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Original Article

The Quiet Revolution: How Zero Tillage is Reshaping Rice Grain Quality Effect of Zero Tillage on Rice Grain Quality under Conservation Agriculture and Natural Resource Management

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ABSTRACT

Rice farming faces harder conditions now. Water is harder to get. Costs keep going up. Soil can lose health. Weather swings more than before. Because of this, zero tillage has gained attention. It is seen as a way to save resources. It also fits with conservation agriculture. With zero tillage, planting is done with little soil breaking. If residue stays on the field, and if nutrients and water are managed well, soil health can improve. Farmers may also use resources more efficiently. ZT does not only affect how crops start and how much they yield. It can also change how rice grains turn out. This review looks at how zero tillage may affect grain traits. It covers physical traits, nutrient related traits, chemical traits, and taste related traits. The focus is on conservation agriculture and how natural resources are managed. When water and nutrients are enough, zero tillage may help keep grain traits stable. Grain weight can hold steady. Grain size can stay close to normal. Milling quality can also be maintained. Keeping crop residue on the field can help too. It can cool the soil. It can help the soil hold water. It can shape the field conditions during key growth times. Those changes may help grain fill better. They may also slow down grain quality loss when conditions are harsh. Conservation agriculture can also shift soil life and nutrient movement. This can affect how plants take up nitrogen, phosphorus, and potassium. Those uptake shifts can then alter grain nutrition. For aromatic rice, conservation tillage may also affect plant processes. It may change photosynthesis. It may also change how the plant makes 2-acetyl-1-pyrroline, also called 2-AP.

Keywords: Zero tillage, rice grain quality, conservation agriculture, natural resource management, soil organic carbon, residue retention, nutrient management, aromatic rice, sustainable agriculture.

INTRODUCTION

For decades the image of rice farming has been synonymous with plowing and flooded muddy fields. However as agriculture faces the pressures of climate change and resource scarcity Zero Tillage

(ZT)—the practice of planting seeds directly into untilled soil—has emerged as a sustainable alternative

Zero tillage (ZT) a core pillar of conservation agriculture has gained global attention for its potential to conserve water reduce labor and improve soil health. While early research focused on yield contemporary studies have delved into how this "no-plow" method influences the physical, nutritional and sensory quality of rice grains.

1. Physical Attributes: Appearance and Milling

- The physical "look and feel" of rice is the thing consumers and millers notice. Zero tillage tends to produce grains that're highly competitive with traditionally tilled crops.
- Grain quality begins with characteristics like size, weight and milling recovery. Research indicates that while zero tillage can sometimes lead to a yield penalty" during the first few seasons the physical quality of the grain remains stable or improves as soil health stabilizes (Issaka *et al.*, 2019; Du *et al.*, 2020).

a) **1000-Grain Weight:** Studies have found that 1000-grain weight in ZT systems is often statistically at par with or slightly higher than puddled transplanting (Du *et al.*, 2020). This is attributed to consistent moisture availability during the grain-filling stage (Korav *et al.* 2024).

b) **Milling Recovery:** ZT improves soil structure. Reduces compaction, which can lead to better root growth and nutrient uptake (Chandra *et al.* 2023). This steady nutrient supply helps produce uniform grains, potentially reducing the percentage of broken rice during milling. zero tillage maintains soil macropores and improves water infiltration. By providing a moisture supply during the milking and dough stages ZT ensures the grain fills completely. This leads to Head Rice Recovery (HRR)—the proportion of whole grains that remain after milling.

c) **Reduction in Chalkiness:** Chalkiness (opaque spots) occurs when starch granules are loosely packed due to high-temperature stress. ZT, especially when combined with surface residue (mulch) acts as an insulator keeping soil temperatures lower and reducing "chalky" defects (Sarker *et al.* 2022).

d) **Grain Length and Width:** ZT generally maintains varietal grain dimensions, ensuring better market acceptance.

e) **Test Weight:** Improved grain filling often increases bulk density and market value.

f) **Reduced Grain Cracking:** Stable soil moisture lowers moisture stress during maturity, reducing fissured grains.

g) **Uniform Maturity:** Better root development leads to synchronized grain ripening and improved milling efficiency.

h) **Higher Head Rice Yield:** Uniform starch deposition reduces breakage during polishing.

