.7 mg/100g contents).

7) Bhu Sree-Bhu as previous

Sree (Beauty of mother earth with healthy food attributes like Ca; 24 - 26 mg/100g; Zn; 0.8 - 0.9 mg/100g; Fe; 0.7 mg/100g contents).

8) Bhu Swar-Bhu as previous

Swar (Voice of earth in the form of healthy food rich in calcium, zinc and iron).

All those Bhu Series tuber crops varieties developed and released after testing their yield, nutritional attributes, palatability as well as their resistance to pests, diseases and tolerance to salinity, mid season drought. Such varieties tests have been conducted initially at Institute farm and later in different agro climatic zone of Odisha and in India through All India Coordinated Trials. The best performing ones recommended and were released during 2016-17. The leaves of white, orange and purple flesh sweet potato studied further for their nutritional attributes. The results are encouraging for use of the leaves as source of leafy vegetables. Such attributes conferring their potentials as nutritional leafy vegetables are briefed below.

4. Sweet Potato Leaves as Source of Nutritious Leafy Vegetables

Use of sweet potato leaves as fodder is common in all sweet potato growing countries. However, use of sweet potato leaves as leafy vegetables are limited unlike "Water Spinach" (*Ipomoea aquatica*). The valued traits [12] of tubers of varied flesh colour sweet potato led to think the potentials of sweet potato leaves as source of green vegetables. Studies on lutein contents [19] [20] has further mooted to think of nutrient composition of leaves of sweet potato of varied flesh colour. In the present study, leaves of orange, purple and white flesh sweet potato are found to be good source of nutrition (**Table 3**). The contents of lutein (5.17 to 14.83 mg/100g), Ze (0.72 to 2.6 mg/100g) and Fe (0.97 to 2.93 mg/100g) in white, purple and orange flesh sweet potato leaves found to be comparable with spinach and water spinach leafy vegetables. Spinach and water spinach, found to have lutein contents (10 mg/100g and 15 mg/100g respectively).

Table 3. Nutrient composition of white-, purple-, and orange-flesh sweet potato leaves.

SI. No.	Variety	Zinc (mg/100g)	Iron (mg/100g)	Lutein (mg/100g)
1	Kishan (White flesh)	0.72 ± 0.02	0.97 ± 0.20	5.17 ± 0.35
2	Bhu Krishna (Purple flesh)	2.53 ± 0.15	2.93 ± 0.23	7.87 ± 0.30
3	Bhu Sona (Orange flesh)	2.60 ± 0.20	2.83 ± 0.15	14.83 ± 0.35

Values represent the mean of three replicates (n = 3). All values are expressed on a fresh weight basis in mg per 100 g.

This observation is encouraging to use sweet potato leaves as leafy vegetable like water spinach. In fact, excessive vine growth of sweet potato in humid rainy season can offer better option to use those as source of nutrient enriched leafy vegetables. Yield and harvest index of specific white, orange and purple flesh sweet potatoes were analysed. The data clearly indicate reasonable amount of bio mass and tuber yield (**Table 4** & **Table 5**). Bio-mass reflects the yield of leaves also. Further the harvest index in hilly zones in rainy season and in plain in winter season found to be on per (data not shown). In plain during rainy season, vine growth observed to be excessive owing to high humid conditions. It indicates low harvest index that also reflect excessive vine growth and low tuber yield. This can offer scope to use sweet potato leaves as leafy vegetables for all. Thus sweet potato tubers and leaves both can serve as nutrition sources in nutrition sensitive areas of sweet potato growing countries. Researchers on age related macular degeneration (AMD) indicated that inclusion of lutein in diet may reduce the severity of AMD [21]-[23]. Intake of lutein 6 mg per day could reduce the risk of AMD by 43%. Use of sweet potato leaves as leafy vegetables may haunt about its pruning effect on sweet potato tuber yields especially in winter season in plain. A study on pruning during winter season revealed no significant impact of pruning on tuber yield (**Table 6**). Harvest index of pruned branches found to be on par with the branches used as control. However, at least 7 - 10 active leaves need to be retained in top shoot during pruning (**Figure 8(A)** & **Figure 8(B)**). The leaves from mid shoot portion of the vine can be pruned for leafy vegetable (**Figure 8(C)**).

Table 4. Tuber yield and harvest index of sweet potato in different parts of Odisha, India.

