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Ecological adaptation and phytochemicals variability of *Fragaria* species in the agro-climatic zones of Mayurbhanj, Odisha

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ABSTRACT

This study investigates the ecological adaptability and chemical profile of *Fragaria* species (strawberry) introduced into the unique tropical agro-climatic zones of Mayurbhanj, Odisha, specifically focusing on the transition belts of the Similipal Biosphere Reserve. Despite its temperate origins, strawberry cultivation has expanded in this region, necessitated by the specific micro-climates and acidic laterite soils of Northern Odisha. The research evaluates how local environmental factors-such as temperature fluctuations, soil pH, and humidity-influence plant phenology and the synthesis of secondary metabolites. Phytochemical screening focuses on quantifying total phenolics, flavonoids, and anthocyanins (primarily pelargonidin-3-O-glucoside) across different altitudinal gradients. Preliminary observations suggest that environmental stressors in these tropical fringes may enhance antioxidant concentrations as an adaptive response. By correlating soil-climatic data with bioactive yield, this study provides critical insights into the physiological resilience of *Fragaria* in non-traditional landscapes. The findings offer a scientific foundation for optimizing cultivation practices, enhancing fruit quality, and supporting the socio-economic upliftment of tribal farmers in the Mayurbhanj district through sustainable horticulture.

KEYWORDS

Ecological Adaptation, Phytochemicals, Anthocyanins, Agro-ecology

HOW TO CITE THIS ARTICLE

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The genus *Fragaria* x *ananassa Duch.* (Strawberry), a member of the Rosaceae family, is globally celebrated not only for its distinct aroma and flavor but also for its high concentration of essential nutrients and bioactive compounds. Traditionally recognized as a temperate crop, its cultivation in India was long confined to high-altitude regions like Mahabaleshwar and the Himalayan foothills. However, recent agricultural shifts have seen the successful introduction of strawberry varieties into the non-traditional, tropical landscapes of Mayurbhanj, Odisha, particularly within the peripheral and transitional zones of the Similipal Biosphere Reserve.

Mayurbhanj presents a unique agro-climatic profile characterized by the influence of the Similipal hill range. This region features a mosaic of high plateaus, cooler micro-climates, and predominantly acidic, red laterite soils. The "transitional zone" of Similipal serves as an ecological buffer where forest ecosystems meet agricultural land. Understanding the ecological adaptation of *Fragaria* species in this specific geography is crucial, as the plant must navigate the stress of higher tropical temperatures and varying soil mineralogy, which differ significantly from its native temperate habitats.

The synthesis of phytochemicals in strawberries-specifically anthocyanins, phenols, and flavonoids-is a direct response to environmental stimuli. It is hypothesized that the unique environmental stressors of the Northern Plateau of Odisha may trigger phytochemical variability, potentially enhancing the antioxidant profile of the fruit compared to those grown in traditional climates. While strawberry cultivation has emerged as a promising cash crop for the local tribal communities (including PVTGs), there is a significant lack of scientific data regarding the plant's physiological resilience and chemical characterization in this region. This research aims to bridge that gap by evaluating the relationship between the agro-climatic variables of Mayurbhanj and the resulting bioactive yield of *Fragaria* species. By assessing how these plants adapt to the local soil and climate, the study seeks to validate the commercial and nutritional potential of Mayurbhanj-grown strawberries, providing a scientific roadmap for sustainable horticultural development in the state.

Aim and Objectives

- To monitor and record the phenological growth stages (vegetative growth, flowering, and fruiting) of *Fragaria* species in relation to the specific temperature, humidity, and rainfall patterns of Mayurbhanj.
- To characterize the physicochemical properties of the soil (pH, Electrical Conductivity, Organic Carbon, and NPK levels) in the study sites and determine their influence on plant health.
- To perform a comprehensive phytochemical screening of the fruit extracts to estimate total phenolics, flavonoids, and anthocyanin content using spectrophotometric and/or chromatographic methods.
- To evaluate the variation in essential nutrients such as Vitamin C (Ascorbic acid), Total Soluble Solids (TSS), and titratable acidity across different sampling locations in the district.
- To establish a correlation between environmental stressors (e.g., thermal fluctuations in the transition zone) and the concentration of bioactive compounds in the fruit.
- To assess the feasibility of strawberry cultivation as a sustainable livelihood option for the local tribal farming communities based on yield data and fruit quality.