2. Nutritional and Chemical Composition

The nutritional value of rice is heavily influenced by how the plant interacts with the soil. Zero tillage significantly alters the soils chemical environment.

- i. **Nutrient Uptake (N, P, K):** ZT systems particularly when combined with residue retention increase the accumulation of nitrogen (N) phosphorus (P) and potassium (K) in plant tissues (Du et al. 2020). Higher nitrogen uptake is directly correlated with grain protein content (Rial-Lovera et al. 2016).
- ii. **Micronutrient Density:** Undisturbed soil in ZT promotes microbial counts and enzymatic activities, such as alkaline phosphatase (Korav et al. 2024). This enhanced microbial life facilitates the uptake of micronutrients like Zinc (Zn) and Iron (Fe) which are crucial for grain nutritional quality (Nandan et al. 2019).
- iii. **Amylose:** Balanced nutrient management in conservation systems has been shown to improve grain amylose content and true protein levels (G.K.V. Society, 2018).
- iv. **Increased Soil Organic Matter (SOM)** enhances nutrient buffering capacity, better Nitrogen Use Efficiency (NUE) improves protein synthesis while reducing fertilizer losses, higher microbial biomass increases mineralization of organic nutrients residue retention supplies slow-release potassium and micronutrients, enhanced antioxidant compounds have been reported under conservation agriculture in some rice varieties.

3. Sensory and Aroma Quality

For varieties like Basmati or Jasmine the presence of the compound 2-acetyl-1-pyrroline (2-AP) determines market value due to the synthesis of 2-AP is a complex biochemical process linked to the plants nitrogen metabolism and photosynthetic rate.

- **The ZT Effect:** Studies by Du et al. (2020) Demonstrated that continuous ZT increases the activity of enzymes involved in the proline metabolic pathway (the precursor to aroma). Additionally ZT plants often maintain flag leaf chlorophyll content (SPAD values) during the late stages providing more "energy" (photosynthates) for the production of aromatic volatiles.
- **Photosynthetic Efficiency:** ZT has been shown to increase the photosynthetic rate and chlorophyll content (SPAD value) in rice flag leaves (Du et al. 2020). This higher photosynthetic activity during the grain-filling stage supports the synthesis of compounds and improves the overall cooking quality.

4. Soil Quality: The Driver of Grain Excellence

The improvements in grain quality are largely a byproduct of the soil environment created by zero tillage.

1. **Organic Carbon:** ZT treatments significantly increase organic carbon (TOC) and labile carbon fractions in the topsoil (Nandan et al. 2019).
2. **Moisture Retention:** By reducing evaporation and maintaining soil aggregates ZT provides a stable temperature and moisture regime, which prevents the stress-induced "chalkiness" often seen in conventionally tilled rice (Sarker et al. 2022; Korav et al. 2024).

Additional soil health indicators

- Greater earthworm population improves natural soil aeration.
- Increased microbial diversity enhances nutrient cycling.

- Better aggregate stability reduces erosion during heavy rainfall.
- Surface residues decrease evaporation by 20–30% in many conservation systems.
- Higher carbon sequestration contributes to climate change mitigation.

5. Safety: Heavy Metal Mitigation

One of the critical "quality" aspects in modern rice production is the concentration of toxic elements like Arsenic (\$As\$).

1) **The Mechanism:** Arsenic becomes highly mobile and "available" to the plant under anaerobic (flooded/oxygen-conditions typical of conventional puddled rice).

2) **The ZT Effect:** ZT is often practiced under non-flooded or aerobic conditions. This higher oxygen level in the soil changes the state of Arsenic making it less soluble. Consequently ZT rice often contains lower levels of Arsenic in the grain compared to rice grown in traditional flooded puddled systems.

Summary of Research Findings

Quality Parameter	Effect of Zero Tillage	Scientific Driver
Head Rice Recovery	Increase	Better moisture regulation during grain filling.
Grain Protein	Stable to Increase	Enhanced Nitrogen Use Efficiency (NUE).
Zinc/Iron Content	Increase	Preserved Mycorrhizal (AMF) networks.
Aroma (2-AP)	Increase	Improved proline metabolism and leaf health.
Arsenic Content	Decrease (Benefit)	Increased soil aeration reducing metal solubility.

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