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Systematic Review

Valorizing Fruit and Vegetable Waste: The Untapped Potential for Entrepreneurship in Sub-Saharan Africa—A Systematic Review

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Abstract: Valorizing food waste (FW) in sub-Saharan Africa (SSA) can enhance the efficiency of limited resources, make healthy diets more affordable, and foster the creation of innovative enterprises. The vast quantities of FW from the agri-food chain significantly threaten food security. To address this issue and maximize potential environmental and socio-economic benefits, valorizing waste, a value-adding process for waste materials, has emerged as a sustainable and efficient strategy. Valorizing FW reduces greenhouse gas emissions, mitigates climate change, enhances resource efficiency, and improves planetary health. As a pivotal player in the transition toward the circular economy, this study investigates the potential of converting FW into value-added products, offering entrepreneurial opportunities for SSA's unemployed youth. A systematic literature review is conducted to identify and filter relevant articles over five years by applying inclusion and exclusion criteria. A total of 33 articles were included for in-depth analysis to address the study's aim. The findings highlight a range of value-added products derived from FW, including renewable energy sources, nutraceuticals, and heavy metal adsorbents. These products present promising entrepreneurial prospects within SSA. Nonetheless, overcoming barriers to FW valorization adoption is crucial for fully realizing its potential as a profitable business avenue.

Keywords: bioactive compounds; circular economy; food waste; sustainable innovation; food security

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1. Introduction

Food security is fundamentally about ensuring everyone has regular access to enough high-quality food to lead active, healthy lives. Agri-food waste (AFW) undermines this goal by diverting resources that could be used to feed the hungry. According to several studies, approximately one-third of food is lost or wasted throughout the agricultural and agri-food chain (AFC) [1,2]. This loss is attributed to various unsustainable practices. The extent of FW and its origins differ across regions; for example, an estimated 61 million tons is wasted annually in America, 92.4 million tons annually in China, and 102.5 million tons each year in the European Union [3], with Canada contributing 35.5 million tons [4], the Kingdom of Saudi Arabia 1.7 million tons, Australia 4 million tons [5,6], and South Africa about 10.2 million tons [7]. Degradable organic substances, which make up about 40–70% of the total global municipal solid waste (MSW), are predominantly found in the organic fraction of municipal waste (OFSMW), with FW being a significant portion [8].

This food could feed the world's growing population, especially in regions with prevalent hunger and malnutrition. Reducing AFW is critical to improving food availability and accessibility for deprived communities. The environmental impact of FW is also profound and multifaceted. Furthermore, AFW in landfills contributes to the emission of greenhouse gases (GHG), including methane, a potent greenhouse gas that exacerbates climate change. The economic implications of AFW are astounding. The global annual cost of AFW is 1 trillion US dollars. This loss may decrease food availability and increase prices, limiting access to food for many low-income consumers. This encompasses the lost value of the food itself and the wasted labor, energy, and other inputs involved in its production, distribution, and disposal. Nearly 40% of municipal solid waste (MSW) in SSA is in landfills, exerting pressure on the environment. Traditionally, in low- and middle-income countries, AFW, for example, is often directly converted into animal feeds. At the same time, a substantial quantity is diverted to composting as the conversion technology [9]. Due to pressure to eliminate hunger by 2030, the rising cost of food insecurity and undernourishment, including limited employment opportunities, is on the rise in sub-Saharan Africa [10].

As the world's population grows, agricultural food production will also increase, resulting in unavoidable and avoidable AFW [11–13]. This will consequently necessitate adequate management of AFW along the agri-food production chains. Waste, in general, if not properly managed, has devastating effects on the environment and the social and economic well-being of the population [13]. Sadly, as the world faces threats of food insecurity and the reality of not meeting the United Nations Sustainable Development Goals (SDGs) by 2030, 40% of annual agricultural produce will be wasted along the AFC [14]. Furthermore, the Food and Agricultural Organization (FAO) estimates that between 702 and 828 million people face malnutrition due to poor access to nutritious food [10]. The adverse effects of AFW on the well-being of populations necessitate implementing mitigating measures to find alternative value-added uses [15].

Fruits and vegetables (VFs) can be eaten for nutritional well-being [16]. Rich in essential nutrients, including vitamins, minerals, and antioxidants, FVs can reduce malnutrition by addressing dietary deficiencies. Their high fiber content aids digestion and regulates blood sugar levels. At the same time, their hydration properties prevent dehydration, which is crucial in regions such as SSA with limited access to clean water. Moreover, these foods boost immune function and reduce the risk of chronic diseases such as heart disease and diabetes. Additionally, their affordability and accessibility make them practical solutions for improving undernourishment and overall health and well-being. Fruit is the edible fleshy/succulent part of some plants, which can be sweet or non-sweet in its raw form [14]. On the other hand, vegetables are the edible portions of a plant that can be eaten, such as leaves, stems, tubers, roots, and bulbs. The inedible parts of fruits and vegetables constitute the peels, stalks, pulp, leaves, pomace, and seeds, as shown in Figure 1. Classifying food as edible or inedible is based on various reasons. For example, blemishes in the skin of some fruits, as shown in Figure 1, and agrochemicals from conventional agricultural production have potential health risks, often leading to non-consumption and discarding due to social or cultural reasons.

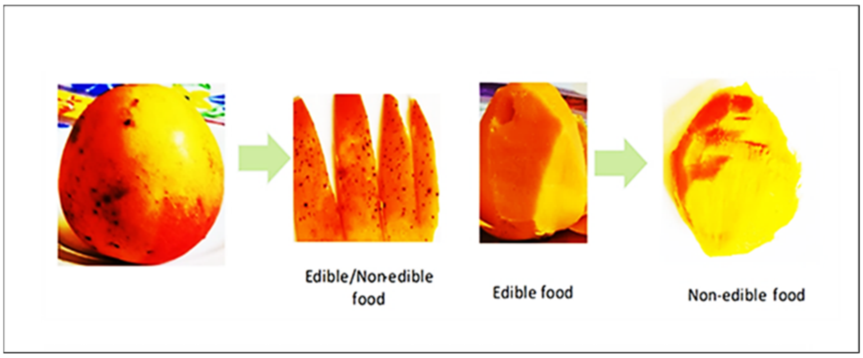

Figure 1. An illustration of the edible and non-edible parts of a fruit, a mango.

Definitions of Food Waste

There is no universally agreed-upon definition of FW in the literature. Just as various factors influence its generation, the definition also varies by market, sector, or the specific purpose of a scientific inquiry [17]. According to the FAO, food loss and waste (FLW), collectively referred to as wastage, represent the edible parts of plant or animal products that people do not consume. In 2019, the FAO redefined FLW as the decrease in quantity or quality of food along the value chain. In this context, food loss (FL) is perceived as a product of unintended outcomes, whether managerial, technical, or due to improper handling. These may include food damaged during harvesting, transportation, or due to lack of infrastructure, including packaging, which is often discarded, disposed of, or incinerated [14]. In contrast, food waste (FW) refers to deliberate decisions to discard food, mainly at the AFC's retail and consumer stages. According to the FAO's definitions, the inedible food parts and those destined for upcycling for commercial purposes, such as industrial or animal feed, are excluded from the definition despite having implications for food security, nutrition issues, and environmental impacts.

Alternative definitions of FW include those of Food Use for Social Innovation by Optimizing Waste Prevention Strategies (FUSIONS), which include both the edible and inedible parts of food in the definition. Accordingly, "FW is any food, and inedible parts of food, removed from the value chain to be recovered or disposed of" [18]. The definition does not distinguish FL from FW but does so between food surplus (FS) and FLW. FS is an essential component of the AFC and is fit for human consumption, but it could still end up as waste if prevention or reuse is not implemented. Other institutions, such as the Economic Research Service of the US Department of Agriculture, have provided definitional frameworks, considering only the edible parts of foodstuffs as waste [19].