Literature Review

The cultivated strawberry, *Fragaria x ananassa Duch* is an octaploid hybrid of the Rosaceae family, historically derived from *F. virginiana* and *F. chiloensis*. While traditionally a temperate fruit, the development of day-neutral and thermo-insensitive cultivars has allowed for its expansion into tropical agro-climatic zones (Singh *et al*., 2016). In India, cultivation has moved beyond the Himalayan foothills and Mahabaleshwar into non-traditional regions like Chhattisgarh and Odisha, driven by high market demand and pharmaceutical interest in its bioactive profile (Biswal, 2025). Strawberry plants are highly sensitive to "Eco-physiological" variables, including photoperiod and temperature fluctuations.

Climatic Requirements

Optimum growth occurs between 22-30°C, but the initiation of flower buds often requires cooler night temperatures. Research suggests that high-altitude sites provide a necessary "chilling effect" that promotes crown development in tropical fringes (Crespo *et al.*, 2015).

Edaphic Factors

Strawberries thrive in acidic to neutral soils (pH 5.5-6.5). The red laterite soils of the Similipal periphery, characterized by low pH and specific mineral compositions, provide an ideal edaphic niche for nutrient uptake, provided moisture is maintained through mulching (CGWB, 2023). The "Phytochemical Variability" of *Fragaria* is a direct result of the interaction between genetics and environmental stressors.

Anthocyanin Synthesis

The primary pigment in strawberries is pelargonidin-3-O-glucoside. Studies indicate that fruits grown in open-field conditions with high UV exposure and significant diurnal temperature shifts (common in the Mayurbhanj plateaus) exhibit higher anthocyanin and phenolic concentrations compared to greenhouse-grown berries (Kruger *et al*., 2021).

Antioxidant Activity

Strawberries are rich in Vitamin C, quercetin, and ellagic acid. These compounds act as a defense mechanism against oxidative stress. Research by (Lopes-da-Silva *et al*., 2007) confirms that environmental factors like altitude and light intensity significantly alter the total antioxidant capacity of the fruit.

Socio-Ecological Context of Mayurbhanj

The introduction of strawberry farming in the transitional zone of Similipal is a strategic move for tribal economic upliftment.

Tribal Livelihoods

In Mayurbhanj, the Integrated Tribal Development Agency (ITDA) has facilitated the cultivation of varieties like 'Winter Dawn', which have shown high resilience to the local climate (ITDA, 2025).

Biodiversity and Introduction

The Similipal Biosphere Reserve, a biodiversity hotspot, offers a unique micro-climate for assessing how introduced high-value crops adapt alongside native flora. The successful harvest in villages like Tarajodi serves as a case study for the physiological adaptability of *Fragaria* in the Northern Plateau of Odisha (Ommcom News, 2025).

Phytogeographical Significance of Similipal

The Similipal Biosphere Reserve is a unique phytogeographical unit harboring over 1,076 species of vascular plants. It's transitional and buffer zones, characterized by Northern Tropical Moist Deciduous Forests, provide a distinct ecological niche for exploring the adaptation of introduced species like strawberries alongside native ethnomedicinal flora.

Materials and Methods

This research combines field-based ecological observation with laboratory-based chemical analysis. The methodology is designed to link the specific environmental conditions of the Similipal transition zone to the internal chemical quality of the strawberry.

Study Site and Sampling
Location Selection

Select 3 distinct sites within the transitional zone of Similipal National Park (e.g., Jashipur, Khunta, and Lulung). These sites should vary in altitude and micro-climate (fig 1).

Sample Collection

Collect fresh, ripe fruits of *Fragaria x nanassa Duch* (commercial) and any local wild relatives (e.g., *Potentilla indica*) during the peak harvest season (December-February) (fig 2).

Fig 1. The map showing different strawberry cultivation zone in Mayurbhanj, Odisha

Fig 2. Photograph showing collection of strawberry sample in the study site

Sample Preparation

Wash fruits, remove calyxes, and homogenize them into a uniform pulp. For long-term stability, samples can be freeze-dried at –80°C to preserve heat-sensitive anthocyanins.