Variety	Tuber yields t/ha at different parts of Odisha			Harvest Index (%) different parts of Odisha		
	Farm	Balasore	Kendrapada	Farm	Balasore	Kendrapada
White flesh						
Bhu Swami	25.00	23.85	24.88	54.73	57.44	56.13
Kishan	20.50	19.90	20.48	52.40	50.80	52.20
Purple flesh						
Bhu Krishna	17.57	19.61	18.32	48.57	48.74	48.80
Orange flesh						
Bhu Sona	18.93	20.65	21.79	52.54	50.74	51.69
Gouri	15.86	16.13	16.72	45.72	47.84	46.76
CD (0.05)	2.85	3.12	2.64	3.44	3.21	3.09

Table 5. Pooled analysis.

Variety	Tuber Yield (t/ha)	Harvest Index (%)
White flesh		
Bhu Swami	24.57	56.10
Kishan	20.29	51.80

Continued

Purple flesh		
Bhu Krishna	18.50	48.70
Orange flesh		
Bhu Sona	20.46	51.66
Gouri	16.24	46.77

Table 6. Harvest Index (%) of pruned and controlled (not pruned) of different flesh colour sweet potato in Rabi (winter season).

Varieties	HI (%) of Selectively Pruned Leaves			Harvest Index (%) Control		
	R1	R2	R3	R1	R2	R3
White flesh						
Kishan	51.7	52.2	51.5	52.3	51.4	52.0
Orange flesh						
Bhu Sona	51.6	50.9	52.2	51.8	52.0	51.8
Purple flesh						
Bhu Krishna	48.2	47.8	48.5	47.7	48.8	46.8
CD (0.05)	1.00					

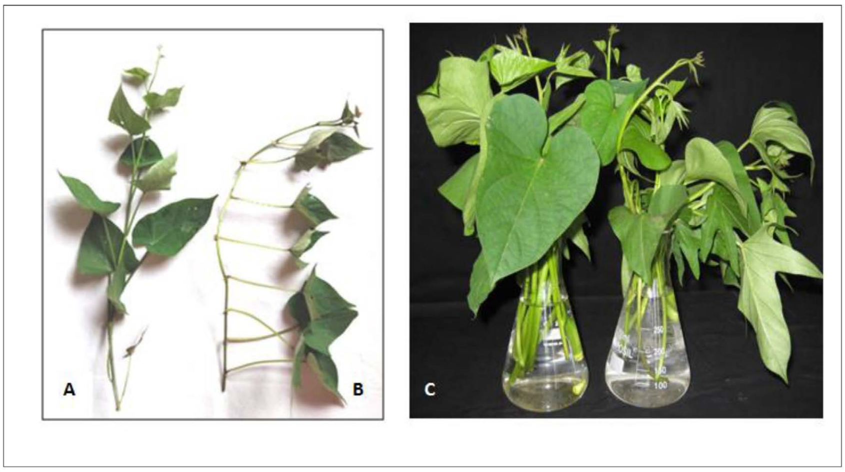


Figure 8. (A)-(C) The leaves of the top shoots of Bhu Sona (A), Bhu Krishna (B) and the pruned leaves of middle shoots of both the varieties (C).

These results are encouraging to find out the minimum numbers of required active leaves for tuber bulking. This will help in reducing farm inputs for the excessive vine growth which compete with tuber bulking. Rather it will also help to offer green vegetables thereby increasing farm returns.

Further the vine types of genetic resources are different. Some are of spreading type vine growth, some with semi compact and some with compact growth. In the present investigation, semi compact growth types were used. Use of spreading vine growth types' sweet potato can offer more green vegetables along with good tuber yield.

Sweet potato can be grown throughout the year to supply nutrient rich green vegetables and nutrient rich tubers at least twice in a year depending on climatic conditions conducive for tuber bulking [24].

From 40 days old grown branches, number of leaves are more in purple Bhu Krishna as compared to orange flesh, Bhu Sona. Hence some varieties can offer more green vegetables than others.

These results offer scope to further augmenting in sizeable vine growth types to use sweet potato in dual purposes across the fragile zones of the globe having nutrition sensitive populace.

5. Discussion

The mass bound energy $E = mc^2$ of Einstein is very much evident in matter related energy flow. The radiation and chemical elements are getting trapped in green world of vessatile nature. The energy trapping in tuber science is also not exception of that nuclesosynthesis. It is happening with each energy conserver including edible nutritional energy stored food like root and tubers.

The broader implications of these findings support the framing of food systems as embedded components of planetary and cosmic processes. The flow of energy from stellar synthesis to plant photosynthesis, through trophic transfer and ecological processing, and ultimately into geological or atmospheric reservoirs, defines a non-isolated, systemic continuum. Tuber crops serve as a measurable interface in this continuum due to their high conversion efficiency, carbon density, and close coupling with soil systems.

