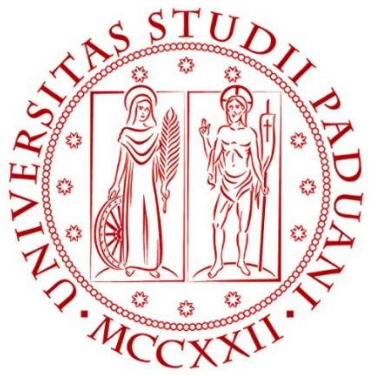

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Banana Peels as Novel Food: Policies and Marketing of a Sustainable Product

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Abstract

This paper examines the potential use of banana peels as a sustainable food product, and the possibility of marketing it as a novel food. Currently, over 8 billion people need nourishment and resources are getting scarce to accommodate the growing population. That's why governments, companies and organizations are now holding hands to reach a common goal: building a sustainable future. When it comes to food sustainability, there's been much progress in creation of cultivated meat and plant-based products.

But food waste valorization has been on the back burner. This literature review mentions the latest studies on the health benefits of banana peels as a food byproduct and how incorporating it in new recipes can combat food waste. In conclusion, the review found that there isn't any specific EU legislation or a sustainability framework concerning the topic of food byproducts. And investments from both public and private sectors in the EU are needed to kick start product development.

Moreover, establishing food safety regulations are required with strong use of IoT and data analytics for production quality control. Finally, the right marketing techniques, including product education, are needed to gather consumer interest in fruit peel consumption. All in all, there's high market profitability in banana peel production and distribution.

Introduction

The Earth's population is on the rise, projected to reach 9.8 billion by 2050 (United Nations). While that seems like a positive benefit for humanity because of the boost in the quality of care thanks to revolutionary medical breakthroughs, it also means our current food supply chain should be evaluated. Besides the increase in population, the effects of climate change on crop yields also cannot be discarded.

Invasive pests and environmental degradation stemming from global warming have worsened crop yield losses (Tonnang et al., 2022)[1]. Furthermore, farmers and large factories that are practicing intense agriculture are contributing to soil depletion and a rise in antibiotic resistance (Kopittke et al., 2019; Kousar et al., 2021)[2]. This calls for an urgent transformation to a more sustainable food system.

These days, lab-grown meat and plant-based proteins have been at the forefront of sustainable practices. However, there hasn't been much media attention given to food upcycling.

One such opportunity lies in the upcycling of agricultural byproducts like banana peels. Historically considered a waste product, banana peels are now emerging as a potential source of novel food products with notable health benefits. Banana peels aren't the only ones that have been deemed worthy of pursuit.

Similar approaches have been explored with other food byproducts, such as coffee grounds (de Melo Pereira et al., 2020)[3], grape residues (Alfaia et al., 2022)[4], tomato waste (Trombino et al., 2021)[5], and dragon fruit waste (Tripathi et al., 2023)[6]. These studies highlight the potential of food byproducts to contribute valuable nutrients and functional properties when repurposed effectively.

Despite the growing body of research on the benefits of upcycled food byproducts, there are several challenges to exploring this field.

This literature review aims to provide: 1) a comprehensive examination of the potential of banana waste by-products, with an extra focus on banana peels, as a sustainable and novel food product, diving into the brief history of bananas, then evaluating recent research on their health benefits and applications. 2) It also highlights the gaps in current EU policies and frameworks in regulating food waste byproducts. 3) Plus, the need for substantial investment from both public and private sectors that pose significant barriers to advancing product development. 4) Moreover, the establishment of robust food safety regulations and the integration of advanced technologies, such as data analytics and IoT, which are essential for ensuring production quality and consumer safety. 5) Finally, it touches upon the importance of effective marketing and consumer education for generating interest and acceptance of upcycled and novel food products derived from byproducts.

By covering the latest research and assessing the major barriers related to food waste upcycling, the consumption of such food byproducts like banana peels can become a reality in the near future.

Brief History of Banana Origins and Cultivation

Regarded as one of the largest herb groups in the world (Ploetz et al. 2007)[7], bananas belong to the genus Musa of the family *Musaceae*. They are perennial plants, with stems growing from the underground, from which pseudostems emerge giving life to tightly packed leaf sheaths, ending in big undivided leaf blades. Originally very seedy, generations of cultivation has resulted in a seedless type we consume today.

In fact, thanks to human ancestral intervention, bananas have undergone changes that have led to reduction in seed size, generation of oversized pulps, and the development of the fruit without the need of fertilization (Arvanitoyannis and Mavromatis 2009; Ploetz et al. 2007)[8,9]. Asexual reproduction or parthenogenesis resulted in haploid species, while regular fertilization methods led to diploid species.

Generally, there are many Musa species, however the most common ones are *Musa acuminata* and *Musa Balbisiana.* Though bananas are heavily cultivated in Africa today, it wasn't until the year 2700 to 2100 bp that they reached African countries according to archeological sites in Cameroon. (Perrier et al., 2011)[10]. Moreover, scientists still don't know the exact time bananas reached Latin America; Alexander Von Humboldt, the famous German scientist and explorer of the 19th century, assumed that they should have reached that continent before the Spanish Conquest. (Browne, 1944)[11].

Now, the origins of the banana can be traced back to the late Eocene, when the genus Musa diverged and developed in northern Indo-Burma. During the Oligocene and Miocene, it migrated southeast across Southeast Asia and Oceania (Janssens et al., 2016)[12]. Species distribution models based on biogeographic data from 59 wild species indicate that northern Indo-Burma, peninsular Malaysia, Sulawesi, lowland Borneo, northeast India, and northern New Guinea have high species richness (Mertens, Swennen, et al., 2021)[13].

More extensive research into the origins of banana cultivar diversity indicates that Musa acuminata subspecies *banksii* from New Guinea gave rise to genomes AAA East African Highland Banana and AAA Cavendish, that's used in international trade. Before Cavendish took the banana trade by storm, Gros Michel, which is closely related to the Cavendish once dominated the international banana trade. (Hippolyte et al., 2012)[14].

1. The Dark Past of Banana Trade

The term "banana republic" we use today came from the atrocious monopoly of banana trade in Latin America back in the 1920's. The rise in popularity of bananas in the US made American corporations hungry for more control. Thus, a notorious company known as United Fruit Company, started allying with corrupt governments, bribing them, to secure land concessions in their favor. (Moberg, 1996)[15] This eventually led to cutting down large acres of land, making them available solely for banana cultivation. Low pay and unbearable working conditions made Colombian plantation workers angry, prompting them to go on frequent strikes. (Elias Caro & Vidal Ortega, 2012)[16].

In their effort to quell the unrest, the Colombian army proceeded to fire at unarmed civilians who wouldn't back down. The drama surrounding United Fruit, which now goes by Chiquita brands, continued until 2007 when they were accused in funding paramilitary groups in Colombia. Though United Fruit has since lost its stronghold in the Latin American banana trade, other disputes involving the US, EU, and Latin America have also caused changes in how countries trade bananas over the years.

In 1993, when the EU imposed tariffs on bananas imported from the US and Latin America, the US wasn't elated by this news. Supported by huge donations from Chiquita Brands International, the US administration under Clinton, initiated legal proceedings via the World Trade Organization (Patterson, 2001)[17]. Though the EU made a few changes to its trade tariffs, the US put 100% tariffs on a range of EU goods, such as French cheese and Scottish Cashmere. After these mini trade wars, the EU decided to reduce their tariffs on Latin American bananas to $75 per tonne in 2020.

2. Banana Export and Value

Today, banana's major cultivation is carried out in countries like India, China, Ecuador, Nigeria and the Philippines. However, India, China and other African countries, have been more inclined to cater their bananas for local consumption, while countries of Latin America have become the world's top exporters between the years of 2016 and 2020 (FAO Banana Market Review Preliminary Results 2020). According to figures that are now available, the average amount of bananas produced worldwide increased from 69 million tonnes in 2000–2002 to 115 million tonnes in 2017–2019, valued at almost 40 billion USD (FAOSTAT 2019).

Based on this same FAOSTAT 2019 data, the worldwide banana export sector brings in approximately $13.5 billion USD annually. It is crucial to remember, nevertheless, that only about 18% of the world's banana production gets exchanged on international markets.

3. Pests and Fungal Diseases Affecting Banana Cultivars

When banana leaves get black streaks, with reddish-brown discoloration, this can pinpoint to a fungal disease known as Black sigatoka. The fungus behind this disease is called Pseudocercospora fijiensis, and it's considered to be the most crucial foliar disease of bananas. (Marín et al., 2003, Ploetz,2001)[18,19]. Its first appearance can be traced back to Fiji, where it spread to other areas in the tropical region likely with the help of climate change. (Bebber, 2019)[20]

Another well-known fungal disease is Fusarium wilt or Panama disease caused by the soil-born fungus *Fusarium Oxysporum f.sp. cubense* (Foc). This fungus attacks the roots of the banana plant, then blocks the vessels, preventing essential nutrients from reaching the other parts. It then releases spores that spread easily to neighboring banana plants. (Dita et al., 2018; Pegg et al., 2019)[21,22]. In the 60s, When Gros Michel was the main banana used in international trade, a genetic race of Fusarium called Foc Race 1 attacked bulk banana cultivations and spread itself quickly, thereby disrupting total supply chains. Fortunately, the Cavendish variety was resistant to this type of Fusarium and soon replaced Gros Michel. However, a new strain of Fusarium called Tropical Race 4 TR4 soon arrived to terrorize the Cavendish trade in many regions, from Southeast Asia, all the way to the Middle East and Peru. (Ploetz, 2021)[23].

