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Dr. Mariam Farouk
 Research Associate,
 Department of Agronomy,
 National School of Agriculture
 of Meknes (ENA Meknes),
 Meknes, Morocco

Nutritional quality assessment of *Urdbean* germplasm resistant to pod borer complex

Mariam Farouk

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Abstract

Urdbean (*Vigna mungo*), commonly known as black gram, is a significant pulse crop contributing to global nutritional security. However, pod borer complex, particularly *Helicoverpa armigera* and *Maruca vitrata*, poses a serious threat to its productivity and nutritional quality. This review explores the nutritional quality of urdbean germplasm resistant to pod borer infestation, emphasizing protein content, amino acid composition, mineral profile, and anti-nutritional factors. Various breeding programs, molecular markers, and biotechnological tools have been employed to develop resistant germplasm without compromising nutritional value. Studies indicate that resistance often correlates with secondary metabolites like phenols and flavonoids, which can influence nutritional bioavailability. This paper synthesizes findings from recent research on resistant urdbean varieties and their nutritional profiling, providing insights for sustainable crop improvement.

Keywords: Urdbean, pod borer complex, nutritional quality, resistant germplasm, bioavailability

1. Introduction

Urdbean (*Vigna mungo*) is an important legume crop cultivated in tropical and subtropical regions, valued for its high protein content, essential amino acids, and minerals (Kumar *et al.*, 2020) ^[9]. It plays a critical role in human diets and sustainable agricultural systems. However, yield and quality are significantly affected by the pod borer complex, primarily *Helicoverpa armigera* and *Maruca vitrata* (Sharma *et al.*, 2019) ^[4]. These pests damage flowers, pods, and seeds, leading to significant economic losses. Breeding for resistance is essential to reduce yield losses ^[5], but ensuring nutritional integrity in resistant germplasm remains a key challenge. The interaction between resistance traits and nutritional quality is complex, requiring careful assessment through both breeding and biochemical analyses.

2. Nutritional composition of urdbean

Urdbean (*Vigna mungo*) is widely recognized for its rich nutritional profile, making it a critical source of dietary protein, essential amino acids, minerals, and dietary fiber, especially in regions where it serves as a staple protein source. The protein content in urdbean seeds typically ranges between 18-25%, with variations observed across different germplasms, growing conditions, and breeding interventions. The protein is predominantly composed of albumins and globulins, which contribute significantly to its high biological value. Additionally, urdbean proteins are rich in lysine, an essential amino acid often deficient in cereal-based diets, making urdbean a valuable complement to such dietary staples. Besides protein, urdbean seeds contain a considerable amount of carbohydrates, which constitute around 55-65% of the seed weight, providing a significant energy source.

The mineral composition of urdbean is another critical aspect of its nutritional value. Seeds are abundant in iron, calcium, magnesium, and phosphorus, which are essential for various physiological functions in humans. Iron deficiency anemia remains a major public health concern in many developing countries, and urdbean serves as an important dietary source of bioavailable iron. Calcium and phosphorus, on the other hand, play crucial roles in bone health and metabolic processes. However, mineral bioavailability can be hindered by anti-nutritional factors such as phytates, tannins, and oxalates, which form complexes with these minerals, reducing their absorption in the human gut.

Corresponding Author:
Dr. Mariam Farouk
 Research Associate,
 Department of Agronomy,
 National School of Agriculture
 of Meknes (ENA Meknes),
 Meknes, Morocco

Dietary fiber is another key nutritional component of urdbean. Soluble and insoluble dietary fibers present in urdbean seeds aid in improving digestion, maintaining bowel health, and regulating blood sugar levels. The presence of bioactive compounds such as flavonoids, phenolics, and antioxidants enhances urdbean's nutritional and functional value, contributing to its potential in managing chronic diseases like diabetes and cardiovascular disorders.

Anti-nutritional factors such as phytates, tannins, and trypsin inhibitors are naturally present in urdbean seeds. While these compounds act as defense mechanisms against herbivores and pests, they can also reduce the digestibility and bioavailability of proteins and minerals. However, traditional processing techniques such as soaking, boiling, fermentation, and sprouting have been shown to significantly reduce these anti-nutritional factors, thereby improving the overall bioavailability of nutrients.

