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Food science innovations and sustainable development: Trends in reducing greenhouse gas emissions under agenda 2030-2050

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Abstract: This study evaluates current trends in food science and innovation, emphasizing the urgent need to achieve zero greenhouse gas emissions generated from food waste across supermarkets, households, markets, and industries, as well as to implement effective food loss mitigation strategies. Regardless of region, food waste and postharvest losses have become widespread issues. While some populations continue to face food insecurity, other parts of the world experience food abundance, where food security challenges have largely been resolved—resulting in surplus food supplies but also giving rise to health, environmental, and waste management problems. In nations with food surpluses, these challenges have been mitigated through extensive supply chain networks that ensure efficient movement of food from farm to fork, with products being properly processed, packaged, and distributed. Both processed and packaged foods, as well as fresh produce, are regulated by "use-by" and "expiry" dates. Once these dates are exceeded, such food becomes unfit for consumption and is classified as waste. Wasted food accumulates in large quantities, often destined for garbage incineration. Each year, vast amounts of prepackaged and processed foods are discarded in developed nations, while in developing countries, greater losses occur at the harvesting and processing stages. In recent years, sustainable strategies have been introduced to reduce postharvest losses and minimize food wastage at the household level.

Keywords: carbon footprints, innovations, wasted foods, food loss, food science and strategies

1. Introduction

The right to food for all persons has necessitated the need to upcycle food waste to high end nutritious products, swap imperfect foods for lesser fee and donation of unused perishable groceries to offset certain carbon footprint (Todd and Faour-Klingbeil, 2024). In Japan for instance, supermarket outlets have a price reduction policy once it clocks 7pm, the price tags are automatically adjusted to avoid waste of perishables. Significant amount of food waste is accumulated annually from unsold and uneaten food products which translates to 80million tons of wasted food (Kim, 2023). Food processing and storage are the least problem for Organisation for Economic Co-operation and Development Countries (Maye and Duncan, 2017), irrespective of these research, other statistics has shown that with every tick of the clock food is wasted. Certain indices from behavioral science have pointed to food waste from the angle of consumer's science to include people's perception, different lifestyle changes, health, diet related issues, and nutritional transition (Borrello et al., 2017; Sharma and Deutsch, 2023)

The downside remains whether developed or developing countries, food is wasted; however, the numbers are different since the technical knowledge are different (Nogueira et al., 2021). Established evidence showed that food wastes are evident from farm to retail for developing countries and from retail to consumers for extremely developed countries (Andam et al., 2020; Todd and Faour-Klingbeil, 2024).

The medium of food waste generation was best illustrated in Figure 1. The pattern of waste for developed nations differs with the adaptation of technology in every segment of the food system and food chain process, these applications have resulted to shelf stable foods all year round (Ishangulyyev et al., 2019). As per supermarket policy certain processed food group such as dairy or meat products are discarded, and declared

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unsafe to curb food poisoning of salmonella, certain microorganisms. These safety precautions have been achieved and safety with product recalls and food destruction (Ulrich, 2014). Home pantries are hoarded and packed with food to meet the needs of household, which sometimes are discarded for health reasons by consumer choice, when past due date, infested by pests or rodent (Murat, 2023). Restaurant policies are similar with supermarkets, celebrations such as birthday, wedding ceremony are accompanied by large food preparation and buffet. These are means to which food are wasted. Research has shown that food festivals and waste are synonymous, one study showed that 150,000 tones of tomatoes are wasted annually in La Tomatina festival in Spain, Bavarian beer in Oktoberfest, and Brewfest in Miami. In addition to waste generated by organizers of these events, waste from food vendors that are unsold are estimated negligible as these are redistributed as charities (Carvache-Franco et al., 2025, Rossetti et al., 2024, Zhang, 2025).

Developing nations have amassed the largest food waste issues from farm to table. The distance of farmlands is farther compared to slaughterhouses and fishing waterways. Purchasing power with prices of foodstuff are determinant in food distribution to the bigger markets. These are excluding the likes of insecurities at the farm front of farmers by herdsmen to interstate restrictions and travels ban to certain regions, to finally losses in the market front (Rolker et al., 2022).

The practice of upcycling of comestibles helps make our food systems more sustainable, from waste reduction to lowered greenhouse gas emissions, with less pressure on the environment.