Since this type of fungal race is soil-born, it's therefore hard to eradicate without extensive fungicide use. Though, there have now been new ways in trying to mitigate its spread through crop rotation. For example, Chinese farmers have noticed that underplanting bananas with a species of leek known as *Allium tuberosum*, seems to stop Foc infection. (Huang et al., 2012)[24] Similar results were achieved through a chili and banana crop rotation experiment. (Shan Hong et al, 2020)[25] Such natural ways to combat fungal disease progression in banana cultivars can be a huge positive feat in attaining a sustainable and healthy food system.

Banana Plant Waste

Even with the absence of fungal diseases, major parts of the banana plant are already discarded after harvest. Generally, banana by-products comprise the pseudostem, leaves, inflorescence, fruit stalk (floral stalk/rachis), rhizome and peels. The majority of these by-products are categorized as commodities with little application or commercial value; in other situations, they may even be regarded as agricultural waste.

However, farmers use pseudostems and leaves to fertilize the soil and some indigenous cultures of Southeast Asia consume the young shoots, pseudostem piths and inflorescence. (Kennedy 2009). Banana leaves are also used by native Southeast Asians as wrapping paper for some specific ethnic foods. Other uses of banana waste products include animal feed, however this way require additional processing because of the high water content that greatly reduces the nutritional density. (Akinyele and Agbro 2007).

The banana plant produces waste that's 80% of its mass. Though the peels and the stalks are discarded during processing time and not at the harvesting level, they are still thrown away as garbage later on. When all this collective waste is burnt, piles of it contribute to an ecological problem since damaged soil prevents farmers from planting new cultivars. It's estimated that around 220 tonnes of banana by-products are produced per hectare annually. (Shah et al. 2005) If all these by-products, including stalks and other parts get burned, they will release heaps of methane gas (CH4) and nitrous oxide (NO2), which have 28 times and 298 times higher global warming potential than CO2 gas (Fenghao Jiang et al, 2023).It would be a huge waste not to utilize them. Luckily, innovative ways of food upcycling can solve this issue.

1. ***Banana By-Products in Biomass and Green Technology***

It wasn't until the last few years, when the words "sustainability", "green tech" and "biomass" became buzz-worthy. When the UN issued its sustainability goals in 2015, it cemented a

pathway towards achieving a healthier planet by the year 2030. (The 2030 Agenda for Sustainable Development) Among the goals, there's the importance of building sustainable cities and using sustainable methods in making products.

Renewable resources such as biomass can break the cycle of pollution by becoming raw materials that can be reused. For this reason, biomass, or products obtained from agricultural and animal materials can be used to replace petroleum and gas products, including precious metals and minerals.

Having this in mind, farmers can benefit from such solutions as sources for additional income through selling banana byproducts to third party companies. This would be a win-win situation, as companies would also become less-dependent on non-renewable resources, thus preventing their fast depletion (Reddy and Yang 2005)[30].

It's vital to note that even though some papers refer to banana by-products requiring less land than other crops, (Birdie Scott Padam et. Al 2012)[31], it's unclear if this claim can be applied when referring to mass production. More experiments and studies have to be done to reaffirm such a claim.

Furthermore, Green technology (like energy-saving light bulbs or solar panels) utilizes environmental-friendly methods to make products/materials that conserve our natural resources, resulting in less waste and stopping the destruction of habitats.

Such tech should be used outside of the existing agro-food commodity market, since diverting essential foods for energy use can lead to food insecurity, as in the case of using corn as biofuel (Pimentel and Patzek 2005)[32]. Since banana by-products are rarely consumed as food, they can serve as highly valuable resources for green technology and extra ingredients in food applications. Fig. 1 illustrates how banana by-products can be used in different ways which are discussed in detail in the next sections.

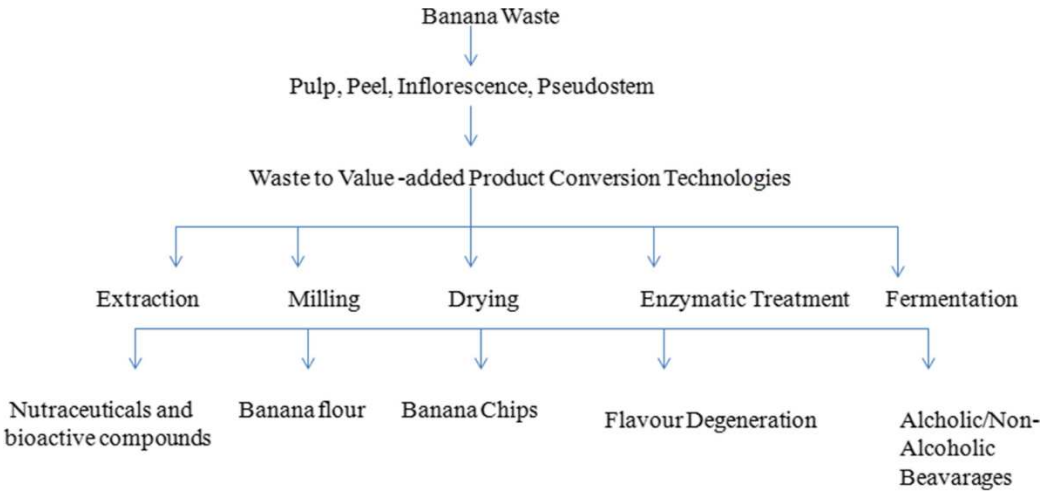

Image Source: ***Utilization of banana waste as a resource material for biofuels and other value-added products***

2. Banana By-Products Uses in Bioremediation

Heavy industrialization and rapid urbanization has led to difficulty in controlling environmental contamination of both water and soil. Several research and experimental studies have been conducted throughout the years using microorganisms like bacteria to solve contamination issues. One such study on oil spills used bacteria called *Alcanivorax borkumensis,* where the bacteria showed adherence to oil in a simulated oil spill condition. They formed a biofilm after congregating, thus gaining access to the hydrocarbons present in the oil for degradation (Michael P. Godfrin et. al, 2018)[33]. Besides bacteria, plant by-products have also become the subject of bioremediation.

Banana by-products, such as carbon foams made from peels, the peels themselves plus the stems have shown their metal ion-binding capabilities. They are able to absorb heavy metals like copper, lead, chromium, and cadmium. In fact, banana fiber has the ability to absorb zinc, iron, copper, and cadmium.

Various heavy metals, including copper, lead, zinc, copper, and cadmium, can be bound by banana peel cellulose. Carbon that has been separated from banana pith effectively binds

nickel and mercury, respectively (Kadirvelu K, 2003)[34]. Moreover, products made from banana waste have also been used to rid contaminated rivers of pesticides.

For instance, carbofuran, 2,4 diphenoxy acetic acid, and benzaton have all been removed from contaminated waters using activated carbon made from banana stalks (Ahmed T. et. al, 2018)[35]. Banana components have also been shown to remove dyes from contaminated material. For example, banana pith and banana stalk waste, have been successfully used to remove methyl orange (Prachpreecha O et. al, 2016)[36].

3. *Banana By-Products as Sources of Starch, Pectin, Cellulose and Fermentation Substrates*

The dominating ingredients used as thickening agents are corn starch, xanthan gum, gelatin, pectin, and potato starch. Banana by-products such as pseudostem pith or green culled bananas are rich in pectin, cellulose, and starch.

Banana starch can be considered as a replacement for corn starch, since its starch has lower amylase content, higher heat resistance, and lower swelling and solubility properties (Zhang P et. al, 2005). [37]

Pectin can also be extracted from banana peels and used to modify and upgrade the quality of jellies, for example, as implemented in an experimental study by Apsara et al in 2002[38]. Pectins extracted from banana peels contain a variety of monosaccharides, including glucose, galactose, arabinose, rhamnose, and xylose, according to Emaga et al. 2008[39]. Because they transform into fermentable sugars rather easily, starch and cellulose are important feedstocks for bioethanol from an industrial standpoint.

Bacterial species have been used in the food industry since time immemorial to produce new food products for human consumption. The species known as *Acetobacter Bacterium*, for example, was utilized as a starter culture to ferment ethanol from wine to produce vinegar in Ancient China 3000 years ago (Peng Chen, 2021)[40].

Research has shown that banana peels can be utilized as a substrate to produce lactic acid (Liang S, 2016)[41]. Lactic acid is an organic acid that finds extensive use in the food, chemical,

cosmetic, and pharmaceutical industries. It is used in food preservation, pH regulation, flavoring, skin lightening, and anti-acne agents, among other applications.

Banana peel has also been effective in producing enzymes like laccase and alpha-amylase. Amylase produced by the action of bacteria like *Aspergillus niger* and *Bacillus subtilis* on banana peels can be possibly used in the food industry in various ways such as bread making, brewing and other processes requiring fermentation (Jadhav et al. 2013)[42].