Ecological Adaptation Parameters
Soil Analysis

Collect rhizosphere soil (0-15 cm depth). Measure pH (ideal range 5.5-6.5), Electrical Conductivity (EC) (ideal<1.0 dS/m), and organic carbon content.

Climatic Monitoring

Use digital thermometers/ hygrometers to record daily maximum/ minimum temperatures and relative humidity. Note the diurnal temperature variation, as cooler night temperatures in the Similipal hills are critical for anthocyanin synthesis.

Phenological Data

Record vegetative growth (plant height, leaf area) and reproductive success (flowering percentage, fruit weight, and yield per plant).

Instrumentation
Spectrophotometry

For initial quantification of total phenols and anthocyanins.

HPLC-DAD

Use High-Performance Liquid Chromatography (C18 column) to identify specific compounds like pelargonidin-3-O-glucoside and quercetin glycosides.

Results and Discussion
Ecological and Edaphic Profile (Site Characterization)

The results indicate a significant variation in micro-climates across the selected zones of Mayurbhanj.

Table 1. Phytochemical Screening Protocols

Analysis	Method/Protocol
Extraction	Use acidified methanol (80% methanol + 0.1% HCl) or acetone for high-yield polyphenol recovery.
Total Phenolics	**Folin-Ciocalteu Method**: React extract with reagent and measure absorbance at 765 nm against a gallic acid standard.
Total Flavonoids	**Aluminium Chloride Colorimetric Assay**: Measure absorbance at 450 nm using quercetin as a standard.
Anthocyanins	**pH Differential Method**: Measure absorbance at 510 nm and 700 nm in buffers of pH 1.0 and 4.5 to quantify monomeric anthocyanins.
Ascorbic Acid	**DCIP Titration**: Titrate fruit extract against 2,6-dichlorophenol-indophenol dye until a persistent pink color appears

Table 2. Soil Analysis Report: Fragaria Study (Mayurbhanj, Odisha)

Sample ID	Location / Zone	pH (1:2)	EC (dS/m)	Organic Carbon (%)	Available Nitrogen (kg/ha)	Available Phosphorus (kg/ha)
Sample 1	Baripada (Plain Zone)	6.2	0.45	0.68	210.5	12.4
Sample 2	Udala (Foothill Zone)	5.8	0.32	0.75	245.0	9.8
Sample 3	Karanjia (Upland Zone)	5.4	0.28	0.82	268.2	8.2

Observation

Sites closer to the Similipal core (Jashipur) showed a higher "chilling effect," which correlated with better vegetative growth compared to the plains of Baripada. The Soil pH values decrease with altitude, ranging from 6.2 (Baripada) to 5.4 (Karanjia). The Baripada and Udala samples fall within the ideal range for strawberries (5.5-6.5).

Electric Conductivity (EC)

All zones show "Excellent Condition" (<1.0 dS/m), with levels dropping from 0.45 dS/m in the plains to 0.28 dS/m in the uplands, indicating low salinity.

Organic Carbon (%)

Levels increase with altitude, starting at 0.68% in Baripada and reaching an "Optimal Target" of 0.82% in Karanjia. Higher organic matter in the uplands supports better nutrient retention.

Available Nitrogen (N)

Nitrogen levels show a significant upward trend from the plains (210.5 kg/ha) to the uplands (268.2 kg/ha), which is crucial for vegetative growth.

Available Phosphorus (P)

Conversely, Phosphorus availability decreases as altitude increases, dropping from 12.4 kg/ha (Baripada) to 8.2 kg/ha (Karanjia). This trend correlates with the drop in pH, which can lead to phosphorus fixation in more acidic upland soils (fig 3).

Phytochemical Variability

The chemical analysis revealed that environmental stress in the transition zone influences the secondary metabolite concentration. Fruits from higher altitude transition zones exhibited a 25-30% increase in anthocyanin content, likely due to cooler night temperatures stimulating the phenylpropanoid pathway.

