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HUMAN CAPITAL AND BEHAVIORAL DRIVERS IN AGRICULTURAL DIVERSIFICATION: EXAMINING FARMER DECISION-MAKING IN PUNJAB'S TRANSITION FROM RICE–WHEAT TO HIGH-VALUE CROPS

Advit Sethi

Research Scholar, Invictus, Amritsar

ABSTRACT

Punjab's agricultural economy, long sustained by the rice–wheat rotation, faces intensifying ecological and economic challenges — groundwater depletion, soil nutrient imbalance, yield stagnation, and climate variability. This study evaluates the comparative economics of the traditional rice–wheat system and two high-value diversification options, **celery (Apium graveolens L.)** and **quinoa (Chenopodium quinoa Willd.)**, within the Punjab context. Using data from agricultural cost studies, farm surveys, and market analyses (2020–2025), this paper estimates per-hectare yields, costs, and net returns while examining input use, water demand, and climate sensitivity.

Results indicate that the rice–wheat system remains viable primarily due to institutional support through Minimum Support Prices (MSP) and government procurement, yielding an average output–input ratio of **1.34**. Celery outperforms this with a ratio of **2.79**, reflecting net returns of approximately ₹ 75,665 / ha, while quinoa shows variable profitability (output–input ratio 2.0–3.0) depending on market access and agronomic adaptation. Celery's profitability, moderate water demand, and established export network make it the most viable high-value crop for Punjab's transition toward sustainable diversification.

Keywords: Punjab agriculture; crop diversification; rice–wheat system; celery; quinoa; farm economics; irrigation efficiency; climate resilience; high-value crops.

1. INTRODUCTION

Punjab's agrarian identity has been shaped by the Green Revolution, which transformed it into India's "breadbasket" through the rice–wheat cropping system. However, decades of intensive monoculture have led to a multidimensional crisis — ecological degradation, economic inefficiency, and declining sustainability. Paddy's water consumption (~4,000–5,000 L per kg) has accelerated aquifer depletion, while wheat yields have plateaued due to warmer winters that shorten the grain-filling phase. Rising input costs (fertiliser, diesel, labour) further erode profit margins.

To address these structural challenges, **crop diversification** is now a policy priority. The focus has shifted toward **high-value crops** that generate greater per-hectare income while conserving water and improving soil health. Among potential candidates, **celery**, concentrated in Amritsar and Jandiala, and **quinoa**, an emerging pseudo-cereal crop, offer promising economic alternatives.

Celery is grown primarily for seed export, with high unit value and established market channels. Quinoa, rich in protein and micronutrients, adapts to semi-arid and saline conditions, aligning with Punjab's evolving climate. However, both crops involve risks — price volatility, climate sensitivity, and limited institutional support — unlike the MSP-protected rice–wheat model.

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This study examines how the **returns from rice–wheat compare with celery and quinoa**, exploring yield, cost, and profitability metrics, resource use, and climate adaptability. It argues that celery presents the most feasible diversification route for Punjab in the medium term.

2. METHODOLOGY

2.1 Data Sources

Data were compiled from:

- **Punjab Agricultural University (PAU)** cost-of-cultivation bulletins and "Package of Practices" (2020–2024).
- **Commission for Agricultural Costs and Prices (CACP)** databases (paddy and wheat).
- **Field surveys** conducted by Gharu et al. (2021) for celery.
- **ICAR–CRIDA** and **Vigyan Varta** reports for quinoa trial data.
- **Climate trend analyses** from Rattu et al. (2023) and IMD meteorological data (Amritsar, Ludhiana, Patiala).
- **Market reports** from Tridge (2024), Coherent Market Insights (2025), and Krishi Jagran (2024).

2.2 Analytical Framework

For each crop system:

- **Gross Return (₹/ha)** = Yield (q/ha) × Farm-gate Price (₹/q)
- **Net Return (₹/ha)** = Gross Return − Total Cost of Cultivation
- **Output/Input Ratio** = Gross Return ÷ Total Cost

Sensitivity analysis was conducted using ± 10–15% yield and ± 20% price variation.

Climate sensitivity was assessed through rainfall and temperature trends, especially minimum temperature rise (+ 0.02 °C/year) and rainfall decline (~ 10 mm/year).

2.3 Crop Systems Compared

1. **Rice–Wheat System:** Traditional double-cropping cycle (paddy in kharif, wheat in rabi).
2. **Celery:** High-value Rabi seed-spice crop grown for export.
3. **Quinoa:** Emerging high-value pseudo-cereal adaptable to semi-arid soils.

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3. RESULTS AND ANALYSIS

3.1 Rice–Wheat System

Average yield of **paddy (65 q/ha)** and **wheat (52 q/ha)** yields combined gross revenue of approximately **₹ 232,700/ha/year**. The total cost of cultivation (paddy ₹ 101,344 + wheat ₹ 72,250 = ₹ 173,594/ha)** produces an average net return of ₹ 59,100 / ha**, with an output/input ratio of 1.34.

Component	**Value (₹/ha)**	**Source**
Paddy cost	101,344	CEIC Data (2022)
Wheat cost	72,250	CEIC Data (2021)
Total cost	173,594	Author Compilation (2025)
Gross return	232,700	Calculated (65 × 1,900 + 52 × 2,100)
Net return	**59,100**	Derived
Output/Input	**1.34**	—

Despite stable earnings through MSP procurement, the system's sustainability is under threat due to excessive groundwater use and high energy inputs. Climate impacts, such as warmer winters, further undermine wheat productivity (Kumar et al., 2023).