The High-Level Panel of Experts on Food Security and Nutrition [20] defined food loss and waste (FLW) as a decrease in food at all stages of the AFC from harvest to mass consumption, food initially intended for human consumption, regardless of the cause. This definition distinguishes between FL before the consumption and FW at the consumption levels irrespective of the reasons. The World Resources Institute (WRI) defines FW as "food and associated inedible parts" diverted from the value chain to a destination where they are not further valorized [21]. The European Union, on the other hand, defines FW as any food items discarded from the food supply chain due to economic or aesthetic factors or because they are nearing the 'use by' date. Despite being perfectly edible and suitable for human consumption, these items are ultimately disposed of if no alternative use is found [22]. Despite attempts by various institutions to harmonize concepts related to FW, definitions still differ, making it challenging to develop a consistent framework for FW based on the life cycle of the food items in various geographical regions, causing barriers towards sustainable optimization of FW [23–25]. Without consensus on a precise definition, while acknowledging the various reports, Teigiserova et al. [26] proposed using food surplus, loss, and waste (FSLW). They argue that there is a distinction between the natural inedibility of some food parts, such as bones, peels, and seeds, and inedibility due to degradation or spoilage (avoidable). Both cannot be consumed by humans, resulting in waste.

The current review focuses on fruit and vegetable waste (FVW) at the secondary production (industrial processing residues) and at the consumer levels of AFC, which is critical in the context of the current work. We adopt the term 'food waste', representing all types of wastage along the AFC; therefore, the acronym 'FW' will represent fruit and vegetable waste. The focus on FV waste streams stems from the high volume of this waste stream in SSA, attributed to increased production to meet the rising demand [26–29]. In 2019, the FAO estimated wastage in SSA to be 40% to 50%, a significant percentage given their nutritional content [19]. Furthermore, in SSA, both farmed and wild fruits are plentiful, resulting in a substantial amount of wastage in the form of inedible parts such as peels, stalks, pulp, seeds, and pomace. Furthermore, oil-yielding crops, leafy vegetables, and tubers are produced in large quantities and generate significant waste [30].

2. Literature Review

2.1. Global Perspectives of FW: Quantities and Challenges

The United Nations Sustainable Goals set out a target to halve FW by 2030; nonetheless, the amount of FW generated along the AFC continues to increase globally, as mentioned in Section 1, especially in SSA countries where wastage occurs in more significant quantities with perishable commodity groups such as FVs. Sadly, this loss threatens food security because these foods are critical for human well-being as economies grow and diets diversify. Regardless of where it happens, FW is undesirable from a socio-economic point of view, and its prevalence in SSA is a concern for obvious reasons. First, it negatively impacts the nutritional status of rural low-income communities. Secondly, FW optimization can contribute to high income and better livelihoods [11,31] by diversifying enterprises and creating secondary markets that utilize alternative resources of the circular economy (CE). Finally, less wastage results in better food security, reduced environmental impacts, and lower carbon emissions, including waste management across the AFC. Therefore, strengthening alternative destinations for otherwise underutilized food fractions is crucial to avoid further land expansion that would otherwise be utilized for food production in landfills [32].

The amount of FW along the AFC is governed by different dynamics associated with unsustainable concepts [2,33–35]. The overall scale of FW and its sources vary across various geographical regions. For example, approximately 61 million tons are wasted annually in America, 92.4 million tons per year in China, 102.5 million tons per year across the European Union [36], 35.5 million tons per year in Canada [4], 1.7 million tons per year in the Kingdom of Saudi Arabia, 4 million tons per year in Australia [5,6], and approximately 10.2 million tons per year in South Africa [7]. Of the total global municipal solid waste (MSW), about 40–70% contains degradable organic material, often called organic fraction municipal waste, of which FW is the major component [8]. In China, for example, fruit and vegetable waste accounted for 21% of MSW [37].

Due to either a lack of financial or technical proficiency during harvesting, FW occurs at the early stages of the value chain in SSA and is influenced by several factors [38–40], which include poor road conditions, market accessibility, packaging, and distance to markets, including inadequate transport systems, and accounts for 44% of global FW [10]. Poor road conditions, for example, contribute to bruising, while long-distance travel in poorly maintained vehicles and overloading and other conditions abstract the shelf-life of numerous FVs. In South Africa, however, FW at the pre-consumer level is relatively low compared with the rest of SSA countries due to well-organized transportation infrastructure for agricultural products [41]. Despite global and regional differences, FW on farms includes inappropriate timing of harvesting, overproduction, underutilization of products, climatic conditions, handling, and transportation practices, including postharvest technology [42].

The economic burden of wastage from the AFC amounts to approximately USD 680 billion in industrialized countries and USD 310 billion in low- and middle-income countries, respectively [14]. The FAO report further estimates FW's direct financial, environmental, and social costs at 1 trillion, 700 billion, and 900 billion, respectively. Greenhouse gas (GHG) emissions are estimated to account for 8–10% of global emissions [43,44]. These figures will likely increase due to the world's rapid population growth, projected at 9.6 billion by 2050. This will exert added pressure on AFC across the globe. Thus, without sustainable prevention and mitigation strategies, increased food production will be reflected in increased GHG emissions through deforestation, as land is cleared for food production. This wastage represents the most significant type of waste entering landfills [45], which exacerbates climate change. Accordingly, diverting this waste from landfills has become a priority, considering their negative impacts on GHG emissions and other environmental challenges.

Although FW threatens food security, it can be considered a valuable resource for the CE, as it contains value-added components/compounds. The CE concept has become an umbrella body, guiding principles for environmental management matters and demonstrating noticeable progress in applying various waste streams, such as the organic fraction of municipal solid waste. Several countries are actively implementing prevention and mitigation measures to reduce FW globally. However, alternative consumption models and novel waste valorization technologies are needed in SSA [46]. Interventions targeting FW reduction in SSA, if any, often result in unintended consequences for the environment, food security, and human nutrition as contrasting benefits from various strategies compete. The best way to address FW or identify optimal intervention technologies remains unresolved, which provides a "golden" opportunity for entrepreneurship.

2.2. Sources of FW

FW is generated in all stages of the AFC but under different circumstances, as shown in Figure 2. Despite global regional differences, reasons for FW along the AFC persist, and several factors influence it, including population income, urbanization, customary practices, economic growth, or consumer behavior and values, including attitude [47]. FW also occurs at the retail and household levels in high-income economies and other industries, such as the food industry. High-income economies are responsible for 56% of global FW, and 40% of this occurs during the consumption stage and is influenced by consumer behavior and values, including lifestyle changes [48]. In SSA, FW occurs mainly in the early stages of the AFC due to poor road conditions, market accessibility, inadequate disinfection, packaging, distance to markets, and lack of processing and drying facilities, including inefficient transport systems, which account for 44% of global FW [49]. Poor road conditions, for example, contribute to bruising, while long-distance travel in poorly maintained vehicles and overloading abstract the shelf-life of numerous FVs. In South Africa, harvesting technology is comparable to the European Union (EU) standards, with well-organized transportation infrastructure. Despite this, FW persists [41].