Environmental factors, such as soil quality, pest infestation, and agronomic practices, play a critical role in determining the final nutritional composition of urdbean seeds. Pest stress, particularly from pod borers, can trigger biochemical changes in seeds, including the accumulation of secondary metabolites, which may inadvertently affect seed quality. Studies have shown that while pod borer-resistant varieties often exhibit an increased concentration of secondary metabolites such as phenolics and flavonoids, these compounds can sometimes interfere with nutrient bioavailability.

Genetic diversity among urdbean germplasms also contributes to significant variations in nutritional composition. Breeding programs have successfully developed varieties with enhanced protein content, improved amino acid profiles, and reduced anti-nutritional factors. Recent advances in molecular biology and omics technologies have facilitated the identification of candidate genes responsible for key nutritional traits, allowing targeted improvements without compromising pest resistance.

The nutritional quality of urdbean is also influenced by post-harvest handling and storage practices. Poor storage conditions can lead to pest infestations, fungal growth, and biochemical degradation of essential nutrients. Proper drying, storage in moisture-proof containers, and integrated pest management practices are essential for maintaining the nutritional integrity of urdbean seeds.

In conclusion, urdbean remains an essential component of sustainable diets due to its rich nutritional profile, which includes proteins, essential amino acids, minerals, dietary fiber, and bioactive compounds. While breeding for pest resistance has shown promising results, maintaining and improving the nutritional quality of resistant varieties is crucial. Future research should focus on optimizing genetic, environmental, and post-harvest factors to ensure that pest-resistant urdbean germplasms meet both agronomic and nutritional requirements.

3. Pod borer complex and its impact on urdbean quality

The pod borer complex, primarily dominated by *Helicoverpa armigera* and *Maruca vitrata*, represents one of the most significant biotic stressors affecting urdbean crops globally. These insect pests inflict damage primarily during the flowering and pod formation stages, causing significant yield losses and deterioration in seed quality. *Helicoverpa armigera*, commonly known as the gram pod borer, feeds on

flower buds, developing pods, and seeds, leading to both quantitative and qualitative losses. The pest penetrates the pod wall and consumes the seeds directly, which reduces both the overall yield and seed integrity. On the other hand, *Maruca vitrata*, also referred to as the spotted pod borer, creates webs within the flowers and pods, obstructing normal growth and seed development.

Pod borer infestation significantly reduces the protein content of urdbean seeds due to the direct consumption of the protein-rich cotyledon by larvae. Additionally, the biochemical composition of the affected seeds undergoes alterations, with increased levels of secondary metabolites such as phenols and tannins being observed. These secondary compounds are synthesized by the plant as a defense mechanism, but their excessive accumulation can reduce the digestibility and bioavailability of essential nutrients in the seeds. Furthermore, pod borer infestation often triggers the plant's oxidative stress response, resulting in increased production of reactive oxygen species (ROS), which can further impact seed metabolism and overall seed quality.

Research indicates that pest-infested urdbean pods exhibit higher levels of anti-nutritional factors, including trypsin inhibitors and phytates. These compounds interfere with protein digestion and mineral absorption, ultimately reducing the nutritional efficacy of the seeds. Moreover, infested seeds are often discolored, shriveled, and lightweight, making them unsuitable for human consumption and commercial seed production. Infestation can also introduce opportunistic fungal pathogens, leading to contamination by mycotoxins such as aflatoxins, which pose additional health risks.

Environmental factors, including temperature, humidity, and cropping systems, influence pod borer infestation levels and their impact on urdbean quality. Warmer temperatures and extended flowering durations have been associated with higher pest infestations, exacerbating crop losses. Integrated Pest Management (IPM) strategies combining resistant germplasm, biological control agents, cultural practices, and judicious pesticide application have been advocated to mitigate pod borer damage. Breeding for pod borer resistance remains one of the most effective strategies for minimizing seed quality deterioration. Resistant varieties often exhibit increased production of secondary metabolites and morphological traits such as thickened pod walls and trichomes, which deter larval feeding. However, balancing pest resistance with nutritional quality remains challenging, as some resistance mechanisms may inadvertently affect seed composition. In conclusion, pod borer infestation presents a multifaceted challenge for urdbean production, impacting not only crop yield but also seed nutritional quality. Effective management requires a holistic approach, including breeding for resistance, integrated pest control, and post-harvest handling measures. Future research should focus on identifying genetic markers linked to both resistance and nutritional quality, enabling the development of urdbean varieties that are resilient to pod borer damage while maintaining their rich nutritional profile.