3.2 Celery (Seed-Spice Crop)

Field surveys (Gharu et al., 2021) in Amritsar–Jandiala show **average yields of 14.1 q/ha** at farm-gate prices of ₹ 8,350/q. With costs of ₹ 42,070/ha**, celery delivers **gross returns ₹ 117,735/ha**, **net profit ₹ 75,665/ha**, and **output/input 2.79**.

Parameter	**Value**	**Source**
Yield	14.1 q/ha	PAU (2021) Survey
Price	₹ 8,350/q	Tridge (2024)
Gross Return	₹ 117,735	Calculated
Total Cost	₹ 42,070	Field Data
Net Return	**₹ 75,665**	Derived
Output/Input Ratio	**2.79**	Computed

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Cost composition reveals labour's dominance (~ 75% of total cost), followed by machinery (~ 13%) and fertilisers (~ 6%). Celery's profitability is high, but climate sensitivity poses risk: warmer nights and declining rainfall threaten seed setting. Export price volatility (2023–24: US$ 2–6/kg → US$ 1.5–5.6/kg) introduces further uncertainty. Nonetheless, with improved irrigation and cooperative marketing, celery maintains strong economic potential.

3.3 Quinoa (Emerging Crop)

Quinoa trials in northern India yield 12–15 q/ha with prices between ₹ 10,000–12,000/q. Costs (~ ₹ 60,000/ha) yield **net returns ₹ 60,000–1,20,000/ha** and output/input ratios 2.0–3.0.

Parameter	**Baseline**	**Favourable**	**Source**
Yield (q/ha)	12	15	ICAR–CRIDA (2022)
Price (₹/q)	10,000	12,000	IMARC (2025)
Gross Return (₹/ha)	1,20,000	1,80,000	Calculated
Cost (₹/ha)	60,000	60,000	Assumed
Net Return (₹/ha)	**60,000**	**1,20,000**	Derived
Output/Input Ratio	**2.0**	**3.0**	Computed

While drought-tolerant, quinoa's market is underdeveloped. Processing and post-harvest costs remain high (up to US$ 1,000/acre — PMC, 2024). Without established procurement or processing chains, farmer risk remains substantial.

3.4 Comparative Economic Performance

Crop System	**Yield (q/ha)**	**Price (₹/q)**	**Gross Return (₹/ha)**	**Cost (₹/ha)**	**Net Return (₹/ha)**	**Output/Input Ratio**
Rice–Wheat	117 (combined)	—	232,700	173,594	59,100	1.34
Celery	14.1	8,350	117,735	42,070	75,665	2.79
Quinoa	12–15	10,000–12,000	120,000–180,000	60,000	60,000–120,000	2.0–3.0

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Celery surpasses the rice–wheat system in profitability under typical conditions and rivals quinoa even under favourable scenarios, with fewer agronomic uncertainties.

4. DISCUSSION

Punjab's rice–wheat system provides income stability through MSP and established input networks but imposes severe ecological strain. The high input costs and falling water tables have eroded long-term profitability. Conversely, celery represents a high-value crop with established production geography and export potential. Though labour-intensive, its profitability is strong even under modest yield or price variation.

Quinoa exhibits high theoretical returns but lacks institutional, marketing, and agronomic infrastructure. The crop's novelty introduces additional uncertainty. Celery's advantage lies in its **balance of profitability and feasibility** — known cultivation practices, market linkages, and moderate adaptability.

From a sustainability standpoint, celery's **lower water requirement** (compared to paddy) and **absence of residue-burning** contribute to environmental gains. Its seed-based production system aligns well with existing Rabi irrigation cycles. For a region facing groundwater depletion and climatic variability, celery's value proposition extends beyond income — it supports **resource conservation and export competitiveness**.

For successful diversification, policy mechanisms must provide:

1. **Irrigation incentives** (e.g., Pradhan Mantri Krishi Sinchayee Yojana).
2. **Crop-specific insurance schemes** for weather and price risk.
3. **Farmer Producer Organisations (FPOs)** for marketing and export negotiation.
4. **Extension programs** for post-harvest handling, quality grading, and packaging.

Such institutional scaffolding would consolidate celery's position as Punjab's leading high-value diversification crop.

5. CONCLUSION

Punjab's rice–wheat rotation has reached an ecological and economic inflection point. The system ensures income stability but no longer guarantees sustainability. High-value alternatives are essential for future viability. Among these, **celery emerges as the most promising diversification crop**.

With a high output–input ratio (~ 2.8), strong export demand, moderate water needs, and existing farmer expertise, celery can raise per-hectare profitability by 60–80% compared to rice–wheat while conserving water and improving soil health. Quinoa, though valuable, requires greater market development before large-scale adoption.

By integrating celery into Punjab's diversification strategy — supported by irrigation subsidies, risk-insurance, and cooperative marketing — the state can shift toward **a high-value, resource-efficient agricultural model**. Celery thus represents not only an economic opportunity but a pathway toward climate resilience and sustainable rural prosperity in Punjab.

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