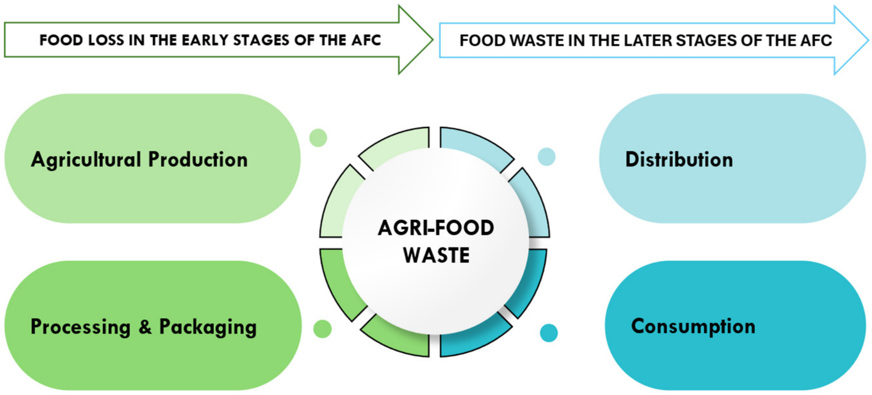

Figure 2. A schematic representation of food waste along the AFC (source: adapted from Hoehn et al. [50]).

During processing and packaging, FW can result from equipment malfunction or human error or due to the limited shelf-life of produce, insufficient handling, and storage [10,27]. Wastage may also increase because of high food prices due to production costs and weak or non-existent incentives for FW prevention and mitigation measures [51]. Nonetheless, the United Nations Environment Programme (UNEP) estimates that approximately 931 million tons of food are wasted each year, the majority of which comes from retailing, households, processing/canning plants, and food services [52] and accounts for 44% of global waste by commodity [53–55]. FW contributes about 20%, while other food items, such as cereals, contribute about 19%.

2.3. An Overview of the Waste Valorizing Concept

Valorizing FW is not new and has been practiced for many years [56]. However, in recent years, there has been renewed interest in valorizing FW, attributed to increased waste generation and landfilling, depletion of natural resources, and the need for more sustainable, cost-effective, and environmentally friendly waste management [1,57,58]. Valorizing FW into value-added products has created a way into a CE for many countries; however, limited studies examine FW valorization in SSA, particularly as a source of entrepreneurial opportunities for unemployed youth. SSA is a region characterized by high unemployment and poverty rates. As a result, creating business opportunities through valorizing FW is a strategy that researchers and policymakers must implement in the region to move a step closer towards a circular economy.

As the global amount of FW increases, finding alternative valuable uses for waste material can maximize resources and contribute to alternative revenue streams, particularly in low-income economies [30,49]. FW valorization includes converting or repurposing waste materials into value-added products such as biofuel, livestock feed, bio-fertilizers, and other value-added products [56–59]. These products are generated through several conversion processes, including hydrolysis, hydrothermal carbonization (HTC), fermentation, and anaerobic digestion (AD).

Thus, valorizing material from FW contributes to or enables a CE concept that seeks to keep raw materials (such as farm produce) in a closed-loop system [60–62]. This maximizes resource use, reduces the need for new resources, avoids waste, and extends the product life cycle [63]. Several authors, scholars, and institutions have conceptualized a food recovery hierarchy, summarizing conventional and alternative FW management methods to promote sustainable FW management, as shown in Figure 3. The model's preferred actions are "prevention and reduction" and "repurposing and recycling", while "landfilling or incineration" is the least preferred.

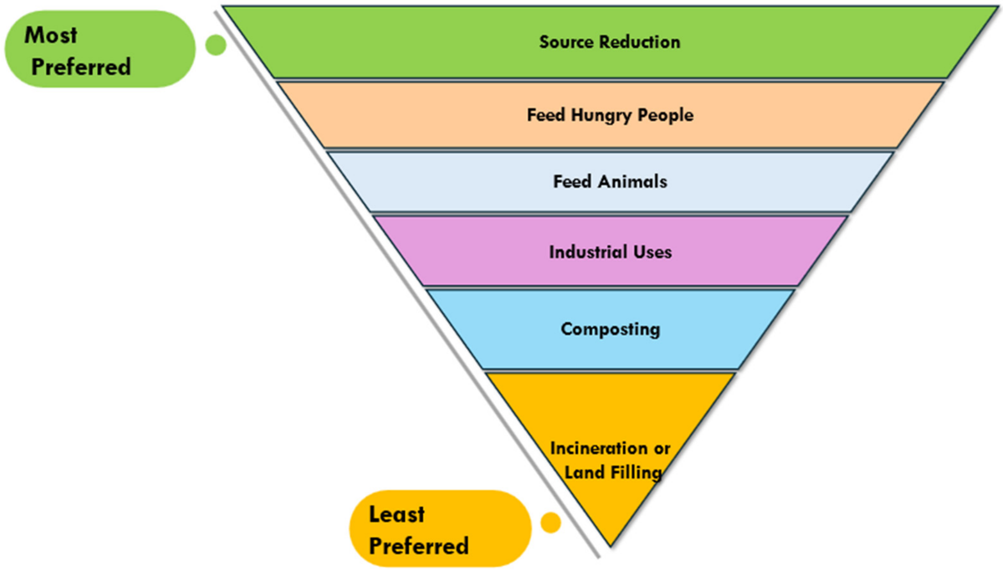

Figure 3. Adapted from The U.S. E.P.A. Food Recovery Hierarchy (FRH), this diagram lists strategies to address food waste in descending order of preference.

3. Conceptualizing the Potential Benefits of Valorizing FW in SSA

As mentioned in Section 1 of this review, despite food insecurity matters and other health challenges such as undernourishment and food insecurity in SSA, a significant amount of FW still prevails along the AFC. Noticeably, there is little in the literature about the region's quantity, quality, or application of innovative valorizing techniques. Moreover, excluding some aspects of FW matters from statistical deliberations (FW occurring in rural and peri-urban areas) is also a concern. Regardless, the implications of FW highlight the urgent need for long-term solutions that include not only finding optimization and mitigation strategies but also identifying FW valorizing approaches that can be applied in the SSA context as a means of entrepreneurship opportunity. These two solutions could bring the SSA closer to a circular bioeconomy and achieving the United Nations (UN) Sustainable Development Goals (SDGs), especially Goals 1 to 3 [64].

Existing research on FW, including pre-and post-consumer waste, tends to focus on quantification, drivers, and environmental consequences [65]. Typically, FW has been measured in physical terms using tons as reporting units, which is useful in estimating the environmental impacts but does not consider the possible economic gains of the various commodities by-products. Although it is necessary to eliminate or reduce FW, there has been an inadequate focus on understanding the trade-offs faced by various stakeholders across the ASC [24], specifically in SSA. Another research gap in SSA is that most studies on FW do not focus on developing innovative technology for repurposing FW as occurs within the European Union (EU) and in some emerging economies (BRICS) such as India, China, and Brazil. In SSA, the emphasis is on preventing and managing municipal solid wastes rather than FW. For example, a literature search on the valorization of FW shows that literature on the topic is very scarce and far between.

As a result, it is alarming that there is a paucity of literature on the valorizing FW to value-added. Furthermore, this region needs urgent food insecurity, nutrition interventions, and job creation opportunities, including establishing innovative small business enterprises. Data on FW valorization is only beginning to emerge. However, it is still insignificant compared to the wastage of cereals and grains in the region [66]. FW plays a crucial role in the transition toward the CE, a fact that has gained significant traction in academic discourse over the past six years. FW is a rich source of untapped enterprise opportunities, and different waste treatment strategies can significantly impact its resource potential. The environmental impact of these treatment technologies is also a key aspect of FW resource efficiency.