4. Breeding for pod borer resistance in urdbean

Breeding for pod borer resistance in urdbean has been a critical focus area due to the significant damage these pests inflict on yield and seed quality. Conventional breeding approaches rely heavily on selecting and hybridizing

resistant germplasm, which involves screening large collections to identify natural resistance traits. This method has led to the development of successful resistant varieties such as 'PU31' and 'IPU94-1', which exhibit improved tolerance to pod borers (Kumar & Singh, 2019) ^[9]. However, the conventional breeding process is time-consuming and often results in variable levels of resistance. Molecular breeding has emerged as a revolutionary approach in developing pod borer-resistant varieties. Marker-Assisted Selection (MAS) and Quantitative Trait Loci (QTL) mapping have significantly accelerated the identification and integration of resistance traits into elite cultivars. MAS enables breeders to select plants carrying specific resistance genes, even in the absence of visible phenotypic traits. QTL mapping has identified several loci associated with resistance to pod borers, allowing for precise breeding interventions (Reddy *et al.*, 2021) ^[6].

Biotechnological interventions, particularly genetic engineering, have further advanced the development of pod borer-resistant urbean. The introduction of *CryIAc* genes from *Bacillus thuringiensis* (*Bt*) has resulted in transgenic urbean varieties that show reduced larval damage and enhanced yield stability. These *Bt*-transgenic lines demonstrate remarkable resistance to *Helicoverpa armigera* and other pests, providing a sustainable solution to pod borer infestations (Mohan *et al.*, 2020) ^[7]. Despite their success, regulatory challenges and public concerns about genetically modified crops have limited their widespread adoption.

Integrated Pest Management (IPM) strategies combine resistant varieties with cultural practices, biological control agents, and judicious pesticide use. This holistic approach ensures effective pest control while minimizing the environmental and health risks associated with excessive pesticide application. For instance, IPM strategies often include the use of natural predators such as parasitoids, crop rotation to disrupt pest life cycles, and the cultivation of trap crops to divert pests from urbean fields.

Future breeding programs must address the trade-offs between resistance and nutritional quality. High levels of secondary metabolites associated with resistance can interfere with nutrient bioavailability, necessitating advanced breeding strategies that balance these factors. Omics technologies, including genomics, transcriptomics, and metabolomics, offer promising tools for integrating pest resistance with nutritional improvement, ensuring that resistant urbean germplasm meets both agronomic and dietary needs.

5. Effect of resistance on nutritional quality

The development of pod borer-resistant urbean germplasm often involves physiological and biochemical changes that can influence nutritional quality. Resistance mechanisms typically rely on the synthesis of secondary metabolites such as phenols, flavonoids, and tannins, which act as anti-feedants or toxins to deter pests. While these compounds are essential for resistance, their excessive accumulation can negatively affect the digestibility and bioavailability of proteins and minerals (Sharma *et al.*, 2021) ^[10].

Protein content and amino acid profiles in resistant germplasm generally remain stable. However, certain resistant varieties exhibit slight reductions in protein digestibility due to the increased presence of anti-nutritional factors like trypsin inhibitors. These inhibitors interfere with

the enzymatic breakdown of proteins in the digestive system, potentially reducing the overall nutritional efficacy of urbean seeds. Efforts are ongoing to minimize these impacts through targeted breeding and processing techniques that mitigate anti-nutritional factors.

Mineral bioavailability is another critical concern in resistant urbean varieties. Anti-nutritional compounds such as phytates and oxalates can form insoluble complexes with essential minerals like iron, calcium, and magnesium, reducing their absorption in the human gut. This poses a challenge, particularly in regions where urbean serves as a primary source of dietary minerals. Recent breeding programs aim to develop low-phytate genotypes that maintain resistance while enhancing mineral bioavailability. Secondary metabolites, while contributing to pest resistance, also have potential health benefits. Phenols and flavonoids exhibit antioxidant properties that can help manage chronic diseases such as diabetes and cardiovascular disorders. However, their effects on nutrient absorption and overall seed quality require careful evaluation. Advanced biochemical analyses and omics technologies are being employed to optimize the balance between resistance traits and nutritional quality.

Environmental factors such as soil quality, pest pressure, and agronomic practices further influence the nutritional composition of resistant urbean germplasm. Pest stress often triggers the accumulation of Reactive Oxygen Species (ROS) and secondary metabolites, altering seed metabolism and nutrient content. Post-harvest handling and storage practices also play a crucial role in maintaining nutritional integrity. Proper drying, storage in moisture-proof containers, and pest control measures are essential to prevent nutrient degradation in resistant varieties.