Moreover, since it is known that certain fungal species, including *Aspergillus, Penicillium*, and *Saccharomyces*, can grow on banana peels. The development of a wide variety of such microbes aids in the fermentation of the peels and results in biomolecules that can be vastly utilized in the food industry (Jamal p, 2012)[43].

4. Banana By-products as Flavor Enhancers

People's interest and drive to consume many products puts a strain on our planet's resources. If companies were to make strawberry-flavored chocolate from real strawberries, this effort would deplete their fields, and result in food insecurity. With the ingenuity of the human mind, scientists have successfully been able to mimic flavors from many fruits and vegetables respectively.

Banana leaves, for instance, contain the enzyme *lipoxygenase* that can be used to produce flavors such as oolong tea, cucumber, and melon when treated with soybean oil and linoleic oil (Kuo JM et. al, 2006)[44]. Banana juice has also been experimented on by Chen et al in 2020. They used the juice to make banana wine, where post-fermentation banana wine resulted in having a lower pH, more reducing sugar, and more alcohol than primary fermentation wine. Moreover, according to a study by Hasbullah et. al 2021[45], banana peels were even used as *analog for coffee*. The flavor and aroma of the brewed analog coffee made from ripe banana peel was stronger than the one made from unripe banana peel.

As we've seen, there are many uses of banana waste by-products. The benefits of the banana peel specifically has been studied extensively throughout years. However now, with the extra

spotlight on sustainability and waste management, efforts on uncovering the peel's nutritional quality and incorporating it into diets have become more widespread.

Banana Peels: An In-depth Analysis of its Nutritional Content

Besides being consumed as an unprocessed food, bananas can be processed into banana flour, chips and cookies. But the peels are most often discarded, and left to rot or burned. When in reality, there are a lot of hidden nutrients that benefit humans.

Many ailments, including burns, anemia, diarrhea, ulcers, inflammation, diabetes, cough, and snakebites, have historically been treated with peel Pereira & Maraschin, 2015(46,54).

Because of this, it is a substance with a lot of potential, which encourages the pharmaceutical and nutraceutical businesses to use it. And similar to the pulp, banana peel contains lipids, carbohydrates, protein and bioactive compounds.

1. ***Fatty Acids***

Fatty acids are essential to human bodies, since they comprise the phospholipid bilayer of the cells. They're also used as precursors for steroid hormone synthesis, and utilized for fat synthesis providing insulation to vital organs like the liver. Majority of fat from human diet comes from meat, dairy, oil, nuts or processed goods.

Rarely would one think of consuming peels as sources of fatty acid. However, based on findings from current available research, polyunsaturated fatty acids or PUFA, including *linoleic acid (Omega-6)* and *α-linolenic acid (Omega-3),* which make up about 40% of all fatty acids, are abundant in banana peels (Khawas & Deka, 2016;)[47]. According to Marangoni et al. (2020)[48], a diet high in linoleic acid has shown to lower liver fat and somewhat improve metabolic status without leading to inflammation.

2. Amino Acids

Amino acids are the building blocks of cells. Hormones like insulin and enzymes like amylase are made up of proteins which play important roles in glucose regulation and digestion. In nature, there are essential and non-essential amino acids.

Meat products contain all essential ones or complete proteins, while plant sources usually are incomplete. In case of banana peels, they contain 18 amino acids (essential and non-essential), though at varying levels.

For instance, a banana peel has very low levels of the amino acid Leucine, while maintaining high levels of Glycene (Tsado et. al 2021)[49]. There's also a slight difference between amino acids found in plantains and those found in bananas. Usually, when people think of bananas, they forget that there's also another member of the same Musacae family called plantains.

Generally, it's quite difficult to distinguish between bananas and plantains, however upon closer inspection, plantains are bigger, thicker, and starchier than bananas.

For these reasons, plantains are used for cooking, since the starch degrades and becomes easier to digest, thus sweeter. When it comes to comparing their amino acid content, plantain peels are higher in Leucine and Glutamic acid, as seen in **Table 1**.

Table 1: Amino Acids in Banana Peel (Tsado et al., 2021).

Amino Acid	**Plantain peel (g/100 g protein)**	**Banana Peel (g/100 g protein)**
Leucine	7.76 ± 0.05	0.01 ± 0.00
Lysine	7.90 ± 0.03	6.71 ± 0.06
Isoleucine	5.24 ± 0.05	8.06 ± 0.04
Phenylalanine	4.79 ± 0.06	4.98 ± 0.07
Norleucine	0.02 ± 0.00	5.23 ± 0.06
Trytophan	0.58 ± 0.03	0.01 ± 0.00
Valine	5.67 ± 0.01	0.52 ± 0.02
Methionine	1.60 ± 0.03	5.79 ± 0.03
Proline	3.25 ± 0.02	1.71 ± 0.02
Arginine	4.99 ± 0.03	3.25 ± 0.05
Tyrosine	3.96 ± 0.06	5.50 ± 0.03
Histidine	2.11 ± 0.04	3.96 ± 0.01
Cystine	0.85 ± 0.02	2.24 ± 0.03
Alanine	6.22 ± 0.05	0.85 ± 0.04
Glutamic acid	12.72 ± 0.02	5.31 ± 0.01
Glycine	3.94 ± 0.01	13.02 ± 0.82
Threonine	5.38 ± 0.06	6.10 ± 0.03
Serine	4.05 ± 0.04	4.59 ± 0.04

Amino Acid	Plantain peel (g/100 g protein)	Banana Peel (g/100 g protein)
Aspartic acid	8.68 ± 0.02	9.06 ± 0.05
Total	89.71 ± 5.45	86.71 ± 3.02

Plantain peels are especially high in Leucine and Lysine. Studies have shown that these amino acids act against hypercholesterolemia and hyperglycemia (Zhang et al., 2007)[50].

3. Dietary Fiber

Prehistoric ancestral humans consumed around 100g of fiber per day compared to humans nowadays, who are consuming far less, around 17g daily (Nicola M McKeown et al., 2022)[51]. It's a drastic decline in the consumption of a nutrient that's known to regulate blood glucose levels and help in keeping cholesterol levels in check (Reynolds et. al, 2020)[52].

With LDL cholesterol, that is transported from the liver towards cells, insoluble fiber has been shown to be less effective than soluble dietary fiber found in banana species *Musa paradisiaca* in decreasing its levels in the blood. Oxidized LDL comes from lipid peroxidation involving phospholipid molecules that migrate from the plasma towards the damaged vascular region. Inflammation can trigger such a process to unfold. According to Arun et. al, 2017 [53], methanol and ethyl acetate extracts from *Musa Paradisiaca* were shown to prevent the development of oxidized LDL.

4. Phenolic Compounds

Bioactive substances found in banana peels include flavonoids, tannins, alkaloids, glycosides, anthocyanins, and terpenoids. These compounds have been shown to have a variety of biological and pharmacological effects, including antibacterial, antihypertensive, anti-diabetic, and anti-inflammatory properties (Pereira and Maraschin, 2015) [46,54]. Secondary plant metabolism produces bioactive chemicals that have strong medicinal promise because they

stimulate antioxidant activity. Carotenoids and phenolics are the predominant phytochemicals found in vegetables and fruits. (Singh et al, 2015)[54]. Various health benefits have been connected to phenolic chemicals, including the defense from obesity, diabetes, cancer, and cardiovascular disease (Boots et al., Cheng et al., 2007;2008)[55,56].

5. Antioxidants

Dietary antioxidants lower the incidence of conditions like diabetes, cancer, and cardiovascular disease, according to a number of epidemiological studies (Nisha and Mini, 2014)[57]. Because they minimize oxidative stress and scavenge free radicals, dietary antioxidants may help prevent or treat several disorders.

Dietary antioxidants have the potential to serve as a substitute for synthetic antioxidants, whose usage is closely restricted due to potential health hazards. (Agourram et al., 2013)[58]. Because of the high production of plant bio-wastes, their application can be extended to the food business, where they can be utilized as antioxidants to create novel functional meals.

Genetic factors, the production area, growing circumstances, fruit ripeness, post-harvest management, and the use of processing agents all have a substantial impact on the presence of natural components (Vu et al., 2018)[59].

Mature and overripe fruit peels had less phenolic content, flavonoid content, and antioxidant potential than green peel (Sudaram et al., 2011)[60]. Likewise, numerous specific chemicals, including rutin, dopamine, norepinephrine, and naringin, decreased when the peel turned from green to yellow.

According to a study by Vu et al. (2019), the antioxidant capacity of banana peel rose with ripening and decreased with overripeness, suggesting that phenolic components-rather than chlorophylls and carotenoids-are linked to antioxidant qualities.

As a result, the maturation stage needs to be taken into account. The phenolic and antioxidant contents have also been studied across different banana cultivars. (**Table 2**). It seems that they vary from one cultivar to another, increasing in some and decreasing in others.