From an Earth systems perspective, the coupling between tuber-based agro ecosystems and atmospheric fluxes was evident. Seasonal N_2O and CO_2 emissions correlated with peak microbial activity, soil moisture availability, and nitrogen content, especially under fertilized plots (Butterbach-Bahl *et al.*, 2013). Carbon flux data suggest that tuber crops can serve as modest carbon sinks, particularly when crop residues are retained and integrated into soil organic matter. However, under certain management conditions, losses through leaching and dinitrification present trade-offs requiring systemic optimization [5].

Sediment transport measurements linked to rainfall events and slope gradient highlighted the importance of landform in downstream material redistribution. The particulate organic matter fraction in eroded material carried a measurable load of biologically derived carbon and mineral nutrients, contributing to longer-term geophysical cycling and downstream fertility [18]. The inclusion of these erosional vectors into the broader planetary material cycle connects agricultural landscapes to deep Earth cycling and geochemical sequestration pathways.

Positioning food production within this cycle challenges conventional boundaries of agricultural science. Rather than being viewed solely through local productivity or efficiency metrics, crop systems must also be understood through their role in maintaining elemental continuity and energy distribution across biological and planetary scales. The observed linkage between nutrient transformation, energy degradation, and geophysical feedbacks supports a systems-based framework for crop evaluation and sustainable land use design [7].

This integrative approach does not rely on abstract analogies or philosophical constructs but on empirical data, physically consistent laws (e.g., thermodynamics, conservation of mass and energy), and measurable environmental outcomes. The implications extend beyond academic framing, offering practical insight for optimizing food systems in ways that minimize entropy, retain nutrients, and align with planetary material limits.

Ultimately, edible energy from crops including tuber crop systems are functional mediators within an extended elemental and energy cycle. Such systems are in transitional process whether leafy or tuberous vegetables or any other form [25]. Present investigation also reveals that energy cycling from source to sink provide us with energy often directly as green leafy vegetables (sweet potato leaves) and also through reservoir (tubers). Sweet potato is a very good example of energy continuum. They reflect, in form and function, a deeper material heritage derived from cosmic processes, translated into biological productivity, and reintegrated into Earth's geophysical matrix. Recognizing this continuum provides a foundation for reimagining agricultural practice in harmony with the Earth system and the universe to which it belongs. We, the consumers of edible energy through all sources including root, leaves and tubers, are also infinitesimal mediators in the unified cycle of energy flow. The cosmos is vast, let us be grateful [26] to Mother Earth for providing food and energy continuum for our existence.

6. Conclusions

Tuber crops including all terrestrial food crops play an important role in connecting food production with larger natural cycles that begin with stellar nucleosynthesis and extend through ecosystems and the Earth's surface. The elements that support plant growth, like carbon, nitrogen, and phosphorus, were created in stars and became part of Earth's soils. Through photosynthesis, food crops including tuber crops capture sunlight and store it as carbohydrates, forming a major energy source in food systems through efficient solar energy conversion. This stored energy flows through food chains and returns to the soil and atmosphere through respiration, decomposition, and erosion.

These processes not only support local agriculture but also affect carbon balance, nutrient cycling, and long-term environmental stability. The results show that tuber crops are not just food sources—they are part of a much larger system that transfers and recycles energy and matter.

The continuity between solar input, biological productivity, and nutrient transformation, now modeled through ecological and thermodynamic systems, was outlined in ancient Indian scientific scriptures, underscoring the longstanding recognition of energy–matter interdependence in sustaining life.

By placing food-nutrition, energy, and matter within one unified scientific continuum—from celestial objects to soils to sustainability, of the various food crops, sweet potato (*Ipomoea batatus*) is the best example. Present investigation and discussion on its previous quests reveal source-sink—recycling with unique nutritiousattributes in sweet potato leaves as well as tubers. Our research could help to reshape the future of Agri-technology, education, and environmental sustenance.

We are born and grow from child to an adult depending on the pillars of support. Those are various types like Parental care, Nature's care, Mentors' care and so on. We think we are independent but in reality "no". We all are dependent component of an integrated unified cosmic system. We must express our gratitude to each other and all the living and non living component of the universe. The first author (Dr. Archana Mukherjee) has expressed her immense gratitude to "Mother Earth" through the meaningful names of the improved tuber crops which signifies the value of "Soil Earth" as well as place of their development. We, all the authors—bow down to the unified cycle starting from nucleosynthesis to terrestrial sub surface soil tuber of food nutrition web. Let all the healthy food including leafy vegetables, roots, fruits of Mother Nature of unified cosmic cycle perpetuate with their valued traits and nature adorable names across the world for wellness of all.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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