Study Objectives

The specific objectives are as follows:

- To investigate global practices by exploring and analyzing laboratory studies and international endeavours focused on valorizing FW into value-added products, particularly on successful examples from diverse geographical contexts.
- To evaluate the feasibility of FW valorization in sub-Saharan Africa, considering resources and infrastructure.
- To outline actionable pathways for sustainable economic development and job creation in the region.

4. Methodology

To address the objectives of the study, a systematic literature review (SLR) was used [67]. A systematic literature review allowed for a rigorous, impartial, and literature-wide assessment of existing studies covering FW management, impacts, and valorization techniques. Google Scholar and WoS databases were used to retrieve the relevant publications because of their wide coverage of peer-reviewed articles [68]. The literature search was limited to peer-reviewed publications published between 2017 and 2022. The six years were considered because of the increased global awareness of FWL reduction, prevention, and the use of waste products as starting materials to create products with higher added value. The relevant publications in the two databases were searched using the following keywords: 'food waste' AND 'bioactive compounds' AND 'valorization' AND 'circular economy'.

The results from the two queried databases were screened and filtered using inclusion and exclusion criteria. Publications were included if they met the following criteria: (i) sound scientific and empirical design (e.g., quantitative, qualitative, and experiments), (ii) studies focused on fruit and vegetable waste and valorization, and (iii) studies published in English between 2017 and 2022. Publications were excluded from analysis if they focused on other types of food waste or characterization, used non-open access publications, were dissertations/theses, or were written in other languages.

5. Results and Analysis

Based on the keywords used to query the databases, 1630 articles were identified for this paper. After removing 1074 duplicates, 556 unique titles and abstracts remained. After applying the inclusion criteria, 523 articles were excluded after screening their titles and abstracts (Figure 4).

In total, 33 publications fit the study's objective and were included for further in-depth analysis. The analysis of the included articles revealed that most of the studies on FV waste valorization came from the EU region (N = 19), followed by South and Central America (N = 6). Both Asia and Africa had fewer studies on FV waste valorization. There were three studies from Asia, particularly India (N = 3), while African studies were fewer (N = 2). There were three studies that were not country or region-specific (N = 3). The high number of papers from the EU highlights the advancement in FSWL reduction management and the repurposing of FW into value-added by-products. Conversely, the results indicate a need for more effort in FW reduction management and repurposing, particularly in FV waste.

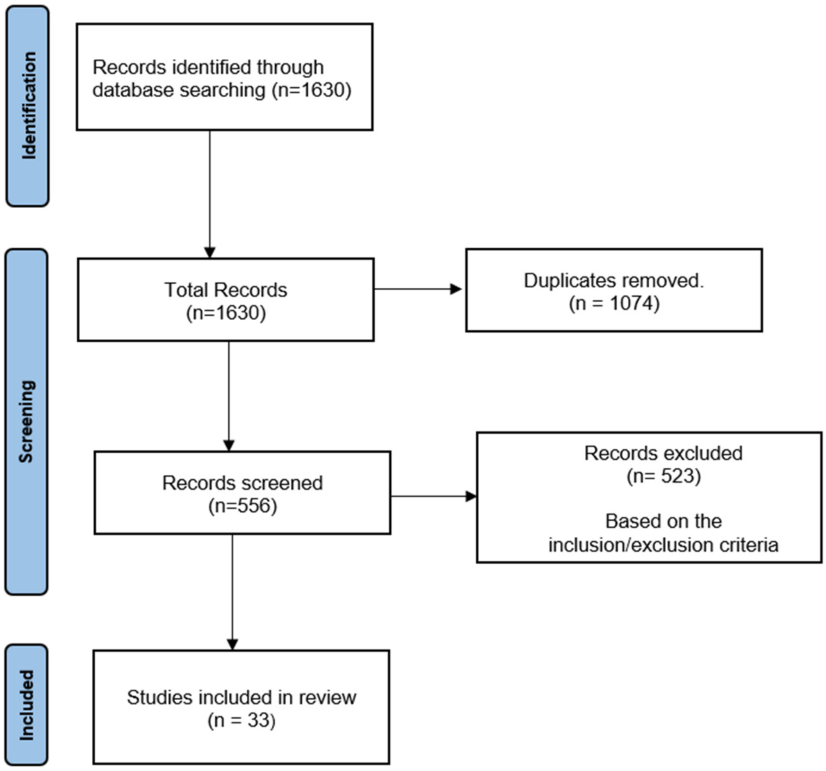

Figure 4. The flowchart of the literature search.

From the analysis of the articles reviewed, FW valorization was mainly used to produce bioactive compounds. Minerals, fatty acids, polyphenols, flavonoids, pigments, and other value-added products are examples of bioactive compounds extracted from FW. The most common vegetables in the FW used in the studies were cabbage, leek, carrots, celery, olive leaves, potato, lettuce, shallots, onion (red, white, yellow), and red pepper. In the fruit category, avocado, orange, apple, pear, kiwi, persimmon, grapes, mango, lychee, pomegranate, raspberry, cherry, banana, melon, pineapple, soursop, pitahaya, and mandarin were all mentioned. Table 1 shows case studies on FW valorization in different geographical regions. The article analysis identified several FW valorizing techniques and potential applications. These include FV valorization for green energy production, nutraceuticals, heavy metal adsorbents, biomaterials, and livestock feed production. SSA cultivates most of these fruits and vegetables, except for soursop, pitahaya, and persimmon. The subsequent section delves into leveraging valorizing technology to enhance the potential of those abundant in SSA.

Table 1. A sample of profiles of materials produced from FVW in different geographic regional blocs (lab-scale/pilot studies).

European Unuion (EU)							
	Title of Paper	**Fruit and Vegetable (FV) Waste Source**	**FV Residue**	**Value Added Component/Bioactive Compounds**	**Recovery Method**	**By-Product**	**Author(s)**
1	Integrated management of residues from tomato production: Recovery of value-added compounds and biogas production in the biorefinery context	Tomatoes (*Solanum lycopersicum*)	Tomato residues (rotten, green and immature stems, branches and leaves)	β-carotene and lycopene, carotenoids, fiber, phenolic compounds, pigments, carbohydrates, volatile compounds, and phenolics: gallic acid; carotenoids: lycopene	Physical and chemical	Biogas Nutraceuticals Cosmetic industry Textile industry Pharmaceutical industry	[69]
2	Turning Agri-Food Cooperative Vegetable Residues into Functional Powdered Ingredients for the Food Industry	Cabbage and leek		Antioxidant properties, phenolic compounds, carotenoids, and fiber	Physical and chemical	Food industry Health products	[70]
		Carrot and celery sticks	Sticks				
		Olive leaves					
3	Avocado Peels and Seeds: Processing Strategies for the Development of Highly Antioxidant Bioplastic Films	Avocado (*Persea americana*)	Peel and seeds	Pectin, cellulose, hemicellulose, and starch	Physical Chemical	Biomaterials, Food industry Cosmetic and pharmaceutical industries	[71]
4	Towards food circular economy: hydrothermal treatment of mixed vegetable and fruit wastes to obtain fermentable sugars and bioactive compounds	(Orange, apple, pear, banana, and kiwi) + (potato, tomato, lettuce, onion, and red pepper)	A mixture of fruits and vegetables	Polyphenols antioxidants	Hydrothermal treatment	Biotechnology Food industry Pharmaceutical industry	[72]
5	Waste streams in onion production: Bioactive compounds, quercetin and use of antimicrobial and antioxidative properties	Onion (*Allium cepa*) Red onion	Edible parts	Quercetin	Chemical	Nutraceuticals	[73]
			Inedible parts				
		Yellow onion	Edible parts				
			Inedible parts				
		White onion	Edible parts	No quercetin			
			Inedible parts				
		Shallots (*Allium cepa* gr)	Edible parts	Quercetin			
			Inedible parts				