Table 2: Total Phenolic Content and Antioxidant Properties of Banana Peel. (Hana et. al, 2022[62])

Cultivar	Genome	Total Phenolic Content	ABTS assay	DPPH assay	FRAP assay	Reference
Musa paradisiaca	AAB	7.71[a]	84.73[d]	–	–	Agama-Acevedo et al. (2016)
Local banana in Mexico	–	4.95[a]	–	9.23[c]	0.32f	Hernández-Carranza et al.s (2016)
Musa paradisiaca	–	55.5[b]	–	66.9[e]	1.6[j]	Devatkal et al. (2014)
Cavendish	AAA	29.2[a]	242.2[d]	–	14.0[d]	Rebello et al. (2014)
Mas	AA	12.24a, k	–	3.47c, k	16.73c, k	Sulaiman et al. (2011)

Image Source: ***Banana peels as a bioactive ingredient and its potential application in the food industry***

6. Anti-microbial agents

Herbal remedies have been used historically to treat a multitude of infections and have shown promise in many cases. Most naturally occurring medications are made from plant parts such leaves, flowers, fruits, and stems.

With the use of these extracts, new antimicrobial agents with unique chemical structures and modes of action will operate as a barrier against microbes resistant to several drugs. According to a prior study (Mokbel and Hashinaga, 2005)[63], banana peels have antibacterial characteristics that are efficient against the following: Salmonella enteritidis, Bacillus cereus, Staphylococcus aureus, and Escherichia coli.

Ethanol extracts of *M. paradisiaca cv. Puttabable* and *M.acuminata cv. Grand naine* showed a wide range of antibacterial activity against the tested microorganisms, with a particularity high inhibitory potency against P. vulagaris and S. paratyphi, according to a different study done by Krishna et al. (2013)[64]. The existence of biologically active substances such as glycosides,

flavonoids, terpenoids, and tannins was shown by phytochemical analysis. These compounds could be applied to the management of harmful microorganisms in therapeutic settings.

Moreover, according to Mordi et al. (2016)[65], oil derived from 30mg/mL methanolic peel extract has a strong antibacterial capability against a variety of bacterial species. Peel has a strong antibacterial component called 2-methyl-5-(1-methylethyl) phenol, which is probably the cause of this discovery. Also, based on the experiment conducted by Aboul-Enin et al. (2016)[66], the presence of tannins has shown some antibacterial activity against the three studied pathogens, S.aureus, P. aeruginosa, and E.coli.

7. Anti-cancer Components

The banana peel extract made from hexane solvent showed the maximum toxicity towards the human colon cancer cell line HCT-116, with 64.02% cell suppression of cell multiplication, according to a study by Dahham et al. (2015)[67].

Durgadevi et al. (2019)[68] showed in a different investigation that the Nendran banana peel's aqueous methanol extract exhibited a notable cytotoxic effect on MCF-7 breast cell lines. According to Vijayakumar et al. (2017)[69], crude extract from banana peels can also be utilized to create gold nanoparticles that are cytotoxic to human cancer cells and prevent Gram-positive bacteria Enterococcus faecalis from forming biofilms.

The anticancer benefits of banana peels were thought to be attributed to their flavonoid concentration. According to a study by Phacharapiyangkul et al. (2019)[70], ferulic acid, which is highly detected in sucrier banana peel, may function as anti-melanogenesis. It was observed to control the expression of a growth factor for vascular endothelial cells, starting the synthesis of nitric oxide synthase, and suppressing tumor-related genes.

8. Anti-nutrient Components

A number of anti-nutritional elements found in banana peels, including tannins, oxalate, and phytate, can have negative effects on the body, including stunted growth, decreased nutrient intake, and harm to important organs (Arslan and Ozcan, 2010)[71]. Banana peels have a high

proportion of *glycosides* among these anti-nutrient chemicals (Ozabor et al., 2020)[72]. Hydrolyzing glycosides can produce hydrogen cyanide (HCN), which is a carcinogen. Acids and metal cyanides combine to generate HCN, a very poisonous chemical. To reduce the amount of anti-nutrient compound in banana peels, it's required to change the way the peel is processed and remove or reduce some unwanted ingredients.

A diet high in oxalate, for instance, raises the risk of hyperoxaluria (Hulton, 2016)[73], which in people with compromised kidney function can cause acute renal failure and renal inflammation (Getting et al., 2013)[74]. But even with the different processing techniques, the amount of oxalate in banana peels is still less than what the body can metabolize (40-50mg/day). The entire amount of oxalate in banana peels may be destroyed by heat treatment (Lawal and Adelbowale, 2004)[75].

According to Schlemmer et al. (2009) [76] the inclusion of phytate in the diet helps prevent calcium crystallization in renal organs like the kidney and decreases blood glucose and cholesterol levels. The phytate concentration was generally low, with long-term levels between 1% and 6%, which can affect mineral bioavailability. However, too much phytate can chilate minerals and decrease their absorption. Banana peels, as indicated in **Table 3**, had phytate contents that were safe, compare to cereals, which had the highest phytic acid content.

Table 3: Anti-nutrient composition in banana peel with its processing condition (Hana et. al, 2022)

Processing Method	**Anti-nutrient Composition**				**Reference**
	Phytate	**Alkaloids**	**Oxalate**	**Glycosides**	
Fermentation	9.27 mg/g	–	8.28 mg/g	149.02 mg/g	Ozabor et al. (2020)
Microwave-drying	4.07 %	5.45 mg %	0.85 mg %	–	Abou-Arab et al. (2017)
Boiled banana peel extract	2.11 %	1.76 %	40.2 %	–	Oyeyinka & Afolayan (2019)
Boiled plantain peel extract	2.34 %	0.45 %	20.0 %	–	
Air and oven-dried	0.28 mg/g	–	0.51 mg/g	–	Anhwange (2009)

When using complete banana peels, without nutrient extraction, it's crucial to subject them to specific pretreatments, in order to keep anti-nutrients as low as possible.

Banana Peels in the Food Sector

Ripe and unripe banana peels have been utilized in previous research to improve the physiochemical and nutritional qualities of a range of food products (examples include bread, noodles, jelly and meat products).

Furthermore, compared to pulp, banana peels contain far more ash, protein, fat, crude fiber, and dietary fiber, allowing for the creation of meals with excellent functions (Nasrin et al., 2015; Agama et al., 2016)[77]. The efficacy of phytochemicals and antioxidants in food formulations may be enhanced by a high banana peel content. But it could lead to food products that are not palatable to the senses and have poor physiochemical qualities. Therefore, it's important to research the right amounts of banana peel that should be used in different food products.

1. Meat Products

Many cultures use specific seasonings like spices to season meat products. One such example is Basterma, a dried meat product consumed predominantly in the Middle East, where a mixture of spices including *Fenugreek* is utilized. Unbeknownst to local people, who have added such spices for enhancing the taste, these seasonings are very beneficial to human health. *Fenugreek* has been studied for its anti-inflammatory, anti-bacterial, anti-cancer, and anti-diabetic properties (Kalyan et. al, 2017)[78].

Curiosity in using banana peel powder in meat products, akin to spices, has led to several studies, including one done by Hana et al. (2022). In this study, banana peel powder from a Saba variety (genome BBB) was used to create a chicken sausage with a higher dietary fiber content. Chemical analysis revealed that the inclusion of banana peel powder did not significantly reduce the amount of ash and dietary fiber in the chicken sausage.

Decreased total fat content from 9.18% in the control sausage to 7.67% in the chicken sausage with 2% banana peel powder is another indication of a successful outcome. The water-holding capacity (WHC) and cooking yield of the chicken sausage supplemented with 2% banana peel powder were also found to have greatly improved, according to the authors. However, adding more than 2% powdered banana peel to a product has a negative impact on its texture and color. Furthermore, compared to the control, which was chilled at +-4 C for 30 days, adding 2% of banana peel powder to sausage prevented lipid oxidation by up to 55%, suggesting that it had antioxidant qualities.

In a different study, Devatkal et al. (2014) [79] found that after 8 days of refrigeration, the aqueous extract of banana peel in raw chicken meat reduced the amount of thiobarbituric acid reactive compounds (TBARS) by up to 38.3%. While sapodilla extract only decreased 37.2% of the total broiler-associated radiation (TBARS) in raw poultry meat. It seems banana peel extract was successful in effectively lowering the TBARS value in the same meat (56.8%).

2. Banana Flour Preparation

Since banana flour is the basis of making bread, cookies and other products, it's vital to mention the steps into processing the banana itself. The process to make banana flour from both pulp and peel is similar, except for the heating methods used.

Most studies mentioned by Hana et. al, 2022 have used *oven drying*, but other methods like *spouted bed drying* and *freeze-drying*(lyophilization) have also been employed.

Moreover, it's key to remember that bananas spoil quickly and need to be dried for longer storage. Banana flour has great potential for shelf life and can be easily added to various food products. The nutritional content of the flour can vary based on factors like the banana variety, harvest time, and drying methods (Haslinda et al. 2009)[80]. Red bananas for example, have high levels of polyphenols because of their red pigment, and have been shown to extend the lifespan of *Caenorhabditis elegans roundworm* (Govindhan Thiruppathi et. al, 2023).