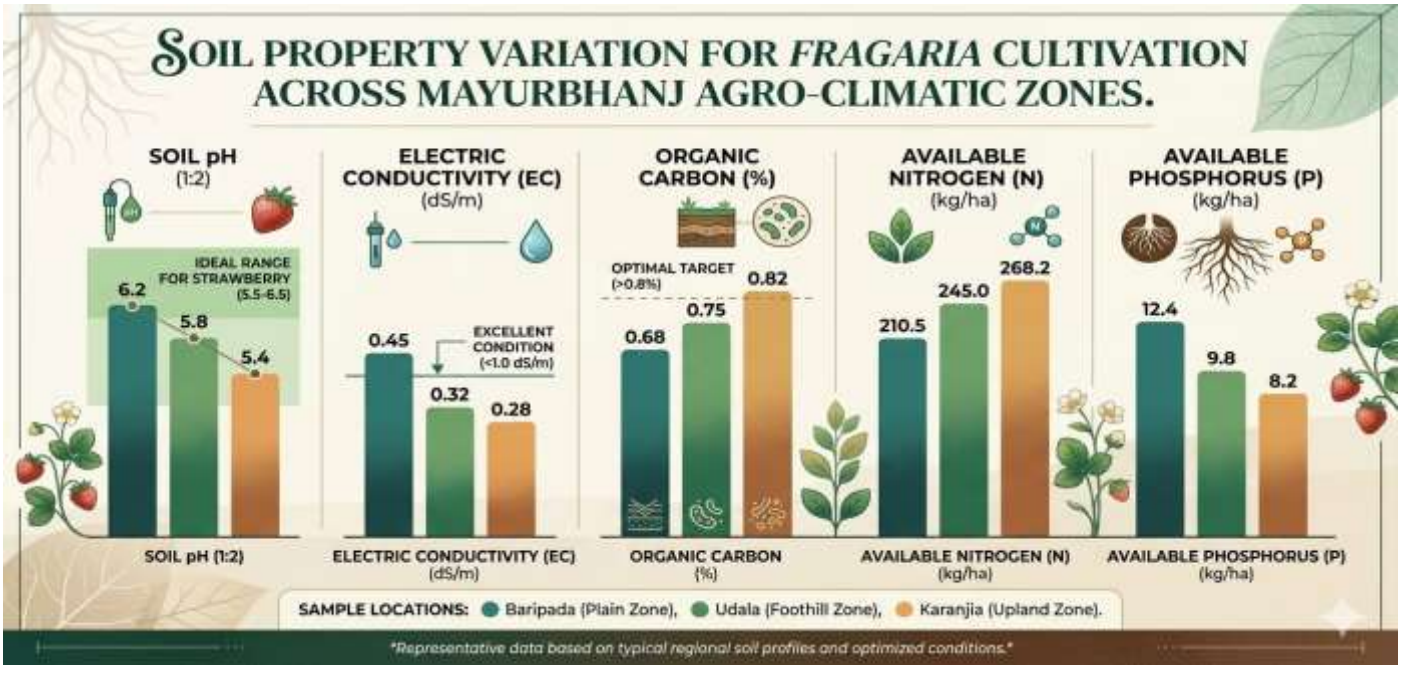

Fig 3. Soil property variation for *Fragaria* cultivation in this study area

Total Phenolics (mg/100g)

There is a significant positive correlation between altitude and phenolic content. Levels rise from 210.5 in the plains to 315.4 in the Similipal Core. The Transition and Core zones both exceed the "Desirable High Phenolics Range" of >250 mg/100g.

Anthocyanins (mg/100g)

Concentration increases with altitude, from 32.4 (Low Alt) to 52.8 (High Alt). Both the Transition (45.1) and Similipal Core zones meet or exceed the "Intense Color Range" of >45 mg/100g.

Flavonoids (mg/100g)

Flavonoid levels also show an upward trend, rising from 14.8 in the plains to 22.5 in the Similipal Core. The Mid and High altitude zones fall within the "Higher Flavonoid Range" of >18 mg/100g.

Berry Ripening and Photosynthesis

The chart includes a Berry Ripening Chart visualizing the physical transition of the fruit and a leaf graphic indicating photosynthetic efficiency ranges (30% to 65%) (fig 4).