Table 1. *Cont.*

European Unuion (EU)							
	Title of Paper	**Fruit and Vegetable (FV) Waste Source**	**FV Residue**	**Value Added Component/Bioactive Compounds**	**Recovery Method**	**By-Product**	**Author(s)**
6	Exploitation and Valorization of Agro-Food Wastes from Grape Harvesting: Production, Characterization of MAE-Extracts from Vitis vinifera Leaves and Stabilization in Microparticulate Powder Form	Grapes (*Vitis vinifera*)	Leaf extracts from two cultivars of *Vitis vinifera* Aglianico (Agl) and Greco di Tufo (Gre)	Phenolic compounds (quercetin and kaempferol)	Physical: Chemical	Health industry	[74]
7	The Impact of Torrefaction Temperature on the Physical-Chemical Properties of Residual Exotic Fruit (Avocado, Mango, Lychee) Seeds	Mango (*Mangifera indica*), lychee (*Litchi chinensis*), avocado (*Persea americana*)	Seeds	(Polyphenols and essential nutrients)	Physical: Chemical	Green energy	[75]
8	Ultrasound-Assisted Extraction of Flavonoids from Kiwi Peel: Process Optimization and Bioactivity Assessment	Kiwi (*Actinidia deliciosa*)	Peel	Phenolic compounds, antioxidant and antimicrobial capacities	Physical: Chemical	Food industry Health industry	[76]
9	Identification of punicalagin as the bioactive compound behind the antimicrobial activity of pomegranate (*Punica granatum* L.) peels	Pomegranate (*Punica granatum* L.)	Peels	Phenolics: ellagic acid, gallic acid, punicalin, punicalagin; carotenoids, antimicrobial activity	Physical: Chemical	Food industry Pharmaceutical industry	[77]
10	Biowaste as a Potential Source of Bioactive Compounds-A Case Study of Raspberry Fruit Pomace	Raspberry (*Rubus idaeus*)	Pomace	Antioxidant compounds	Physical: Chemical	Food industry Pharmaceutical industry	[78]
11	Anti-Inflammatory Effects of Pomegranate Peel Extracts on In Vitro Human Intestinal Caco-2 Cells and Ex Vivo Porcine Colonic Tissue Explants	Pomegranate (*Punica granatum* L.)	Peel extracts	Polyphenols; phenolics: ellagic acid, gallic acid, punicalin, punicalagin; carotenoids, antimicrobial activity	Physical: Chemical	Pharmaceutical industry	[79]
12	Evaluation of Industrial Sour Cherry Liquor Wastes as an Ecofriendly Source of Added Value Chemical Compounds and Energy	Cherry (*Prunus avium*)	Pomace sour cherry liquor	Polyphenolic content and antioxidant activity, cyanidin-3-O-glucoside, (+) catechin and (−)Epicatechin, and phenolic acids	Physical: Chemical	Nutraceutical formulations	[80]

Table 1. *Cont.*

	Title of Paper	Fruit and Vegetable (FV) Waste Source	FV Residue	Value Added Component/Bioactive Compounds	Recovery Method	By-Product	Author(s)
European Unuion (EU)							
13	Investigation on High-Value Bioactive Compounds and Antioxidant Properties of Blackberries and Their Fractions Obtained by Home-Scale Juice Processing	Blackberries (*Rubus*)	Pomace	Polyphenolic compounds antioxidants	Physical: Chemical	Food industry	[81]
14	Novel Adsorbent Based on Banana Peel Waste for Removal of Heavy Metal Ions from Synthetic Solutions	Banana (*Musa*)	Peel	Banana peel ash	Physical: Chemical	Environmental management (ecological adsorbents)	[82]
15	Application of an eco-friendly sodium acetate/urea deep eutectic solvent in the valorisation of melon by-products	Melon (*Cucumis melo*)	Peels	Pectin and polyphenols, oligosaccharides, protein, and antioxidants	Physical: Chemical	Industrial applications	[83]
16	An integrated approach for pineapple waste valorisation. Bioethanol production and bromelain extraction from pineapple residues	Pineapple (*Ananas comosus*)	Core and peel	Bromelain, proteolytic enzymes	Chemical method	Bioethanol	[84]
17	Fruit and Vegetable Wholesale Market Waste: Safety and Nutritional Characterization for Their Potential Re-Use in Livestock Nutrition	Fruit and vegetable	Mixed	Sugars Vitamins	Physical:	Animal feed	[85]
India							
18	Valorization of carrot peel waste by water-induced hydrocolloidal complexation for extraction of carotene and pectin	Carrots (*Daucus carota*)	Peels	β-carotene Pectin	Physical: Chemical	Food processing and biomedical applications	[86]
19	A cleaner and eco-friendly bioprocess for enhancing reducing sugar production from pineapple leaf waste	Pineapple (*Ananas comosus*)	Leaf	Holocellulose	Physical Chemical	Bioethanol	[87]
South and Central America							
20	From Orange Juice By-Product in the Food Industry to a Functional Ingredient: Application in the Circular Economy	Orange (*Citrus sinensis*)	Orange juice by-product	Phenolic compounds/dietary fiber	Physical: Chemical	Food industry	[88]

Table 1. *Cont.*

	Title of Paper	Fruit and Vegetable (FV) Waste Source	FV Residue	Value Added Component/Bioactive Compounds	Recovery Method	By-Product	Author(s)
European Unuion (EU)							
21	Evaluation of the Circular Economy in a Pitahaya Agri-Food Chain	Pitahaya–fruit (*Selenicereus megalanthus*, K. Schum. Ex Vaupel, Moran/(Dragon fruit)	Seeds	Natural fatty linoleic, oleic, and palmitic acids		Biomedical	[89]
			Peel and pulp	Betalains, bioflavonoids derived from quercetin			
			Stem	Proteins			
22	Impact of simulated in vitro gastrointestinal digestion on bioactive compounds, bioactivity, and cytotoxicity of melon (*Cucumis melo* L. *inodorus*) peel juice powder	Melon (*Cucumis melo* L. *inodorus*	Peel	Phenolic compounds	Chemical	Food industry Nutraceutical and pharmaceutical industry	[90]
23	Revalorization of agro-industrial waste as a catalyst source for the production of biofuels	Oranges (*Citrus sinensis*)	Peels	Active carbon	Physical Chemical	Biofuels	[91]
Other Regions *							
24	Valorization of carrot peel waste by water-induced hydrocolloidal complexation for extraction of carotene and pectin	Carrots (*Daucus carota*)	Peels	Carotene and pectin	Chemical method	Nutraceuticals	[86]
25	Recovery of value bioactive compounds from potato peels with sequential hydrothermal extraction	Potato (*Solanum tuberosum*)	Peels	Glycoalkaloids antioxidants polysaccharides nutrients, phenolics: chlorogenic, gallic, protocatechuic and caffeic acids; flavonoids		Improving texture, water retention, and emulsion stabilization	[92,93]
26	Full recycling of high-value resources from cabbage waste by multi-stage utilization	Cabbage (*Brassica oleracea*)	Cabbage waste	Fatty acids, phytosterols, aldehydes	Thermochemical conversion and extraction	Agricultural application (botanical pesticides, insect repellent, and pest avoidance)	[94]
27	Microbial, nutritional, and antioxidant stability of fruit and vegetables discards treated with sodium metabisulfite during aerobic and anaerobic storage	Fruit and vegetables	Fruit and vegetable discards	Antioxidants		Feed ingredients for animals	[95]
28	Enhancement of hydrolysis with Trichoderma harzianum for bioethanol production of sonicated pineapple fruit peel	Pineapple (*Ananas comosus*)	peel	Bromelain, polyphenols, biohydrogen, and biogas cellulose, hemicellulose, and lignin	Chemical	Biofuel	[96]

Table 1. *Cont.*

European Unuion (EU)							
	Title of Paper	**Fruit and Vegetable (FV) Waste Source**	**FV Residue**	**Value Added Component/Bioactive Compounds**	**Recovery Method**	**By-Product**	**Author(s)**
Africa							
29	Tertiary bipolarization of grape pomace	Grape (*Vitis vinifera*)	Pomace	Lignin, holocellulose, and ash total reducible sugars (TRS),	Physical/chemical		[97]
30	Waste prosperity: Mandarin (*Citrus reticulata*) peels inspired SPION for enhancing diesel oil biodesulfurization efficiency by *Rhodococcus erythropolis* HN2	Mandarin (*Citrus reticulata*)	Peels	Phenolic acids, saturated fatty acids, and sugar derivative compounds	Chemical	Petroleum refinery	[98]

* Case studies outside of the aforementioned regional blocks.