3. *Bread*

Due to bread's widespread consumption in global food markets, researchers are increasingly focusing on fortifying bread with a variety of dietary fibers and functional compounds to maximize its potential as a carrier of compounds that promote health (Khoozani et al., 2020)[81]. Eshak (2016) [82]examined the effects on the physicochemical and sensory characteristics of Egyptian baladi flatbread with two different concentrations of banana peels (5% and 10%) used in partial substitution of wheat flour.

The results of the chemical composition analysis revealed that the Egyptian baladi flatbread had more protein, fat, and ash. Furthermore, when banana peel was substituted at 5% and 10%, respectively, the carbohydrate content dropped from 74.93% in the control bread to 50.5% and 44.34%.

For diabetic individuals who want to consume fewer carbohydrates, or who would like to optimize their glucose regulation, low-carb bread may be helpful. With only a minor decline in approval for the texture, scent and color, banana peel flatbread in the same study exhibited comparable sensory acceptance to the control flatbread.

Kurhade et al. (2015) [83] assessed the impact of banana peel powder on the microstructural quality and bioactive components of chapatti in a different study. Banana peels made up of 5%, 10%, 15%, and 20% of the flour were used to make chapatti dough. When compared to the control, chapatti infused with powdered banana peel had a noticeably higher total phenolic and flavonoid content.

4. *Cookies and Cereals*

Functional cookies were created in the study by Arun et al. (2015) [84] using banana flour of the Nendran variety at rations of 5%, 10%, and 15% without changing the overall wheat flour composition. The cookies had high moisture content, ash, and total dietary fiber (15.78%-36.74%). Spread rations, breaking intensity, and cookie index all dropped as the flour derived

from banana peels increased in proportion. The inclusion of banana peel flour gradually raised the phenolic content from 4.36 mg GAE to 5.28 mg GAE in comparison to the control cookie (3.21 mg GAE). In terms of sensory acceptability, cookies containing 105 flour made from banana peels were preferred over the other formulation due to improvements in color, flavor, and texture.

Banana peels were also incorporated in cereals in a study by Vania Silva Carvalho and Ana Carolina Conti-Silva (2017) [85]. The cereal bar made only with oat flour was soft, sticky, and yellowish, whereas the cereal bar made only with banana peel flour was very dark and lacked the distinctive texture of cereal bars. Since rice cakes are frequently used in products of this kind, their inclusion made the bars more akin to commercial cereal bars and may have also boosted the acceptance of the cereal bars.

The combination of the three ingredients may have a positive effect on sensory acceptability because cereal bars are made with a variety of dry ingredients (like rice cakes, oats, and dried fruit) and binders (like glucose syrup and honey), which may indicate that banana peel flour could be an ingredient in producing enriched cereal bars.

5. Noodles

Supermarkets are loaded with the most common types of Asian snack/food: noodles. Whether ready-made or home-cooked, noodles are cherished and enjoyed for their starchy and filling properties and spicy taste. However people like to prepare it, noodles can also be fortified with added fiber in the form of banana peels.

In a study conducted by Saifullah Ramli et al. (2009) [87], noodles made from ripe banana pulp or peel were used to replace some of the wheat flour. In most cases, the starch hydrolysis index, projected glycaemic index(pGI) and physicochemical parameters of cooked noodles were influenced by banana flour addition.

Overall, the cooked noodles' pGI values were as follows: banana peel noodles< banana pulp noodles< control noodles. Since the peel flour was greater in total dietary fiber but lower in

resistant starch levels than the pulp flour, the low pGI of banana peel noodles was mainly owing to its high dietary fiber content. Hence, despite some physicochemical aspects of the noodles being changed, banana pulp and peel flour may be helpful in regulation starch hydrolysis of yellow noodles.

6. Pasta

Italians have perfected the art of pasta making through the incorporation of different ingredients in their sauces; from alfredo to tomato basil, even using pumpkin in raviolis, innovation in this type of dish knows no boundaries. Since the benefits of durum wheat has been widely studied, including its antioxidant and pro-vitamin A content (Pooja Saini et. al, 2022) [87], enriching pasta with dietary fiber has also become a subject of research over the past years.

Two tests were conducted in 2009 to examine the qualities of spaghetti that had been supplemented with semolina flour and various substitution ratios of GBPF (Green Banana Pulp Flour). A decrease in the lightness, protein, and fat content of spaghetti containing 20, 35, and 40% GBPF was documented (Ovando-Martinez et al. 2009)[88], which was in line with a similar trend in the majority of banana bread products.

Additionally, the texture was stickier and chewier due to the release of starch during cooking. Cooking resulted in a loss of less than 7% of the pasta weight (from water absorption or breaking of pasta parts), which is acceptable since losses below 8% are typical for semolina-based products, and this wasn't seen as a negative outcome. The enriched spaghetti also contained a significant amount of resistant starch, making it harder for the body to digest compared to regular pasta. Overall, the banana-enriched spaghetti maintained good cooking quality while offering potential health benefits.

In a different study, researchers replaced 10% of wheat flour with pulp and peel from two banana varieties to make alkaline noodles. They found that the green banana peel flour (GBPeF) had more total dietary fiber (TDF) but less resistant starch compared to GBPF, which is why the banana peel noodles had a lower glycemic index (GI).

Noodles made with pulp from the Cavendish variety were more elastic, while those made with peel from the Dream variety were less elastic. The study noted that the higher sugar content in the banana pulp contributed to a greater amount of total solids, which increased the density of the noodle's molecular structure (Ramli et al. 2009)[89].

7. Ice cream

The way ice cream is consumed nowadays has changed over the past decade. Before the fuss about sustainability and healthy eating, flavors or ingredients were limited. However, nowadays consumers can enjoy lactose-free, dairy-free ice cream and even vegan ones. Research into enriching ice cream with beneficial ingredients, like banana by-products, has led to promising results.

In a study by Filiz Yangilar,2015 [90], the effect of banana flour on the properties of ice cream was carefully researched. The banana flour was added at different levels (1% and 2%) and properties like physical (overrun, viscosity), chemical(dry matter, fat, ash content, acidity, pH, water, water and oil holding capacity, and color), mineral content (calcium, potassium, sodium, phosphorous, sulfur, magnesium, iron, manganese, zinc, and nickel), and sensory attributes were observed. The banana pieces used in the study were high in dietary fiber, containing 66.8 g of total dietary fiber per 100 grams, with 58.6 grams being soluble and 8.2 grams soluble. This shows that bananas are a valuable source of dietary fiber for food production.

The flour made from green banana pulp and peel significantly influenced the chemical composition of the ice cream, with an increase in sulfur content and a decrease in calcium content as the banana flour level increased. Sensory evaluations revealed that the ice cream containing 2% green banana pulp flour received the highest ratings from taste testers.

EU's Farm to Fork Strategy

An essential part of the EU Green Deal, which aims to create a more health-conscious, and ecologically safe system, is the farm-to-fork approach. This strategy places a strong emphasis

on sustainability at every level of the food supply chain, from field production and harvest to consumer consumption. Its objectives are to lower the total environmental effect of food production, support sustainable farming ways, and motivate consumers to eat healthier, more nutrient-dense foods. Thus, a more resilient food system that promotes the environment and human health is the overall goal of the Farm to Fork strategy, which tackles problems like biodiversity loss, soil erosion and greenhouse gas emissions.

For this reason, certain recommendations have been put forward by the EU platform of Food Losses and Food Waste (2019) directed at consumers, suppliers, governmental bodies etc. Regarding proposals related to reducing food waste, the platform recommends investment in food research and innovation in order to reuse food co-products.

1. Novel Food Regulation

In the European Union, "novel food" is defined as food that has not been significantly consumed by people in the EU before May 15, 1997. This includes foods that result from new production processes, contain new ingredients, or are derived from plants or animals that have not been traditionally eaten in the EU. Novel foods must undergo a safety assessment and authorization process before they can be marketed to consumers. The regulation aims to ensure that these foods are safe for consumption, provide clear information, and encourage innovation in the food sector. (EU novel foods)

2. Current EU Regulations Related to Novel Foods and Food Waste Products

The authorization, use, and management of food waste are governed by a set of laws in the EU. These kinds of restrictions are crucial for novel components such as banana peel flour. The approval process for foods that haven't been traditionally consumed in the European Union is addressed under the Novel Foods Regulation *(EU) 2015/2283*. Banana peels can be included in this category, hence in order to utilize them in food items, the EU Commission must first approve a novel food application.

Additionally, all food ingredients including banana peel flour for instance, must be safe for ingestion and shouldn't endanger consumers' health, according to the General Food Law (law *(EC) No 178/2002*).

Regarding laws related to contaminants in food, there's *EC Regulation No. 1881/2006* that sets maximum limits for certain food contaminants including nitrates, mycotoxins, metals, and various chemicals such as dioxins and polycyclic aromatic hydrocarbons. For food by-products used as additives, *EC Regulation No. 1333/2008* applies.

If these products are intended for animal feed, *Directive 2002/32/EC* provides rules on harmful substances in animal feed. Also, *Regulation (EC) 1069/2009* and *Commission Regulation (EU) 142/2011* outline the conditions under which animal by-products can be utilized for animal feed and in other areas like cosmetics and medicines.