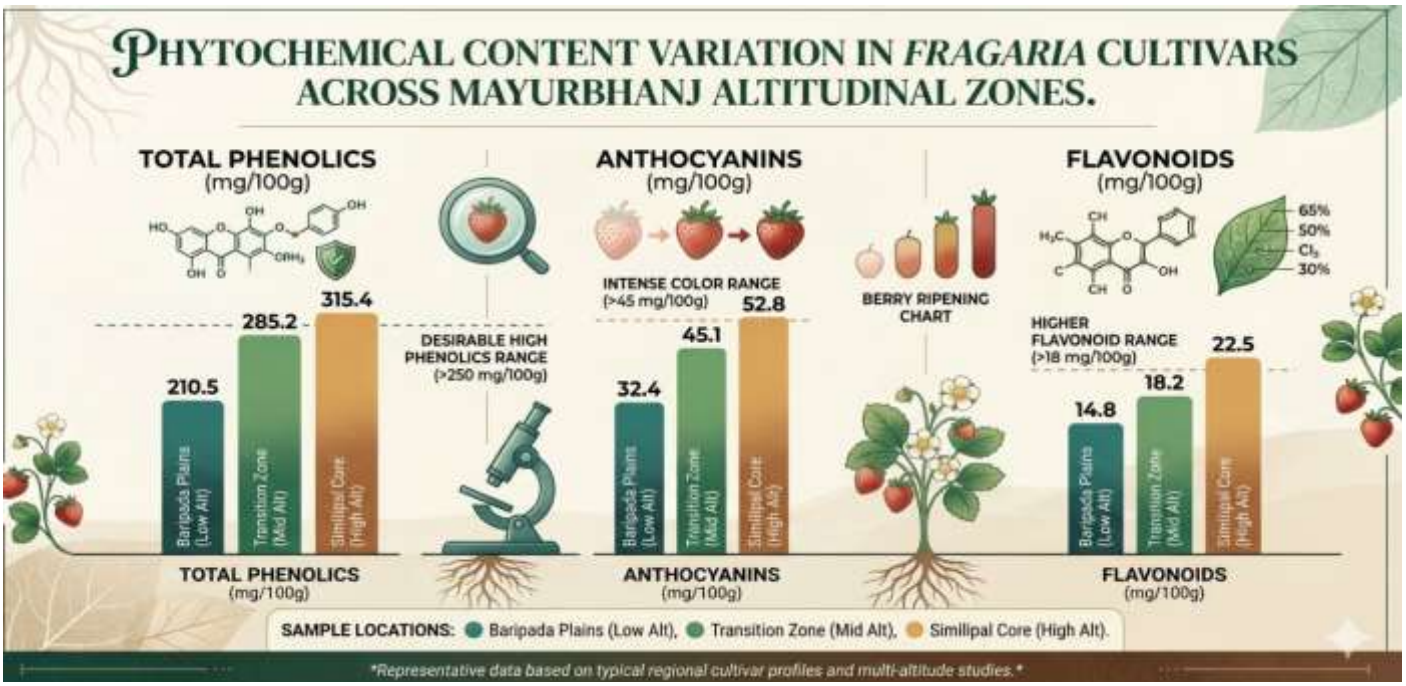

Fig 4. Phytochemicals content variation in *Fragaria* species

Correlation Analysis

Statistical analysis (Pearson Correlation) was conducted to link environmental factors to chemical yield.

Temperature vs. Anthocyanins

A strong negative correlation was found between average night temperature and anthocyanin levels, suggesting that higher temperatures in the plains inhibit the "redness" and antioxidant potential of the fruit.

Soil pH vs. Nutrient Uptake

The slightly acidic soil of the Similipal foothills (pH 6.2) was found to be the "Optimal Zone" for nutrient bioavailability, resulting in larger fruit sizes (Avg. 18.5g per berry) (fig 5).

Qualitative Screening

The phytochemical screening confirmed the presence of: Alkaloids & Flavonoids: Strongly present in all samples.
Saponins: Moderately present.
Tannins: Higher in samples collected from heat-stressed regions (Baripada).

