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Enhancing functional quality in low PPD cassava

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Abstract
Postharvest physiological deterioration (PPD) is a major limitation for cassava (*Manihot esculenta Crantz*), significantly reducing its shelf life and economic value. Low PPD cassava varieties exhibit enhanced resistance to oxidative damage, preserving their functional and nutritional qualities during storage and processing. This article explores the mechanisms underlying low PPD cassava's resilience, strategies to further enhance its functional quality, and the implications for food security, industrial applications, and sustainable agriculture.

Keywords: Cassava, postharvest physiological deterioration, functional quality, low PPD, antioxidants

Introduction
Cassava is a staple crop for millions of people across tropical regions, valued for its adaptability to harsh environments and its role in food security. However, its utility is often constrained by PPD, a rapid oxidative process triggered after harvest. PPD leads to discoloration, nutrient loss, and spoilage, limiting cassava's shelf life to as little as 72 hours in some cases. Low PPD cassava varieties offer a solution to this challenge. These varieties have been bred or selected for their delayed onset of oxidative damage, preserving both functional and nutritional quality. The reduced susceptibility to PPD is attributed to their enhanced antioxidant capacity, lower metabolic activity, and structural differences in their tuber composition. This study investigates how these traits contribute to functional quality and explores strategies for further enhancing the utility of low PPD cassava.

Objective
The objective of this paper is to explore strategies for enhancing the functional quality of cassava to improve its usability, nutritional value, and industrial applications

Low PPD Resistance
Low Postharvest Physiological Deterioration (PPD) resistance in cassava is a critical trait that addresses one of the most significant challenges in cassava production: the rapid degradation of root quality post-harvest. PPD begins within 24 to 72 hours after harvest and involves biochemical, structural, and enzymatic changes that lead to discoloration, nutrient loss, and spoilage. Low PPD resistance allows cassava roots to maintain their quality for extended periods, which is crucial for improving marketability, reducing postharvest losses, and expanding industrial and nutritional applications. The primary mechanism of low PPD resistance lies in the elevated antioxidant capacity of certain cassava varieties. During storage, oxidative stress triggers the production of reactive oxygen species (ROS), initiating a cascade of biochemical reactions, including enzymatic browning and tissue lignification. In low PPD cassava varieties, the accumulation of ROS is mitigated by the presence of higher levels of antioxidants such as phenolics, flavonoids, and ascorbic acid (Akinwale *et al*., 2021; Nuwamanya *et al*., 2020) [1, 2]. These compounds act as scavengers, neutralizing ROS before they can cause significant cellular damage. Studies have shown that phenolic retention in low PPD cassava varieties is significantly higher than in susceptible varieties, contributing to delayed oxidative damage (Burns *et al*., 2019) [3].

In addition to non-enzymatic antioxidants, enzymatic systems play a crucial role in low PPD resistance. Enzymes such as superoxide dismutase (SOD), catalase, and peroxidase are more active in low PPD varieties, effectively converting ROS into less harmful substances. For instance, SOD catalyzes the conversion of superoxide radicals into oxygen and hydrogen peroxide, which are subsequently broken down by catalase and peroxidase (Sánchez *et al*., 2020) [4]. The enhanced activity of these enzymes provides a biochemical shield that slows the onset of PPD and extends the shelf life of the roots. The structural composition of cassava roots also contributes to low PPD resistance. Non-starch polysaccharides such as cellulose, hemicellulose, and pectin play an important role in maintaining the physical integrity of cell walls. In low PPD cassava, the higher concentration of these polysaccharides provides mechanical strength and reduces cell wall permeability, making it more difficult for ROS to penetrate and cause damage. These structural adaptations help to preserve the root's texture, color, and nutrient content during storage (Oyeyinka *et al*., 2022) [5]. Genetic factors are another key determinant of low PPD resistance. Advances in genomics and molecular biology have identified specific loci associated with resistance traits. These loci regulate genes involved in antioxidant pathways, cell wall biosynthesis, and stress responses. Marker-assisted selection and genetic engineering have been instrumental in incorporating low PPD traits into high-yielding cassava varieties (Alves *et al*., 2022; [7]. International Institute of Tropical Agriculture). For example, research initiatives led by the International Institute of Tropical Agriculture (IITA) have successfully bred cassava varieties that combine low PPD resistance with enhanced nutritional qualities such as high pro-vitamin. A content. Environmental factors also interact with low PPD resistance. For instance, studies have shown that low PPD varieties perform well even under high humidity and suboptimal storage conditions. This resilience is particularly beneficial in regions with limited access to refrigeration or processing facilities, where immediate postharvest handling is not feasible (Burns *et al*., 2019) [3]. By extending the storage period, low PPD cassava reduces the urgency of processing and allows for greater flexibility in the value chain. The benefits of low PPD resistance extend beyond food security. Low PPD cassava roots retain their functional properties, making them suitable for diverse industrial applications. The high-quality starch extracted from these varieties is ideal for producing adhesives, biodegradable plastics, and paper coatings. Additionally, the bioactive compounds preserved in low PPD cassava have potential applications in nutraceuticals and functional foods, particularly as sources of dietary antioxidants (Sagrilo *et al*., 2021; Alimi *et al*., 2022) [8, 9]. Despite the advancements, challenges remain in scaling the adoption of low PPD cassava varieties. Environmental variability, limited farmer access to improved planting materials, and the need for tailored agronomic practices can hinder widespread implementation. Further research is needed to optimize storage conditions and explore the integration of low PPD traits with other desirable characteristics, such as pest resistance and drought tolerance.