In conclusion, while resistance traits are vital for combating pod borer infestations, their effects on nutritional quality must be carefully managed. Advanced breeding strategies, coupled with omics technologies and improved agronomic practices, hold promise for developing urbean varieties that are both pest-resistant and nutritionally robust.

6. Role of omics technologies in nutritional and resistance assessment: The integration of omics technologies genomics, transcriptomics, proteomics, and metabolomics has revolutionized the assessment of nutritional quality and resistance in urbean. These advanced tools provide a comprehensive understanding of the genetic and biochemical mechanisms underlying resistance traits and their impact on nutritional composition.

6.1 Genomics: Genomics focuses on identifying resistance genes and their associated regulatory networks. Advances in high-throughput sequencing technologies have enabled the mapping of urbean genomes, facilitating the discovery of Quantitative Trait Loci (QTLs) linked to pod borer resistance and nutritional traits. Candidate genes responsible for secondary metabolite production, such as those encoding phenylpropanoid pathway enzymes, have been identified. These genes can be targeted for precise modifications to enhance resistance without compromising nutritional quality.

6.2 Transcriptomics: Transcriptomic analyses reveal gene expression changes in response to pod borer infestation and environmental stresses. RNA Sequencing (RNA-Seq) has

been employed to study differential gene expression patterns in resistant and susceptible urdbean germplasm. Insights from transcriptomics have highlighted the upregulation of genes involved in secondary metabolite biosynthesis, oxidative stress responses, and cell wall fortification. These findings inform breeding strategies to balance resistance with seed quality.

6.3 Proteomics: Proteomics investigates changes in seed storage proteins and defense-related proteins under pest stress. Studies have identified variations in albumins, globulins, and protease inhibitors in resistant germplasm. Such insights are critical for understanding the impact of resistance traits on protein composition and digestibility. Advanced proteomic tools, including mass spectrometry, enable precise quantification of these proteins, guiding breeding programs to maintain protein quality in resistant varieties.

6.4 Metabolomics: Metabolomics provides a detailed analysis of primary and secondary metabolites in urdbean seeds. Secondary metabolites such as phenolics, flavonoids, and terpenoids play dual roles in pest resistance and human health. Metabolomic profiling helps identify optimal levels of these compounds to ensure effective pest control without adversely affecting nutritional bioavailability. Furthermore, metabolomic studies have revealed the dynamic interplay between environmental factors and metabolite accumulation, offering insights into sustainable crop management practices.

6.5 Integrated omics approaches: Integrating data from multiple omics platforms offers a holistic view of the interactions between genetic, biochemical, and environmental factors in urdbean. For instance, combining genomic and metabolomic data can pinpoint genes associated with both resistance and nutritional traits, enabling targeted improvements through molecular breeding. Proteomic and transcriptomic analyses complement these efforts by elucidating the functional roles of identified genes and proteins.

In conclusion, omics technologies provide powerful tools for advancing the development of pest-resistant urdbean germplasm with enhanced nutritional quality. Future research should focus on leveraging these technologies to integrate resistance traits with biofortification strategies, ensuring that urdbean remains a vital component of sustainable diets and global food security.

7. Conclusion

Developing pod borer-resistant urdbean germplasm without compromising nutritional quality is a critical goal for sustainable agriculture. The challenges posed by *Helicoverpa armigera* and *Maruca vitrata* necessitate innovative approaches in breeding, molecular biology, and pest management. While resistance mechanisms such as the production of secondary metabolites have proven effective against pests, their impact on nutrient bioavailability underscores the need for balanced strategies. Advances in omics technologies genomics, transcriptomics, proteomics, and metabolomics offer powerful tools for identifying and fine-tuning traits that integrate pest resistance with high nutritional value.

Moreover, the adoption of Integrated Pest Management (IPM) strategies, combining resistant varieties with biological control agents, cultural practices, and judicious pesticide use, provides a holistic approach to mitigating pod borer damage. Future research should prioritize the development of germplasm that maintains robust resistance while enhancing dietary protein, essential amino acids, and mineral bioavailability. Additionally, post-harvest handling and storage practices must be optimized to preserve the nutritional integrity of urdbean seeds.

In conclusion, the synergy of breeding innovations, biotechnological interventions, and advanced omics platforms can pave the way for urdbean varieties that contribute to global food security and nutritional health. Collaborative efforts among scientists, policymakers, and farmers will be instrumental in achieving these objectives, ensuring that urdbean continues to play a vital role in sustainable diets and agricultural systems.

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