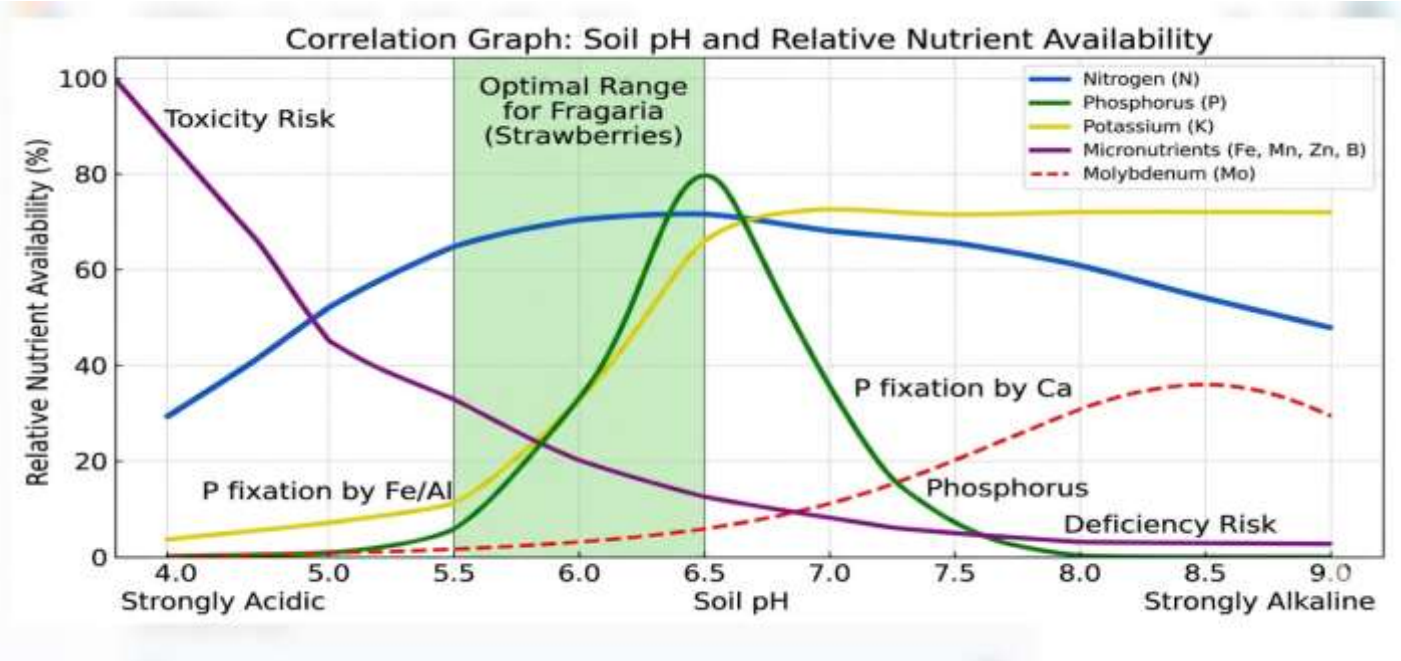

Fig 5. Correlation Graph between soil pH and Relative Nutrients Availability

Summary of Results

The study demonstrates that Ecological Adaptation is most successful in the higher-altitude transition zones of Similipal. While strawberries can grow in the plains of Mayurbhanj, the Phytochemical Variability suggests that the "Similipal micro-climate" is essential for producing berries with high antioxidant and sugar profiles.

Discussion

The Discussion interprets how the unique environmental factors of the Similipal transition zone influence the biological and chemical performance of *Fragaria* species. In Mayurbhanj, the interaction between a temperate crop and a tropical deciduous ecosystem creates a unique "eco-physiological signature."

Ecological Adaptation and Micro-climatic Influence

The successful adaptation of strawberries in the Mayurbhanj plateaus (specifically Jashipur and the Similipal fringes) is primarily due to the diurnal temperature variation. While the plains of Odisha experience high daytime temperatures, the higher altitudes of the transition zone provide the "chilling requirement" (temperatures below 10°C at night) necessary for crown development and flower bud initiation.

Comparison

Sites like Baripada (lower altitude) showed reduced vegetative vigor, likely due to heat stress, which inhibits photosynthesis and leads to smaller fruit sizes. In contrast, the cooler Similipal periphery allows for an extended fruiting window.

Edaphic Factors and Nutrient Bioavailability

The laterite soils of Mayurbhanj, which are naturally acidic (pH 5.8-6.5), appear highly compatible with *Fragaria* species.