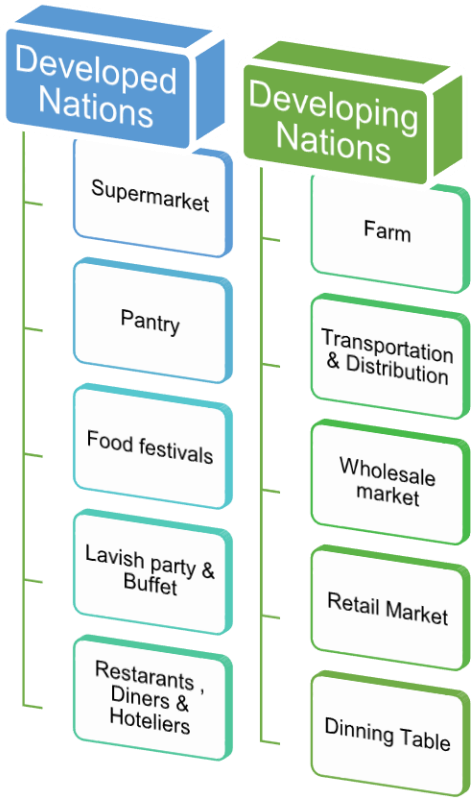

Figure 1: Illustration of food waste medium in developed nations versus developing nations

The idea of transforming imperfect foods to a high-end nutrient dense product, has been termed an innovative approach in food systems (Wikström et al., 2019).

At present eight billion persons exist in the world (Live, 2023); according to Ministry of Agriculture in India, fifty thousand worth of food goes to waste, the problem is not restricted to raw foods, but lavished weddings, hotels, restaurants, large scale events have all contributed to food wastage.
The use of a sustainable management approach has been advocated to halt wasted food, whether in developed or developing countries.

In this paper a concise review of different sustainable practices has been presented as pertaining to wasted food policies, market strategies, and innovations all geared towards Sustainable Development Goals of 2030 and beyond.

MDG's was largely successful globally though the dearth of synergy among goals resulted to less interconnectivity with eco-friendly goals for the environment. SDGs has far greater improvement with more considerations on the planet's environmental and economic goals that are measurable; with greater push towards sustainable dimensions such as: housing, jobs, foods, information, expertise, Artificial Intelligence, and technology (Schiff, 2008).

The question why MDG failed in India, Nigeria and other African countries with regards hunger and food practices would help trigger solutions to achieving SDGs with food innovation practices in Asia and Africa at large.

Several factors contributed to the inability of many African countries to achieve MDG's. Among the key factors was that: models adopted for MDG were all western inclined, weak governance, mismanagement of funds, poor synergy between parastatals, state, local government officers and market traders, poor traders, poor infrastructure, low-income earnings of consumers, weak institutions, and policies (Oleribe, Obinna and Taylor Robinson S. D, 2016).

According to the United Nations at the current rate of happenings, there are likelihood of not enough food to feed the planet teeming population. Food sustainability is very important, presently food waste amounts to half of the processed product, excluding agricultural produce of food loss. For a sustainable planet, economist, agricultural extension agents, banks, government bodies, farmers, food technologists, producers and consumers must strive to ensure that half of the food produced are not wasted (Niles et al., 2017). This has become a food problem and requires specific tasks for food processors and distributors in the supply chain; and where food lapses are generated, efforts are seen to mitigate the food scraps into useful ingredients for meal preparations and ready to eat high end products. Examples are nibbles from dried mangoes, bananas and veggie chips which are shelf stable products of food waste.

Therefore, the use of postharvest simulations and technologies such as cell technology for cultivated foods from cells of crustacean, meats, fish, and insects helps to incorporate upcycled produces during processing thereby offsetting carbon print. These methods are efficient and innovative to cushion the effect of the rising population, while converting food wastes to perfect food products (Blomqvist, 2009; Garcia-Gonzalez and Eakin, 2019).

2. Solutions

2.1. Food waste programme

The establishment of measurable food waste programmes, ensuring separation of waste for ease of processing. Application in household level, grocery stores, restaurant chain and large scale for big food industries. Charging of residents by the weight of the household waste generated and vice versa for food industries. Intentionally, adhering to first in first out rule in household level and for supply chain department raw materials needed for product formulation. These transitioning campaigns for zero waste during continuous production, with established teamwork and planning among staffs prior to shifts (Borrello et al., 2017).

2.2. Policy

Empowerment of farmers, processors, wholesalers, consumers, and cities to tackle food-loss and wastage of food, thereby addressing food insecurity in the various associated systems. Continuous sensitization of pilot programs in schools for kids and teens on how to convert imperfect produce to delicious recipes and the need to decipher that zero food waste possibilities exist for a better planet. Restaurant policies have been administered successfully in OECD countries, where leftovers and food scraps are directed to food bank delivery system always ensuring food for all ages (Bharucha, 2018). Advocacy policies also mandates supply chain distributors and groceries stores to send less than perfect groceries, truckloads of unsold foods and rejected foods for pickup. Established channels have been created online for online presence for a lesser price if to be resold or stock up food banks. Examples are dropping of Happy Fridge in India, for residents to drop off

foods as well as Second Harvest, Flash Foods and Food Rescue in Canada that operate towards mobilizing people to donate to those who do not have access to food regularly and temperature regulated vans are used to move cooked and imperfect products to certain homes and food banks (Antle and Capalbo, 2010; Schiff, 2008).