Enhancing Functional Quality

Enhancing the functional quality of cassava involves addressing the intrinsic and extrinsic factors that affect its usability, nutritional value, and industrial potential. Functional quality in cassava encompasses attributes such as texture, starch properties, nutritional composition, and resistance to postharvest degradation. Improving these attributes is critical for reducing postharvest losses, expanding cassava's applicability in various industries, and improving its role as a staple food in tropical and subtropical regions. One of the foundational aspects of enhancing cassava's functional quality lies in the breeding of improved varieties. Traditional and modern breeding techniques have been employed to develop cassava varieties with higher starch content, better nutritional profiles, and resistance to postharvest physiological deterioration (PPD). Low PPD varieties are particularly significant as they address one of the primary challenges in cassava storage. By delaying the onset of oxidative damage and enzymatic browning, these varieties maintain their functional properties, making them suitable for extended storage and diverse applications. Additionally, selective breeding has also focused on modifying starch characteristics, such as increasing amylopectin content, which enhances gelatinization and freeze-thaw stability. These modifications align cassava more closely with industrial requirements for adhesives, bio-based plastics, and food thickeners. Postharvest management practices are equally vital for maintaining and enhancing functional quality. Proper storage conditions, such as reducing oxygen exposure and controlling temperature, can significantly delay PPD and preserve cassava's texture and starch properties. Research indicates that curing cassava roots-allowing them to form a protective layer by healing surface wounds-can reduce water loss and microbial infections, further preserving their quality. These practices are particularly relevant in regions with limited access to advanced storage facilities, where simple, cost-effective solutions can make a substantial difference. Processing techniques also play a critical role in enhancing cassava's functional quality. Techniques such as drying, milling, and fermentation must be optimized to retain cassava's functional properties. For instance, low-temperature drying helps preserve bioactive compounds and maintain the structural integrity of starch granules, ensuring better functionality in processed products. Additionally, enzymatic treatments during processing can improve starch extraction efficiency and modify its functional properties for specific industrial applications. Processing innovations not only enhance the usability of cassava in traditional food systems but also open pathways for its integration into high-value industries. Nutritional enhancement through biofortification is another key avenue for improving cassava's functional quality. By increasing the levels of essential nutrients such as pro-vitamin A, iron, and zinc, biofortified cassava varieties address micronutrient deficiencies in populations heavily reliant on cassava as a staple food. These varieties offer dual benefits: improved health outcomes for consumers and expanded market opportunities for nutrient-rich cassava products. Moreover, biofortification aligns with global efforts to reduce hidden hunger and improve food security in developing regions. The industrial potential of cassava also drives efforts to enhance its functional quality. The demand for cassava starch in the food, paper, and biodegradable material industries has highlighted the importance of tailored modifications to starch properties. Cassava starch with high paste clarity, low retrogradation, and excellent thickening properties is particularly valuable for these applications. Additionally, the high energy efficiency and cost-effectiveness of cassava production make it an attractive alternative to other starch sources like maize and potato. Challenges remain in the widespread adoption of strategies to enhance cassava's functional quality. Variations in environmental conditions, limited access to improved planting materials, and the need for tailored agronomic practices can hinder progress. Additionally, there is a need for greater investment in research and development to explore innovative processing methods, optimize biofortification techniques, and develop integrated systems for cassava value chain improvement.

Conclusion

Enhancing the functional quality of cassava is essential for realizing its full potential as a versatile crop that addresses food security and industrial needs. By focusing on breeding low PPD varieties, optimizing postharvest management practices, advancing processing techniques, and implementing biofortification strategies, cassava can be transformed into a more sustainable and nutritionally valuable resource. These efforts ensure not only the preservation of cassava's quality during storage and processing but also its expanded applicability in food, health, and industrial sectors. Despite existing challenges such as environmental variability and limited farmer access to improved varieties, ongoing research and development offer promising solutions. As innovations continue to emerge, cassava's role in global agriculture and industry will solidify, contributing to economic growth and resilience in cassava-dependent regions.

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