



Transforming Food Systems through Circular Economy for Enhanced Security, Nutrition, and Innovation

Johan Esteban Villamil-Galindo^{1,2*}

¹Instituto de Tecnología de Alimentos - Facultad de Ingeniería Química-Universidad Nacional del Litoral, Santa Fe, Argentina

²Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina

***Corresponding Author:** Johan Esteban Villamil-Galindo, 1Instituto de Tecnología de Alimentos - Facultad de Ingeniería Química-Universidad Nacional del Litoral and Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina.

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The rapid global population growth, expected to reach approximately 9 billion people by 2050, presents an urgent need for a secure, nutritious, and reliable food supply. However, this challenge is compounded by the fact that, according to the World Bank, approximately 9% of the world's population currently lives in extreme poverty. The Food and Agriculture Organization of the United Nations (FAO) estimates that around 811 million people worldwide suffer from chronic malnutrition. Paradoxically, while hunger and food insecurity persist, it is alarming to note that approximately 13% of the world's food is lost within the supply chain, from post-harvest stages to the retail level. Additionally, another 17% is wasted in households, catering services, and retail, as reported by the United Nations (UN). What exacerbates the situation further is that nearly 30% of greenhouse gas emissions are attributed to the food sector. These statistics underscore the critical need for global efforts to address food loss and waste, not only to ensure food security but also to reduce the environmental footprint of our food systems.

The complex challenges posed by these issues have spurred efforts to find effective solutions, particularly in developing countries. Policies, research initiatives, and extensive international collaboration have been dedicated to developing sustainable and replicable models for addressing these interconnected environmental and food security concerns. In this context, the concept of the circular economy has emerged as a promising solution with the potential to tackle food security challenges comprehensively and sustainably.

The circular economy approach necessitates a fundamental revaluation of the entire food supply chain, spanning from production and distribution to consumption and waste management. Firstly, the circular economy promotes the adoption of sustainable agricultural practices that minimize reliance on agrochemicals and prioritize the responsible use of natural resources. This encompasses the implementation of regenerative farming techniques, the efficient management of water resources, and the preservation of biodiversity. By reducing dependence on external inputs and en-

hancing the resilience of agricultural systems, the circular economy contributes to ensuring future food availability.

Furthermore, the circular economy encourages the cultivation of local crop varieties, providing an opportunity to harness the nutritional, bioactive, and economic potential of native fruits and vegetables in each region. Many of these indigenous crops remain underexplored, despite compelling evidence of their valuable attributes.

Another vital aspect of the circular economy approach is the reduction of food waste at every stage of the supply chain. This involves measures to prevent, reduce, and repurpose food waste, addressing both economic and environmental aspects of sustainability. Addressing food waste within the circular economy framework necessitates the implementation of a multifaceted approach. This approach encompasses several key components, including the adoption of more efficient production practices, enhancements to storage and distribution systems, and the elevation of consumer awareness regarding the significance of minimizing food waste. Efforts to reduce food waste yield multiple benefits. Notably, they serve to maximize the nutritional value of food and ensure its availability for those who are most in need. By mitigating waste, valuable resources are conserved and the overall sustainability of the food system is improved.

Additionally, attention has turned to the management of non-avoidable waste, such as inedible parts generated during the industrial processing of fruits and vegetables. The scientific community has increasingly focused on studying and understanding the composition and potential applications of all the biomass generated by these processes. Bioprospecting studies have even been undertaken to explore the pharmacological and nutraceutical potential of these waste materials. These efforts signify a commitment to achieving greater resource efficiency, reducing environmental impact, and harnessing untapped value within the food supply chain. In doing so, they align with the principles of the circular economy and contribute to more sustainable and resilient food systems.

The global challenge of malnutrition extends beyond mere food scarcity, encompassing issues related to poor dietary choices and a growing epidemic of chronic degenerative diseases. However, a solution lies in the revaluation of agro-industrial waste to harness high-value bioactive compounds. Leveraging biotransformation techniques involving enzymes, yeasts, and microorganisms enables the expansion of production chains and the creation of circular processes that yield safe food, renewable energy, and functional, bioactive ingredients. Comprehensive biomass utilization not only curtails environmental impacts but also initiates a virtuous cycle of production. At each juncture where value is added to the chain, more employment opportunities are generated, fostering regional growth. The incorporation of innovative technologies reduces production timelines and costs, facilitating access to sustainable food and nutraceutical supplements for lower-income populations. The circular economy emerges as a holistic and sustainable approach to tackle global food security challenges. By adopting sustainable agricultural practices, curbing food waste, and valorising waste streams, it becomes possible to guarantee the availability of sufficient, nutritious food for both current and future generations. This transformation is a testament to the potential for innovative, envi-