2.3. Patronize sustainable agriculture

The deliberate patronizing of farmers that use electric vans for food distributions are welcomed. Sourcing of ingredients from sustainable farmlands with innovative ideas like hydroponics that disrupts traditional farming; supporting sustainable food suppliers that offset carbon emission. These food producers find ways to remove carbon from the atmosphere by supporting and switching to farmers, distributors brands and advertising agencies that are accountable to the environment and making continuous efforts to be socially responsible at the same time to offset the total amount of greenhouse gases generated daily. Patronizing insect farming as the farming requirements of less land use and water is sustainable (Kuzmin, 2016; Springmann et al., 2018).

2.4. Adopting sustainable innovations

A lot of food industry activities promote greenhouse gas emissions, there is need to get zero emission by 2030 and beyond. Food industries can decide to introduce the use of electric trucks, solar powered forklifts and mini electric vans that move through the motor-able safety routes in the industry. The recycling of wastewater for washing and cleaning processes, saving water and energy. Additionally, the measurable treatment of waste effluents prior to emptying into the municipal water ways (Arcese et al., 2015).

2.5. New companies and startups

Establishment of new companies and start-ups that focus on plant-based food, feed, and more restaurants with plant-based recipes for a sustainable food system. New product development and upscaling of existing products could integrate edible insects in food production. These products are high in protein and omega-3 and omega-6 fatty acids. The production of carbon-negative spirits and vodka has been introduced to reduce greenhouse gas emissions, with less water use during production (Mensi and Udenigwe, 2021; Petrini, 2009; Springmann et al., 2018).

Mergers and start-ups alike are encouraged to diversify into plant-based alternatives. The demand for red meat, white meat and other animal by products continue to grow. Laboratory grown meat, has cushioned the effect of production cost, less land use and water consumption. Therefore, consumer acceptability of such products is advised through proper advertisement channel on the nutrition and safety status, including sensitization of the benefits of plant-based alternatives as food-based solutions with far less environmental impact (Mylan et al., 2023; Wood and Tavan, 2022).

2.6. Food companies' sustainable ideas

Every day, millions of single use foils, cans, and trays used to bag goods, non-biodegradable containers, straws, and plastic cutlery used in food takeout and deliveries are wasted worldwide. Despite their convenience, some of the most fashionable food packaging materials are however harmful to the environment. Food company's sustainable ideas may include adoption of environmentally friendly packaging materials that readily decomposes and safe for the planet. Examples are adoption of technologies with avocado pits for making biodegradable products like spoons, forks, trays, straws, and containers; sustainable beverage packaging example is Garson wines has used novel shaped bottles that are eighty-seven percent lighter than glass, thus packing bottles without additional packaging which ensures efficient use of space, with allowance of more product pack on a single shipping pallet. Thereby reducing loading time and cutting half of the carbon footprints emissions (Earle, 1997; Mensi and Udenigwe, 2021).

Sustainable Cellulose bottles for wines, beers and soups made of 95 percent recycled paper boards and weighs five times less than glass have been adopted by Frugal Pac Company, these cellulose bottles are alternatives to glass and plastics (Kan and Miller, 2022).

The use of sustainable corn starch-popcorn-mushroom based containers or packages, this innovation has been reported as a good substitute for Styrofoam and plastic containers because of its biodegradable nature. This hundred percent plant based agricultural waste is the new bioplastic that offers a viable, excellent insulating and eco-friendly packaging material (Sharma and Deutsch, 2023).

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Another similar sustainable packing material is the use of hemp herbs and mycelium mushrooms in production of serving trays and packs like paper boards. The future of food packaging now includes bamboo and cassava peels made by Bio Pak; these materials easily disintegrate in the soil three months after production. Thereby addressing plastic waste catastrophe. The use of cleaning agents made from fruits scraps, have been advocated for a safer planet. Pineapple fruits is one fruit high in digestive enzymes suitable for surface clean-ups. Effluent treatments are efficiently managed, resulting to less algae growth, with reduced synthetic detergent pollution (Wikström et al., 2019).

2.7. Market sensitization

This measurable sensitization scheme should be scheduled regularly to cause a shift in the learning participation of market traders of perishable produce in Nigeria and West Africa at large (Aamir et al., 2018; Kuzmin, 2016). The urgency has stemmed from the huge amount of vegetable and fruit waste generated from the market trash places which would have been otherwise sold for far lesser price or donated for charity. These traders need to know the consequences of hoarding perishables for better sale and throwing away unsold produces when bargain is not profitable. From the transportation cost to labor wasted, land use, water and energy wasted to the consequences to the Nigerian economy and environment at large (Brown et al., 2017).