6. Valorizing FW into Value-Added Products

Building upon existing domestic and international research, this study explored the potential for transforming FW into high-value products. By examining successful models of valorization from laboratory experiments and global initiatives, the research sought to identify viable strategies for harnessing these practices within the context of sub-Saharan Africa.

The escalating global recognition of FW's profound environmental and socio-economic repercussions has ignited a powerful drive towards pioneering waste management solutions. As communities and industries increasingly grapple with the pressing need to address FW, there is a growing realization that traditional disposal methods are neither sustainable nor viable in the long run. In response, valorization has emerged as a pivotal strategy poised to mitigate FW's staggering environmental footprint and catalyze socio-economic progress, particularly within SSA, where the impacts of FW are a grave concern.

Valorization involves transforming FW into valuable products or resources, extracting maximum benefit from what was once considered waste. This paradigm shift reduces the burden on landfills and incinerators and unlocks various economic opportunities. By repurposing FW through innovative valorization techniques, such as composting, anaerobic digestion, and bioconversion, communities can not only curb greenhouse gas emissions and alleviate pollution but also generate renewable energy, produce nutrient-rich fertilizers, and even create new revenue streams. This section elaborates on potent valorization techniques tailored to FW. Research into refining these methods offers a gateway to lucrative business ventures and sustainable development opportunities. From small-scale entrepreneurial endeavours to large-scale industrial initiatives, the potential for leveraging FW valorization is vast and multifaceted. By embracing these strategies, stakeholders can mitigate FW's environmental and social impacts and foster resilience, innovation, and prosperity in communities across SSA and beyond.

6.1. FW Value-Added Products from Diverse Geographical Regions Relevant to the SSA Context

6.1.1. Green Energy Production

Converting FW into renewable energy can be a long-term, environmentally friendly solution to the energy crisis that most SSA countries experience. FW is usually compostable, has a high moisture content, and can be used to generate bioenergy [25]. Biogas is a naturally occurring and renewable energy source produced by the anaerobic breakdown of organic matter, primarily plant and animal products. This process converts FW into biogas, which can be used as a source of energy. Biogas and biofuels are renewable energies that can be produced from FW [69,75,84]. For example, Almeida et al. [69] conducted a study to produce biogas from tomato waste, including rotten, green, and immature tomatoes and other non-edible parts (stems, leaves, and branches). The authors examined the biochemical methane potential (BMP) and substrates in all three types of tomato waste under anaerobic conditions. The study identified significant differences in methane production between the different parts of a tomato plant. The BMP of rotten and immature green tomatoes ranged between 232–285 mL CH4/g, while parts like stems, leaves, and branches exhibited lower values of 141 mL CH4/g VS. The findings suggest that tomato waste can be used for green energy production.

Biofuel is another renewable energy commonly manufactured domestically from FW. Ledesma and Beltramone [91] conducted a study assessing the bio-waste valorization approach to produce biofuels, among other uses. In their study, they synthesized activated carbons from orange peels using various synthesis conditions. Here, various phosphoric acid concentrations were used as carbon activation agents. The substrate-to-activating agent ratio and the contact time between the substrate and activating agent were determined. The best results were obtained with a carbonization time of 1 h at 470 °C, 50% by weight phosphoric acid concentration, and a bacterial endotoxin (BET) area of 1429 m^2/g. Nanoparticles were thereafter deposited on activated carbon and used as a catalyst in hydroxymethylfurfural (HMF) hydrogenation to 2,5-dimethylfuran (DM). In a separate study, Nassar et al. [99] explored the valorizing of agriculture or domestic wastes such as mandarin peels to photosynthesize and functionalize superparamagnetic iron oxide nanoparticles (SPION). The resultant stable and spherical-shaped Fe_3O_4 NPs, with an average size of 11.58 nm and a magnetic saturation of 51.12 emu/g, were thereafter used for magnetizing biodesulfurizing (BDS) on Rhodococcus erythropolis HN2. SPION was found to be non-toxic for HN2, and in a 120 h biphasic batch BDS process (30% *v/v* oil/water), the green magnetizer HN2 was able to remove approximately 86 and 90% of the 500 mL and 690 mL total sulphur content of the hydrodesulfurized diesel, respectively. SPION, synthesized by green methods, was then used as a microbial decorator to enrich and accelerate the hydrodesulfurized petro-diesel feed's BDS process. Results demonstrate the application of emerging technologies, such as nanotechnology, in valorizing FW.

In SSA, citrus fruits are among the most consumed fruits, and their level of consumption per capita is growing. In South Africa, for example, the citrus industry stands out locally, regionally, and internationally regarding exports and job creation. However, in other countries in SSA, domestic market outlets include rural, urban, and roadside markets and supermarkets where most of the by-products, such as peels and seeds, often end up in landfills. Consequently, converting mandarin or orange peels into renewable energy, such as biogas and biofuels, using an anaerobic digestion conversion process in conjunction with emerging nanotechnologies can be a source of entrepreneurship. The entrepreneurship can be in the form of developing FW digestion systems, which can then be sold to individuals, schools, and food service sectors. On the other hand, individuals and/or organized groups can capitalize on starting FW valorizing services that can either focus on biofuel or biogas production.

6.1.2. Nutraceuticals

Another value-added product identified in FW valorization that can be a source of entrepreneurship is the manufacture of nutraceuticals. Bioactive compounds in FW fractions can be extracted and utilized to develop nutraceuticals. From the reviewed articles, the most common bioactive compounds in FW were polyphenols, phenolic acids, and their derivatives [86,90]. Plant phytochemicals confer color, flavor, and structure with various health benefits and are, therefore, termed bioactive nutraceutical compounds [100].

Buro et al. [101] conducted a study to recover bioactive compounds from red oranges (peels, pulp, and seeds) and olive leaves. The effects of red orange extract (ROE) and olive leaf extract (OLE) on HepG2 fatty storage capacity were assessed by performing Oil Red O′ staining, and the antioxidant properties of the extracts were evaluated following the steatosis model. The results obtained indicated that residues originating from red orange by-products and olive leaves were rich in bioactive compounds such as polyphenols, had good antioxidant capacity, could reduce the accumulation of free fatty acids, and could also act as cholesterol-lowering agents. The synergistic effect highlighted by the co-treatment of HepG2 cells with the two extracts (ROE and OLE) implied that the preparation of a new nutraceutical formulation derived from the combination of both extracts can enhance their antioxidant effect and can help prevent, counteract, or delay the onset of hepatic steatosis complications.