Furthermore, food companies are required to adhere to certain hygienic requirements put forth by *Regulation (EC) No 852/2004*, which guarantees safe processing procedures. Following hygienic procedures is important in preserving food safety during the complete production process. Also, the significance of regulatory compliance is emphasized by the *Official Controls Regulation (EU) 2017/625*, which specifies the inspections and controls that have to be carried out for novel ingredients.

Moreover, *the Waste Framework Directive (2008/98/EC)* addresses waste management and emphasized the recycling and use of food by-products. The incorporation of banana peels in food items aligns with this directive by promoting the upcycling of food waste, however it's essential to comply with the relevant waste management/recycling standards. Together, these regulations ensure the safety and efficacy of novel foods and contribute to the development sustainable practices in the food industry.

3. The Need for a Clearer EU Regulation Regarding Food Waste Products

An estimated 59 million tons of food are wasted annually in EU (Eurostat 2024). Although it might be impossible to recover a lot of this waste, there's one innovative way to go, and that's through upcycling of the food waste products.

It's important to note that this method compromises consumer food safety. Adapting to evolving food safety requirements must be a key component in developing new products through waste recycling.

Till now, the term "safe food" isn't defined in the EU General Food Law. Instead, it emphasizes the negative meaning of "unsafety" by declaring in Article 14(2) that food will be regarded as unsafe if it's thought to be harmful to health or inappropriate for ingestion by humans. Hence, further revisions in the EU food waste laws are required to clear the path in front of companies wanting to upcycle their waste products.

4. Regulations on Pesticide Limits of Bananas and their By-products

As mentioned in this review, banana peels offer a multitude of benefits, however the use of pesticides can hamper their full utility. If there's too much pesticide present in the banana peels, this can tamper with people's health.

That's why it's crucial to regulate and keep an eye on their amount on these peels. Consequently, research into the dynamics of pesticide residue in bananas and the development of bio-pesticides to lessen dependency on chemical pesticides are important for the responsible use of pesticides and banana by-products (Fanglei Zou, et. al, 2022)[92].

The World Health Organization (WHO), the Food and Agriculture Organization (FAO), and Codex Alimentarius set the maximum residue limits (MRLSs) for pesticide use in bananas. Hiago de O. Gomes' 2020 [93] evaluation pointed out that Brazil imposes more stringent regulations than the EU does. 38 pesticides from different chemical classes are legal in Brazil (ANVISA, 2018;MAPA, 2018); nevertheless, not all pesticides were included in the evaluation. Regulations

are inconsistent since there isn't a single worldwide standard for pesticide use or residual limitations.

Moreover, there were just two studies that have looked particularly at pesticide residues in banana peels. According to a 2009 study by Hernandez-Borges et al.[93], pulp concentrations were higher than the MRLs established by Codex, the EU, and Brazil, however chlorpyrifos residues were mostly maintained in the peel. Only five pesticides in total are permitted for use in the cultivation of bananas in Brazil, compared to nine under Codex and 22 in the EU.

This disparity highlights the lack of agreement in international law regarding the use of pesticides and Maximum Residue Levels (MRLs), which may affect the quality of fruit that is eaten. Therefore, there's a pressing need for a global re-evaluation of using pesticides and more research for MRL assessment, considering the varying requirements across different countries.

Regarding food by-products, there are safety concerns during production and processing because there are no explicit criteria for their usage in the EU's circular economy, which aims to reduce waste and promote material reuse. For instance, hazards from heavy metals and mycotoxins must be evaluated at every stage of the flour-making process including banana peels and pulp.

Hazards from soil or water can build up and result in additional pollution problems, as M. Focker et al. (2022) [94] pointed out. This further highlights the important requirement for a circular redesign of main production systems, with a special focus on safety-by-design principles.

Current Methods in Tracking Data in the Food Supply Chain

A wide range of tools, such as cloud computing, the Internet of Things (IoT), blockchain, sensor technologies, and more are examples of digital technologies utilized in food supply chains that enhance supply chain performance. “Digitally connected supply networks aren’t about whether the products or services are physical or digital, but it’s the way the supply chain is managed”, according to Buyukozkan et al.[95] who also claim that there are many unrealized benefits of digitization in supply chains.

1. ***Digital Platforms***

Many times, fresh food that’s ready to be shipped to factories can experience hurdles along the way. This can be in the form of transportation problems (not enough truck drivers, blocked roads, weather disturbances), and also how they’re stored in the facilities (in brines, or under frozen temperatures). Such issues can be dealt with digital solutions. When farmers log in to shared platforms where they can share information and communicate with other stakeholders, this can ease some supply chain problems Cane and colleagues(2020).[96]

Food waste applications like *Too Good to Go*, do their fair share of handling food waste. Customers interested in buying leftovers or surplus food from restaurants and food stores can do so using this app.

Of course, there’s the chance of getting expired food, however it seems that many people are fine with taking such risks, judging by the high number of registered users and business partners. (Too Good to Go, history 2024).

2. *Internet of Things*

Over the years, manual tasks have been declining in all areas of life. Smart phones and smart TVs have paved the way for technology to "talk" to each other in electric waves. With more companies embracing automation, there's now a need to implement such tools in the food sector.

The Internet of Things or IoT refers to the network of physical devices embedded with sensors, software and other tech that lets them connect and exchange relevant data over the internet. Such connection allows for real-time monitoring, data aggregation, and automation, resulting in a more efficient ecosystem.

An overview of the technological factors that facilitate transparency in food supply chains from an Internet of Things standpoint was provided by Astill,2019[97]. Among the physical tool used in data acquisition technologies are sensors, which may gather, process, analyze, and store data. Such sensors range from smart ones used in industrial food processing to biosensors that may, for instance, measure and transmit livestock's temperature.

The integration of sensor tech with recently developed computing capabilities can ensure increased traceability and control across the food supply chain. Moreover, the use of radio frequency identification (RFID) for traceability in food supply chain management has already been covered in literature.

An information infrastructure for RFID-enabled traceability and a system architecture with standard implementation and compatible interfaces are proposed by Kelepouris et al,2007[98]. However, current knowledge in generating models for traceability systems is lacking.

3. Blockchain Technologies

Blockchain is a relatively new concept that's gaining traction as a means of enabling digital platforms to provide data access to various supply chain participants. A blockchain according to Astill et al. 2019, is a system that lets transactions on a public or private ledger become accessible to a variety of groups or individuals without the need for a formal third party to oversee the transactions.

Powell et al. provided blockchain as a solution to food supply chain traceability issues and highlight IoT as a useful data collection tool for its use. There aren't many research on the real-world difficulties of implementing blockchain tech in food ecosystems, despite the fact that it can make the supply chain coordination more robust and boost data integrity.

4. End-to-end Integration

Paperless information sharing between parties involved in the food system can be accomplished in a number of methods (such as emails or faxes).

Nonetheless, enterprise information systems that can provide end-to-end solutions in real-time are crucial for on the spot information interchange, particularly in industries where time is of the essence like fresh food. With next-generation enterprise resource planning (ERP), for instance, manufacturers and wholesalers can collaborate across organizational boundaries.

In this sense, real-time product-centric data straight from the door can be obtained using an enterprise information system called MES. MES's features, like product tracking and origin detection, can enhance supply chain traceability during the ordering, production, and delivery of fresh food products.

Hence, in order to ensure smooth machine communication across the supply chain, enterprise information systems must be developed and implemented utilizing contemporary integration and computing concepts. (Mantravadi, Charles Moller,2019)[99].

Verdict Regarding Integrating New Tech into the Food Supply Chains

In his analysis of the specific systems used to manage the food supply chain, Zhong divides them into two categories: decision-making systems and traceability systems. Information and communication tech have the potential to boost the decision-making inside agricultural supply chains, according to research.

Trienekens et al describe the data processing and storage requirements for a range of business operations, including order and warehouse management, and also talk about how information systems promote openness. They suggest an adaptable information system design that makes it easier for various stakeholders-such as the government, manufacturers, and consumers-to communicate with one another.

However, given that the Internet of Things (IoT) incorporates a wide variety of digital devices and sensors throughout the supply chain, the conventional design of supply networks might not function well with it. Clearly, there's more research required for the use of IoT in the food supply chain.

ReSOLVE Framework and the Circular Economy: Their Roles in Food Sustainability

Using peels as ingredients fits just right in the world of circular economy. Though the idea of reusing food waste products might be tempting, there aren't many companies that have gone to the end of the earth and back to implement such strategies. Rightfully so, since it requires financial sacrifice and tons of funding for research.

However, frameworks that encourage recycling have come up during the past few years, including the one called **ReSOLVE Framework.** The ReSOLVE framework by Ellen MacArthur is a thorough strategy created to ease the shift to a circular economy. The five main tactics of the framework are Virtualize, Loop, Share, Optimize, and Regenerate. Every tactic provides a

different technique to cut waste, advance sustainability, and lengthen the useful life of goods and resources in the market.

1. **Reenergize**

Energy is neither created nor destroyed. Thus, when talking about conserving energy in a sustainable way, the first thought that comes to mind is to improve and restore natural systems. Regenerative agriculture, for example, places a strong emphasis on techniques that enhance soil health, boost biodiversity, and sequester carbon.

2. **Share**

Sharing is caring, and the thought of being more community-oriented will pay off big time in the future, where resources are predicted to dwindle.