2.8. Introduction of integrated supply chain and waste system

The lack of integrated whole supply chain system, still following the traditional way of produce distribution causes a big chunk of fruits and vegetables to be lost during transportation, with inadequate packaging material (primary and secondary package) to cushion the goods. Most fruit and vegetables have been wasted due to gaps in packaging materials, and supply chain. Market traders should unlearn their traditional ways and adopt proper supply chain route as taught by Government and private agencies (Kim et al., 2019; Nogueira et al., 2021).

Market traders of perishables should be made to contribute their own quota to help eliminate food insecurities in the economy. Corporate social responsibility can be facilitated for community service by giving out perishables for far lesser prices to less privileged, and to foodbanks that would otherwise be discarded. The enforcement of taxation on excess waste generated per persons and or per grocery shops. Local Government partnership with market bodies and chairpersons in various provinces, territories, and states on cutting taxes for registered market traders of perishables that become accountable; that has unlearned and relearned sustainable practices. Establishment of measurable taxation systems to tax the amount of waste generated in marketplaces located in the metropolitan cities, villages, suburbs, and other rural areas (Aamir et al., 2018; Brown et al., 2017; Todd and Faour-Klingbeil, 2024).

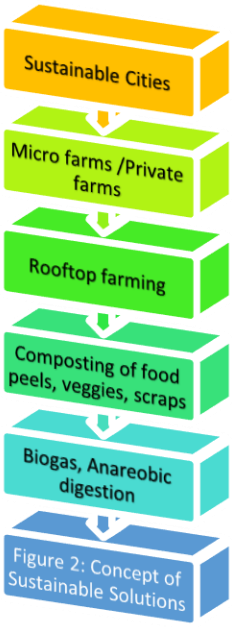

Figure 2: Concept of Sustainable Solutions

Figure 2 showed examples of application of the solutions that are useful and replicable. The incorporation of the concept of trending cities would invariably translate to availability of food material such as veggies, mini farmland in and around the community. Research has shown that a rooftop greenhouse farm with caged poultry is manageable. The use of wilted leaves for rearing, and the use of manure for the growing of veggies are termed sustainable.

Centralized system for composting of wasted foods is practiced, however the separation of wastes have not been perfected in developing countries. Training on composting for animal feed, biogas production, and efficient waste separation measures using coded colored nylon should be adapted to communities and equivalent cities (Shurson, 2023). These sustainable practices when channeled have resulted to newer streams of income and invariably, opportunity exist to creating solutions to solving waste management issues in the environment and communities at large (Manios et al., 2024).

2.9. Regulations Measures for Food Waste

Universally, food waste regulatory measures have been adapted, and exist to checkmate, and stand as a barrier with buffer effect against food movement from farm to landfill. These are dependent on establishment of legislative framework, national laws and binding rules that show clear and mandatory goals for reducing food waste across sectors of the supply chain. Examples are pay as you dispose systems, wastes are charged per disposal to landfills; ban of food and organic waste disposal with taxes options; donation of foods through price slashing, donation to homes, and foodbanks (Baig et al., 2022)

Additional global and regional regulatory measures include the following but not limited to;
Republic of China in 2021 enacted an anti-food waste law with consumers levied with tax policies and regulations aimed at curbing excessive consumption in restaurants (Shen et al., 2024). Singapore has a resource sustainability act that mandates large commercial and industrial premises to segregate, and treat food waste, with mandatory reporting requirements.

United Nations Sustainable Development Goals12, have been summarized to mean accountable consumption and production, with exact aim to halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains by 2020 (Manios et al., 2024).
European Union have decreed as part of its circular economy package, to develop a food waste measurement methodology as well as a solid platform for food losses and food waste to facilitate action among member states. This anti-food waste law has invariably been enacted in France that mandates supermarkets to donate unsold food. For countries like Spain, food chain operators must have waste prevention plans (Cahyani et al., 2022).

Conclusions

With 2030 around the corner, scientific hands are on desk to birth a sustainable future free of wasted food and unwanted loss. A society where nothing goes to waste because the knowledge of food perishability is well taught, discussed, articulated, and advocated more on the need to reuse foods and with food outreach. The use of sustainable practices by farmers, consumers and stake holders should be promoted and reinforced by the law governing the people and the environment. This whole possible development practices are all geared towards offsetting carbon footprints with a sustainable future, of food security.

Authors' contribution

Ijeoma Adaeze Nwaeze, Experiment and analyze data, Writing-original draft; editing, proofread.

Conflicts of Interest

The authors declare no conflict of interest.

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