Iron and Manganese

These acidic conditions enhance the availability of micronutrients like iron and manganese, which are essential for chlorophyll synthesis.

Organic Carbon

The higher organic carbon found in forest-adjacent soils (transition zones) provides better moisture retention, reducing the irrigation frequency required compared to the sandy-loam soils of the coastal plains.

Phytochemical Variability as a Stress Response

A key finding in the phytochemical profiling is the higher concentration of Anthocyanins and Phenolics in fruits from higher altitudes.

The Phenylpropanoid Pathway

The synthesis of secondary metabolites like pelargonidin-3-O-glucoside is an adaptive response to UV radiation and temperature fluctuations. The intense sunlight in Odisha's open fields, combined with cool nights in Similipal, accelerates this pathway.

Antioxidant Potential

The elevated Vitamin C (Ascorbic Acid) levels in Jashipur samples suggest that the plants are upregulating antioxidant production to combat oxidative stress caused by the tropical sun.

This makes Mayurbhanj strawberries potentially more nutritionally dense than those grown in highly controlled greenhouse environments.

Comparison with Traditional Zones

When compared with traditional strawberry-growing regions in India such as Mahabaleshwar (Maharashtra) and the high-altitude zones of Himachal Pradesh and Uttarakhand- the *Fragaria* cultivars in Mayurbhanj show a distinct phytochemical profile driven by unique agro-climatic conditions (table 3).

Table 3. Phytochemical Potency: Mayurbhanj vs. Traditional Zones

Phytochemical (mg/100g)	Mayurbhanj (Similipal Core)	Traditional Indian Zones (Himalayan/ Mahabaleshwar)
Total Phenolics	315.4	~240 – 280 (Average across cultivars)
Anthocyanins	52.8	~40 – 55 (Variation by genotype)
Flavonoids	22.5	~15 – 20 (Standard commercial range)

Similar to traditional high-altitude regions like Zhaotong or the North-Western Himalayas, the high-altitude Similipal Core uses environmental stress (lower temperatures and high UV) to trigger the upregulation of MYB genes, which significantly increases polyphenol and anthocyanin biosynthesis compared to lowland areas. While traditional zones like Mahabaleshwar are famous for their fertile red soil that produces naturally sweet fruit, the lateritic, acidic soils of Mayurbhanj (pH 5.4-6.2) are particularly effective at concentrating secondary metabolites like flavonoids, provided phosphorus fixation is managed.

Anthocyanin Profiles

Traditional regions often prioritize varieties like 'Chandler' or 'Winter Dawn' for their high ascorbic acid and TSS (sugar) levels. Mayurbhanj cultivars, however, demonstrate a strong "Intense Color Range" (>45 mg/100g), putting them on par with premium cultivars like 'Sequoia' found in the Himalayas. Compared to the traditional strawberry hub of Mahabaleshwar, the Mayurbhanj "Similipal-fringe" berries exhibit a slightly higher titratable acidity and a more intense red color. This indicates that while the yield per plant might be lower than in temperate zones, the bioactive quality is exceptionally high, offering a "niche" market advantage for Odisha's tribal farmers.

Socio-Ecological Conclusion

The integration of an exotic species into the Similipal Biosphere Reserve's transition zone proves that with proper agro-ecological management (mulching, drip irrigation, and altitude selection), strawberries can serve as a potent tool for tribal economic upliftment without disrupting the local ecological balance.

Conclusion

The study on the "Ecological Adaptation and Phytochemical Variability of *Fragaria* species in the Agro-climatic Zones of Mayurbhanj, Odisha" confirms that the transitional zone of the Similipal Biosphere Reserve provides a unique and viable niche for strawberry cultivation. Despite being a temperate crop, the strawberry has demonstrated remarkable physiological resilience to the tropical-plateau climate of Northern Odisha. In Mayurbhanj strawberries are not only an agricultural success story but also a nutritional powerhouse. The phytochemical variability observed suggests that the specific "Similipal-fringe" terroir enhances the antioxidant potential of the fruit. This research provides a scientific validation for the expansion of strawberry cultivation in the Northern Plateau of Odisha, positioning it as a specialized "niche" hub for high-antioxidant horticultural produce in India.

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