The share tactic lowers the total demand for new items by promoting the sharing of goods and services among individuals and organizations. Platforms for automobile sharing, co-working spaces, and tool libraries are a few examples. These approaches strengthen ties among the community while also optimizing resource utilization. By extending the life cycle of products, cutting waste, and lowering the demand for new production, sharing helps to conserve energy and materials.

3. **Optimize**

Ever since the invention of the dishwasher, people have become accustomed to optimizing their time. Now, companies striving to achieve optimization can reduce energy use and material waste through the use of data and technology. To reduce extra inventory, for instance, producers can record information about their daily orders into the system. This way, they will be able to track their spending and customer orders.

4. **Loop**

A Loop is a closed circle and this concept focuses on developing closed-loop systems that continuously reuse materials and reduce waste. This entails considering how a product will be used in the end and making sure that its materials can be readily recovered, recycled, or put to new uses. Companies can encourage customers to return products at the end of their life cycle to receive financial compensation for job well-done, for example.

5. **Virtualize**

Finally, the term "Virtualize" describes the use of digital tech to minimize the consumption of physical things. This can include using digital services in place of tangible goods, e-books in place of printed books or online meetings in place of trips. Businesses can reduce their environmental impact and increase customer accessibility and convenience by embracing such virtualization.

For now, the "status-quo" or "business as usual" mode of thinking, which is the standard practice for the majority of the food firms and restaurant chains that control the global food market structure, is challenged by the implementation of innovative food production methods. In fact, if someone were to ask most businesses if they know how to transition into greener pastures or use banana peels as a new food ingredient, they would look at the person dead in the eye and avert their expressions towards their KPIs and productivity graphs.

Notably, in this instance, changes can only be made in response to this structural adaptability through incentives. Therefore, governmental regulations and guidelines are essential to guaranteeing the long-term viability of a circular economy (Maria Luiza M. B. B. Gonçalves and Guilherme J. Maximo, 2022).

Marketing and Acceptability of Sustainable Products

When shopping for products, consumers didn't have many choices as they have now. With the addition of the terms "organic" and "sustainability", it can get confusing to choose which product they should go for. That being said, if products get clearly labelled by producers or supermarkets, consumers don't have any issues with choosing that product. According to Susan M. Harris, 2007, customers from New Zealand were more than eager to buy certified sustainable lamb meat when the appearance and label were made to be signify as high quality. Other factors also play a role in encouraging consumers to choose sustainable products and contribute their part in the circular economy.

1. *The Choice of Ugly Food*

In a choice experiment conducted by Wen-Shin Huang et al., 2020 [101], participants were asked to choose between citrus fruits based on elements which include appearance, size, freshness, and price discounts. The findings showed that customers place a higher value on fruit look overall and freshness indicators such harvesting and packaging date labels. It's interesting to note that, in contrast to flawless fruits, people are willing to pay less for citrus fruits that have imperfections in their look.

Subpar foods do not pose health dangers, yet many consumers are nonetheless hesitant to purchase them, which results in a considerable amount of food waste. This research emphasizes how important it is to spread the word about the acceptance of less-than-ideal foods and how they can help cut down on waste, which will ultimately aid in the cause of sustainable development. Promoting more sustainable consumption habits and reducing waste can be achieved by urging customers to enjoy these fruits.

2. *The Power of Video Campaigns*

Nowadays, consumers, especially young ones are glued to screens scrolling through social media platforms. Many times they might come across ads that prompt them to buy something or educate them on a certain topic. These kinds of vehicles of information can be used to advocate for sustainability causes.

In fact, a study by Arif Try Cahyadi and Muhammad Adhithyas Prasetyo, 2024 discovered that majority of people know about food waste but still continue to impulsively throw away hardly-expired food or leftovers. A 2-D animated animation was made by researchers to spread the word about food waste and how to avoid it by making wise shopping choices.

The film uses characters to depict the topic while using a third-person point of view to deliver the story. The idea that wasting food is the same as squandering money is introduced by a young man who unexpectedly witnesses food turning into money. The animation successfully engages viewers in the conversation about this crucial topic by focusing first on the economic effects of food waste and then on its environmental effects.

3. *Digital Marketing for Sustainability*

Going the digital route for businesses is a no-brainer in the age of technology. Hence, in a study conducted by Yassir Bhakti and Syarifah Rafikah, 2024 [102], looked into how digital marketing tactics affect consumers' decisions to buy in Bandung City's retail industry, with a focus on how consumers feel about sustainable branding. The study evaluated the association between consumer sentiment toward sustainable branding (SCBB) and purchase decisions (KP) using linear regression analysis. F- and t-tests were used in the approach to assess the significance of the results.

According to the data, SCBB had a significant beneficial impact on KP, suggesting that consumers' perceptions of sustainable branding influence their purchase decisions. The study comes to the conclusion that improving customer purchasing behaviors in the retail sector requires the implementation of efficient digital marketing strategies focused on sustainable branding. Retailers can use these insights to help them create strategies that reflect the values of their customers.

4. *The Importance of Social Influence in Choosing Sustainable*

No one can deny the immense effect social norms and cultural traditions have on consumer behavior. Childhood food aversions or food liking can later shape adulthood behavioral choices. A study by Sezgin Tunca et. al, 2024, examined European consumers' intentions to purchase low trophic level aquaculture (LTA) items, such as seaweed and mussels, in light of the growing importance of these products globally as sustainable and healthful seafood options.

They examined how health consciousness, food knowledge, food neophobia (the fear of consuming new foods), socio-demographic characteristics, and lifestyle factors affect purchasing intentions for LTA goods using an expanded theory of planned behavior. A survey was carried out online with roughly 500 participants from Denmark, the UK, and France each.

They discovered five separate categories, each representing various consumer behaviors, using K-means clustering algorithms for customer segmentation based on food-related lifestyles: "Adventurous," "Uninvolved," "Foodies," "Rational," and "Conservative." Furthermore, they discovered that subjective norms a.k.a. social influences, was the best predictor of purchasing intentions for LTA products, followed by attitudes, food neophobia, subjective knowledge, and health consciousness in their analysis using partial least squares structural equation modeling. Additionally, it seems that food neophobia moderated the impact of subjective norms and knowledge on purchasing intentions.

This dual strategy reveals the model's predictive power and pinpoints target customer groups for the promotion of sustainable aquaculture goods. Marketers could concentrate on the "Foodies" category, which is distinguished by high involvement and a desire to try new things, in order to attract more people to use LTA products. Aside from tackling food neophobia and taking advantage of societal norms, strategies should emphasize improving positive attitudes, promoting health benefits, raising awareness about LTA goods, and stressing food quality.

5. *How Individual Beliefs Impact Food Choices*

“No smoking” campaigns and “say no to drugs” slogans might impact people’s choices and how they choose to go about their lives, but at the end of the day, sometimes a “watch out” behavior can trigger the opposite.

For instance, in a study by Maureen Schulze, Meike Janssen, 2024 [103], Self-determination theory (SDT) was used to fill a research gap by investigating the reasons behind Danish consumers' motivation to consume less meat. An examination of 838 typical Danish consumers showed that while external motivation—pressure from the outside—does not contribute to the reduction of meat consumption, intrinsic motivation—internal desire—and internalized extrinsic motivation—values taken from others—are crucial for promoting sustainable eating.

Subsequent investigation revealed four customer segments: 12.4% are extremely intrinsically motivated, 30.4% are somewhat motivated, 27.3% are completely unmotivated, and 29.8% are unsure. The results show that customers' decisions about what to eat are not influenced by perceived outside pressure. Rather, the main motivators are a strong sense of self-determination and a personal dedication to sustainable eating.

Taking into account the above studies and experiments, it’s safe to say that marketing such sustainable products is no easy task and seeking to market banana peels, for example, can be more difficult, judging from the way people may respond to consuming it.

Challenges in Communicating about Food Waste to Consumers

The general people may not fully comprehend the definition of upcycled food that are now in use. A more approachable and straightforward definition is required to enhance engagement with customers. For example, foods that have been upcycled can be labelled as “eco-friendly products” created from safe ingredients that would not normally be eaten, like food scraps, damaged produce, and food by-products. It can be challenging to package and advertise them in an appealing way, but thinking outside the box can do wonders when food companies

collaborate with marketing firms.

In the context of food waste management, upcycled food manufacturing can be positioned within the waste management hierarchy, presenting it as a viable technique for minimizing food waste. In this hierarchy, it can be placed below redistribution initiatives and above animal feed (Hanieh Moshtaghian et. al, 2021).

Tradition vs. Novelty

General distaste or disgust towards food by-products can be a very cultural phenomenon. For instance, the mere addition of pineapple on pizza can send an Italian into a heated argument. However, with the advent of technology and the increase in interest in sustainable products, things are changing even in the most traditional countries.

In fact, a study by Maria Angela Perito et. al, 2020 [104], focused on using olive leaves as upcycled products for consumers. It identified specific consumer groups that could be targeted in marketing campaigns. For instance, for Generation Z and Millennials, fears about technology (technophobia) were significant drivers for purchasing organic food, and they responded positively to words like "organic" and "origin."