Phenolic compounds commonly found in FW include potato peels, apple pomace, tomato peel, blueberry, raspberry, grape pomace, and other vegetables. Flavanones were discovered in grape pomace, onion skin, tomato peel, apple pomace, blueberry pomace, cherry pomace, and citrus peels, among other flavonoids, anthocyanidins, and flavanols. Flavonoids include pigments like betalains, carotenoids, and chlorophylls. In the study by Bas-Bellver et al. [70], bioactive compounds were extracted from selected vegetable residues using hot air drying or freeze-drying and grinding processes. The vegetable residues were then converted to nutraceuticals, such as colorants or flavorings, that promote general human well-being and control symptoms and malignant processes. In another study, Sanchez et al. [72] used a mixture of overripe whole fruits and vegetables to obtain fermentable bioactive compounds and sugars for the food industry. They applied the hydrothermal hydrolysis of the biomass technique to treat FW using various environmental conditions (temperature, time, biomass/water ratio, and pH values). Results show that FW treated at 135 °C for 45 min reduced sugars with low concentrations of inhibitors.

The product outcomes were used for fermentation media, yielding a product with an ethanol concentration of 27 g/L. Lombardelli et al. [102] used a tailored enzyme mix based on polygalacturonase, pectin lyase, cellulase, and xylanase to extract carotenoid-containing chromoplasts from unsold ripened tomatoes. Using a tailored enzyme-assisted extraction protocol (T, pH, enzyme mix dosage, and process time) to enhance the recovery of carotenoids, a higher recovery was achieved at optimal conditions of 50 °C, pH = 5.5, and an enzyme mix total dosage of 25 U/g for 180 min. This study underscores the need for green methods of extracting value-added products from FW. Overripe tomatoes are a common occurrence in many SSA fresh produce markets.

These results demonstrate the potential of FW materials in manufacturing nutraceuticals or functional foods that can be supplied to the food and pharmaceutical industries. Functional food products can be incorporated into school feeding programs. High-income economies such as the United States of America, Europe, and Japan produce approximately 93% of the total global nutraceutical market. However, nutraceutical manufacturing in low- and medium-income economies is still an emerging concept, with countries like India showing the fastest growth [103]. As a result, African countries can tap into the market by capitalizing on the abundance of FW all year round.

6.1.3. Livestock Feed Formulation

FW has made up most of the organic livestock feed worldwide for many years [95,104]. Here, FW microbial, nutritional, and antioxidant stability using sodium metabisulfite under aerobic and anaerobic conditions were investigated. The results suggest that under both conditions, negligible loss of nutrients was observed after treatment with sodium metabisulfite. The microbial population increased in FW samples without treatment, accelerating biomass deterioration, dry matter loss, and sugar exhaustion. The results show that FW is suitable for animal use if appropriately converted. The proximal chemical composition of FW was analyzed after moisture removal. Results show that FW was rich in nutrients and suitable ingredients for animal feed production. The outcomes of the two studies reaffirm the significance of valorizing FW and evaluating its safety, cost-effectiveness, and eco-friendliness.

6.1.4. Heavy Metal Adsorbents

Negroiu et al. [78] evaluated the use of banana peel residues in removing heavy metals from synthetic solutions. This was done using three materials: a biopolymeric matrix consisting of alginate microbeads (ALG), banana peel ash (BPA)–ALG-BPA (1:1), and chitosan (CS)–BPA. After characterization, the materials' capacity to remove selected heavy metals from the synthetic solution was tested. Results from the ALG-BPA microbeads showed high removal efficiency of heavy metal ions from artificial solutions: 100% efficiency for Cr, Fe, Pb, and Zn and 90% for other tested metal ions. Adding chitosan to banana peel ash improved the removal efficiency for Cr (37.09%) and Fe (57.78%). These results suggest that simple banana peel ash can be an adsorbent for managing trace metals in aquatic ecosystems. This is an excellent example that may be relevant in the SSA context, as rapid urbanization and development have accelerated the release and dispersion of anthropogenic trace heavy metals, causing severe threats to aquatic flora and fauna. Bananas are often grown for local consumption and export markets, contributing to the region's agricultural economy. Uganda, for instance, is one of the largest banana-producing countries in Africa, with bananas being a staple food crop and a major source of income for many smallholder farmers. Countries like Kenya, Tanzania, Rwanda, and Cameroon have significant banana farming industries. Besides being valued for their nutritional content, versatility, and economic importance, making them a popular crop in many parts of SSA, the banana peel can be a potentially sustainable resource for trace metal treatment in aquatic ecosystems. These studies demonstrate that valorizing FW can be a viable alternative to FW optimization and a source of entrepreneurial opportunities. Furthermore, awareness of these techniques can lead to a change in mindset regarding the alternative usage of FW, encouraging a sustainable CE. Results suggest that banana peel ash can be an adsorbent for managing trace metals in aquatic ecosystems.

6.1.5. Biomaterials

Merino et al. [71] evaluated the use of processed avocado seeds and peels to develop antioxidant bioplastic films. Their results indicate that combining hydrolysis, plasticization, and pectin blending is critical to obtaining materials with competitive mechanical properties, optical clarity, excellent barrier properties, high antioxidant activity, biodegradability, and component migration in Tenax, making them suitable for food contact applications. The development of the products represents a suitable, sustainable alternative to traditional non-biodegradable plastic food packaging materials.

6.1.6. Soil Amendments

Converting FW into biofertilizer and/or soil amendment was noticeably missing from the reviewed articles but is relevant to improving agricultural productivity in SSA [105]. The conversion of FW into value-added products such as biofertilizers can also be a source for entrepreneurship, given that one of the challenges facing farmers in SSA is the degradation of farmlands, which has led to a drop in the quality of farm produce. Farmers can then apply soil amendment products to nourish the soil for better quality farm produce with minimal environmental impact [106].

The results of the case studies demonstrate that valorizing FW has the potential to improve the shelf life of these commodities and reduce environmental impacts. All the techniques provide viable entrepreneurial opportunities that individuals or organizations can leverage. With the abundance of FW, these value-added products can lead to sustainable economic development for a region plagued by high unemployment rates like SSA.

6.2. Unlocking Entrepreneurial Opportunities in SSA's Agricultural Sector through Valorizing FW

As stated in Section 1 of this paper, SSA faces significant challenges in managing FW, with post-harvest losses and inadequate infrastructure contributing to this issue. However, within these challenges lie opportunities for entrepreneurship through the valorization of FW. An estimated 30–50% of all food produced is lost or wasted annually. Factors such as inadequate storage facilities, poor transportation networks, and inefficient distribution channels contribute to this problem. Furthermore, consumer behavior and market dynamics also play a role in exacerbating food waste in the region. However, within these challenges lie opportunities for entrepreneurship through the valorization of FW waste.

The benefits of valorizing FW are well documented across the literature, given its negative impact on food security, the environment, and human health. As stated in Section 2.3, valorization, as defined in this paper, involves converting FW into value-added products. While studies exploring the productivity of such enterprises in SSA are lacking in the literature, particularly concerning their potential to improve the well-being of marginalized communities, the potential is immense. Entrepreneurs in SSA face numerous challenges in effectively managing and utilizing FW.

6.2.1. Challenges

Entrepreneurs in SSA grapple with myriad challenges in effectively managing and harnessing FW's potential. These obstacles encompass restricted access to technology and financing, regulatory hindrances, and entrenched cultural norms regarding waste. Insights gathered from various studies underscore the need for proactive measures to tackle specific barriers, including logistical impediments and the requirement for specialized skills, infrastructure, and resources. The conversion of FW into value-added products demands a certain level of expertise, a barrier that could be overcome through targeted training and capacity-building initiatives within marginalized communities.