The analysis showed that people who buy organic food are generally more open to trying new products, especially if they have environmental benefits. This finding aligns with existing research, which suggests that organic buyers are particularly concerned about environmental issues.

Overcoming the Fear of Disgust

Thinking about peels and other waste products as viable options for food consumption can sound ludicrous to many people. However, studies have been done lately showing people being open in trying new kinds of food, including those made from food waste by-products.

In a study conducted in 2024 by Nazarena Cela et al.[105] eighty young people between the ages of 18 and 35 participated in a two-step study procedure. They started by sharing their personal details on an online questionnaire. The participants were then divided into two groups: one that was informed about circular economy (CE) activities (CE+) and the other group (CE-) that was not. Three upcycled items were asked about: beer produced from leftover bread, dairy product manufactured from recovered cheese, and biscuits made with grape pomace flour. They were also asked about their purchase intentions and perceived value of these foods.

The findings showed that while sentiments of disgust were not associated with a stronger intention to purchase upcycled foods, traits including a strong sense of personal responsibility, interest in healthy eating, and knowledge of the social consequences of their choices were. For every food that was evaluated, there was no discernible effect of CE information on either sensory acceptance or purchase intention.

Furthermore, 86.83% of the data variability was explained by a good classification of the upcycled foods based on perceived value, as demonstrated by the application of Principal Component Analysis (PCA) to the sensory data. The foods were divided into two categories by the first principal component, and participants' receipt of circular economy information determined the second division. This points to an important need in educating generations, especially the young about healthy eating and social responsibility, not only towards the environment but towards society as a whole.

Possible Promotion Strategies of Up-cycled Products

Upcycled foods are made from surplus food, edible food waste, and by-products that would otherwise get thrown away. Many food and beverage brands are beginning to introduce and promote these upcycled products to consumers. However, there's still a lot we don't know about how consumers feel about upcycled foods and the best ways to market them.

To explore this, researchers Francesca Goodman-Smith et al., 2023 conducted two studies in New Zealand: one online with 300 participants and another in retail stores with 65 shoppers. Both studies looked at consumer attitudes towards upcycled beer. They found that consumers valued the environmental benefits of upcycled foods most highly and that providing information about these products, both on packaging and online, was a key marketing strategy.

Interestingly, consumers felt more aware of and accepting of upcycled foods when shopping in stores, but they also had concerns about taste and price. Only 31% of in-store participants thought there were "no negatives" to upcycled foods, compared to 47% of those surveyed online. These results highlight different strategies that could be used to effectively promote upcycled foods, focusing on increasing consumer awareness and addressing their concerns about taste and pricing.

Discussion

The use of banana peels for many food products has great potential. The once forgotten component that dresses the pulp has finally caught the attention of scientists and food businesses alike. As mentioned before, banana peel's nutrients and benefits extend towards many functions, including anti-bacterial, preservative, and even probiotic.

One study by Chinnappan Ravinder Singh et. al, 2013, examined the antibacterial properties of banana peels in the colors yellow, green, and red against ten clinical pathogens in comparison to conventional antibiotics. Banana peels with three distinct colors were dried individually for thirty days. At normal temperature, the powdered substance was extracted separately with methanol chlorofarm (8:2).

When it came to antibacterial activity, the red peel was the most active, showing a maximal zone of inhibition of 27 mm against Pseudomonas citrii and 18 mm against Staphylococcus aureus. The green banana peel exhibited a 19 mm inhibitory zone against Aeromonas hydrophila and Salmonella typhi. In terms of Aeromonas hydrophila, the yellow banana peel showed 20 mm, and in terms of Staphylococcus aureus, 13 mm. It's interesting to note that

none of the three banana peel extracts shown any activity against the native flora. This is a great thing to keep in mind since taking antibiotic medications against such bacteria like Staphylococci can damage both bad and good bacterial flora.

Another study by Ali Meawad Ahmed et. al, 2018, focused on meat preservation, was conducted to enhance the microbiological quality and safety of traditional beef marinade components by adding banana peel extracts (BPE). Samples of beef were marinated for four hours at 4°C with salt, onion, tomato, and 1%, 3%, and 5% aqueous extracts from banana peels. Before roasting, the meat's sensory parameters showed good values when 1% BPE was added.

However, panel testing revealed that the meat's sensory parameters improved after it was marinated with various BPE concentrations. When the concentration of banana peel was increased, BPE not only demonstrated antibacterial activity against Staphylococcus aureus in vitro but also produced antimicrobial activity against aerobic and enterobacteriaceae, increasing the reduction percent. Hence, using banana peels to combat food poisoning and contamination can prove successful in future experiments.

Regarding probiotic activity, banana peels have been used in camel milk to show their activity in growing probiotic bacteria. For instance, an investigation by Younes Safdari et. al, 2021, examined the impact of varying amounts of banana fiber and banana peel fiber (0, 0.2, 0.5, and 1%) on the chemical and rheological characteristics of synbiotic yogurt made from camel milk. The outcome demonstrated that while the samples' overall acceptability, color, and flavor significantly decreased with an increase in both fiber content, they showed a significant increase ($p < 0.05$) in viscosity, probiotic bacteria survival (Lactobacillus casei and Lactobacillus gasseri), and texture acceptance.

Ultimately, one of the main drawbacks of yogurt is its syneresis, which was lessened by these fibers while also improving health. Since this was an experimental study that didn’t include other ingredients to enhance flavor or color, it’s safe to say that the inclusion of enhancers can greatly affect the overall taste profile of the final product. Adding tahini and lemon juice to such yogurt can be tested to see if the result can be more acceptable.

When trying to consider banana peels for future products, the different levels of pretreatments are essential to evaluate. This review discussed a few of the available pretreatments of peels. Since bananas have a wide variety of cultivars, choosing the same type for cookies and bread can present an issue, because of rheological properties.

To be more specific, there's one study by Tonna A. Anyasi, et. al, 2016 that found the best option flour to minimize browning when making cookies or biscuits, the flour from the Luvhele cultivar would be the most suitable option due to its lower browning index. On the other hand, for bread making, the Muomva-red cultivar may be the way to go, as its elongated starch structure could contribute to a better texture and rise in baked goods.

Moreover, when it comes to current regulations pertaining to food waste-byproducts, EU laws provide a more general rule than dive deep into the type of waste by-product. A new list of EU commission members were put together in September 2024 with their respective portfolios. The commissioner responsible for Agriculture and Food will be responsible for realizing and implementing the goals related to sustainability, combatting food insecurity and also pushing together members of the food supply chain to invest in food innovation. (EU Commission, 2024-2029).

Providing safe food is also a top priority. And the issue of pesticides and ripening agents can deter businesses from using peels altogether. One study by Meiran Wang et. al, 2023, found that migration rate of pesticides increased with increased in ripeness. It also mentions how pesticide treatment affects the banana peel and pulp in different ways, when certain genes get activated under stress.

The banana pulp tissues protected themselves through the ascorbate-glutathione pathway. Thus, it's important that such factors should be taken into consideration when thinking about using peels to make new products.

Pesticide exposure increases the risk of getting contact dermatitis in farmers who work on banana plantations (Homero Penagos, 2013). Till now, universal global standards on each pesticide don't exist. This can further become an issue if pesticides found on peels can interfere

with human health. Further experiments need to be conducted in order to evaluate the rate of pesticide transfer into peels and how it can affect by-products after pretreatments.

In the domain of technology, besides the introduction of IoT, RFIDs and digital platforms, 3D technologies that use ingredients to print new products have made it into the mainstream. A study by Leo et. al, 2022, used orange peel waste to make edible products rich in bioflavonoids. Another study by Shazmina Gull, et. al 2021, built small sensors to detect the gas emissions released from rotting meat, cooked meat and rice. Such sensors can collect data and transmit the information into systems in order to evaluate how much food is wasted in restaurants and home settings.

Finally, related to marketing and promotion, including celebrities or well-known people in campaigns can generate much interest into purchasing upcycled foods. However according to (Knoll and Matthes, 2017), even though celebrities can shape consumer attitudes, true trust into consuming upcycled products can be achieved via researchers and scientists.

Conclusion

The road to fully using banana peels as a certified by-product is a long one. There are many studies and experiments that have proven the immense benefits in the food sector. The EU commission formation and the start of a new era can signal much change in the area of food waste management. Clearly, there's a need in creating regulations specifically for by-products to help farmers and manufacturers navigate safely through the process.

Collecting and sorting of such peels is also a problem, since collection from consumer houses would require extra work from municipalities and would need better sorting techniques to separate from other waste. A better idea would be for manufacturers to process and sort them out at their facilities after

receiving the batches from the fields. Producers can collaborate with companies that are involved in research in food innovation to receive the best and latest information about their harvests.

Judging by the high interest in sustainability as of late, banana by-products have a high chance to be marketed to consumers from different generations. The trick lies in using friendly labels or alluring product pictures to convince them to try such products that normally would cause aversions and disgust.

Ultimately, the process of attaining products from banana peels requires solid investments both from the public and private sectors. More experiments and studies need to be done in order to confirm the viability and safety of these products before launching them into the market. If steps are taken in this direction, the future of having banana peel flour or pasta won't be too far from now.

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