Barriers such as expertise in FW conversion technologies are critical to the success of FW valorization ventures, emphasizing the imperative of providing educational and training programs for underserved populations. Moreover, the initial costs of starting such ventures could impede their adoption, especially among marginalized entrepreneurs facing financial constraints. Factors such as accessibility to research funding and energy demand during production constrain robust engagement in these ventures, necessitating investments in sustainable energy solutions that empower marginalized communities.

Logistical challenges, including transportation, requisite human capital, packaging, and product marketing, present additional barriers that targeted support and capacity-building endeavors can alleviate. The acceptance of FW products, both technically and socially, is pivotal for their commercial viability, highlighting the need for an inclusive ecosystem that fosters sustainable practices across society.

Unlocking the potential of FW valorization requires a paradigm shift and collaborative efforts aligned with CE principles and SDGs, focusing on empowering communities to actively participate and reap the benefits. Skills transfer, information sharing, training, and collaborative research are vital for sustainable FW valorization, offering opportunities for capacity-building and knowledge exchange that enhance resilience in the face of environmental and socioeconomic challenges.

Despite the obstacles, entrepreneurs possess significant opportunities to create value from FW by embracing innovative approaches and technologies, yielding economic, social, and environmental dividends. Green conversion methods such as composting, anaerobic digestion for biogas production, and insect bioconversion offer environmentally friendly avenues for transforming FW into valuable resources. While using such green methods is nascent in SSA, there is an urgent imperative to scale up demonstration projects to reach broader audiences across all societal strata. The case studies in Table 1 illustrate the feasibility and potential impact of FW valorization projects in SSA.

6.2.2. Opportunities

The EU has emerged as a global leader in reducing and converting FW, offering valuable lessons for SSA countries. The EU has made significant strides in addressing FW challenges through various initiatives and strategies, which could be particularly relevant for African countries grappling with similar issues. One notable example is the promotion of anaerobic digestion for biogas production from organic waste through initiatives like the EU's "Bioenergy Villages", showcasing how organic waste can be transformed into a valuable energy resource. This approach addresses energy needs and reduces reliance on fossil fuels, a critical consideration for SSA countries plagued by unreliable power supplies. Furthermore, the EU's CE Action Plan emphasizes composting organic waste to promote nutrient recycling in agriculture, offering a sustainable solution for managing FW while enhancing soil health and productivity. African nations could benefit from adopting similar technologies and infrastructure to convert FW into valuable resources, contributing to environmental sustainability and economic development.

In addition, the EU has implemented various policies and platforms to tackle FW at different stages of the supply chain. Initiatives such as the EU Platform on "Food Losses and Food Waste" facilitate stakeholder collaboration to prevent FW and redistribute surplus food to vulnerable populations, demonstrating the potential for entrepreneurship to address FW challenges while creating positive social impacts. African countries could establish similar networks to ensure surplus food reaches those in need, mitigating food insecurity and reducing waste simultaneously. Moreover, the EU's focus on bioeconomy strategies at the national level, coupled with research projects like the EU-funded "BIOrescue", highlights the potential for extracting valuable compounds from FW for various applications. While South Africa is the only SSA country with a dedicated national bioeconomy strategy, there is a clear need for collaborative efforts among African nations to enforce legislative frameworks and promote sustainable waste management practices.

Furthermore, EU initiatives promoting urban agriculture and advanced waste-to-energy plants offer innovative approaches to addressing FW and environmental challenges in urban settings.

By embracing urban farming and community gardening and investing in waste-to-energy infrastructure, SSA countries can green urban spaces, improve food security, and reduce waste while minimizing environmental impact. Technological solutions are crucial for facilitating FW valorization in SSA, enabling entrepreneurs to extract value efficiently from FW through innovations such as anaerobic digestion and composting technologies. Moreover, supportive policy and regulatory frameworks are essential for fostering entrepreneurship opportunities in FW valorization. Governments in SSA can incentivize investment in waste management infrastructure and implement regulations that promote sustainable waste management practices, drawing lessons from the EU's legislative frameworks. Capacity building and collaboration are also vital for the success of FW valorization entrepreneurship in SSA, with training programs and partnerships among stakeholders catalyzing innovation and knowledge sharing. Partnerships with EU institutions, NGOs, and businesses can further enhance access to expertise, technology, and funding for FW reduction initiatives in African countries. Overall, the EU's comprehensive approach to FW reduction and conversion is a valuable blueprint for African countries seeking sustainable solutions to this pressing issue.

7. Conclusions and Future Perspectives

FW's adverse socio-economic and environmental repercussions have sparked a global resurgence in exploring reduction management strategies and waste valorization. This comprehensive review delves into the transformative potential of repurposing FW into value-added products, serving as a beacon of entrepreneurship for unemployed youth across SSA. Harnessing the power of FW valorization in SSA emerges as a sustainable pathway to economic development within the region. Examining a spectrum of the literature reveals many value-added products derived from FW material, from renewable energy sources like biogas and biofuels to livestock feeds, biomaterials, and potent adsorbents for heavy metals and nutraceuticals. Given the abundant FW resources in SSA, these products represent opportunities and imperatives for entrepreneurial ventures. Entrepreneurs can pioneer FW valorization services by catering to diverse industries such as food and pharmaceuticals. For instance, producing nutraceuticals and functional foods from food waste (FW) presents a largely untapped market in Africa, ripe for exploration and innovation. Moreover, entrepreneurs can pioneer novel technologies such as FW digestion systems, paving the way for sustainable business practices.

To fully harness the potential of FW valorization, it is crucial to address the barriers hindering its adoption as a viable business opportunity. This review underscores the pivotal role of higher education institutions (HEIs) in fostering innovation and capacity development in FW optimization. HEIs possess the expertise and resources to spearhead transformative initiatives, bridging scientific knowledge with practical solutions. Through avenues like citizen science, community engagement, and enhanced science education, HEIs can cultivate a sustainable culture of FW reduction and valorization, ensuring a legacy of environmental stewardship for future generations.

Aligned with the SDGs, research in FW valorization promises groundbreaking academic contributions with tangible societal impact. By integrating environmental education into early learning curricula, HEIs can nurture a generation of eco-conscious innovators poised to tackle the challenges of tomorrow. International collaborations further enrich the FW valorization landscape, empowering SSA countries to harness local resources, spur employment, and foster knowledge exchange on a global scale.

As evidenced by compelling case studies from the EU, adopting green technologies in FW valorization mitigates environmental degradation, catalyzes enterprise development, and enhances the well-being of communities. In this symbiotic relationship between innovation and sustainability, job creation, poverty alleviation, and economic prosperity converge. This convergence propels SSA towards a circular bioeconomy and a brighter, more equitable future. Finally, African nations can explore innovative packaging and storage solutions, launch FW prevention campaigns, and leverage FW valorization entrepreneurship to create social impact and promote community development, aligning with the EU's holistic approach to addressing FW challenges.

The future of FW valorization entrepreneurship in SSA exudes promise. Emerging trends, including rapid urbanization, shifting consumption habits, and heightened environmental consciousness, herald a new era of opportunity for innovative waste management solutions. Entrepreneurs poised to seize these trends, armed with technological advancements and a spirit of collaboration, stand to unlock the untapped potential of FW valorization across SSA. Their endeavors are catalysts for sustainable development and drivers of economic prosperity that resonate throughout the region. FW valorization entrepreneurship holds vast potential for tackling the pressing challenges of FW while nurturing sustainable development in SSA. By surmounting obstacles, harnessing the power of technology, and fostering collaboration, entrepreneurs chart a course toward a future where FW becomes a source of value, igniting economic growth and enhancing livelihoods across the region.

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