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Food Waste Processing Trends Worldwide and Valorization of Food Waste from Pune City

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Abstract

This article lays its primary focus on understanding waste from the domestic and commercial hotel kitchens. For researchers, deciding biotechnological treatment and valorization process, it is necessary to refer and understand the food waste (FW) composition and its processing trends worldwide. This paper mentions the FW compositional data from four different locations of "Pune" a metro city of India. Study-approved procedures for sample collection, preparation, and analysis were followed. The results indicate, the presence of carbohydrates, proteins, and fats in all samples and are sufficient to support the microbial growth and desired product formation. Being perishable, microbiological and compositional changes during handling and transportation, in FW are inevitable. The presence of high boiling, low boiling volatile compounds and volatile organic acids indicate the complexity of FW and microbial activity taking place within it. Abundant amount of trace elements essential for enzymatic reactions and building block molecule formation are present. Average important figures to mention, starch- 7.27% w/w, free sugars- 3.39% w/w, proteins- 7.99% w/w and fats- 12.84% w/w. In addition, essential trace elements Zn- 4 mg/lit, Mn- 4 mg/lit, Mg- 239 mg/lit, S-433 mg/lit and P- 922 mg/lit. The numbers help to realize the nutritional richness of the FW in reality and provide fundamental statistical data for researchers. Treatment and recycling can be done to contribute toward a circular bio-economy. Remarkable variations observed in almost all components on day-to-day basis. However, pretreatment process parameters can be decided to account for compositional variations.

Keywords: Sustainability, Composition, Nutrition, Recycle, Sampling, Bioeconomy

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INTRODUCTION

A UN report released in March 2021 summarized that an estimated 931 million metric tons (MT) of food were wasted in 2019 globally.[1] On September 2, 2015, the 193 Member States of the United Nations adopted the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development. According to the Agenda, global objectives are expected to guide the actions of the international community over the next 15 years (2016-2030). The agenda has been defined as-"Target 12.3" which aims to halve per capita global FW, at the retail and consumer levels by 2030 and reduce food losses along production and supply chains, including post-harvest losses.[2]

On one hand, while efforts to address hunger, ensure food for all, and optimize food production are underway, the question remains, whether the food that's binned should be left to decompose or can its nutritional value be utilized productively? Biotechnologists advocate for the valorization of FW, turning it into a valuable source of naturally derived raw materials for various industries.

From agricultural production to post-harvest storage, processing, distribution, and final consumption, it's evident that the highest losses occur at the consumption level ultimately resulting in FW.[3] It's important to inform world communities about the need to minimize food losses is a priority, but it's also important to study, how to convert waste into useful resources. This research work is an endeavor to review the potential of recycling FW and focuses on its compositional fitness as a nutrient medium for microbial growth.[4]

FW refers to domestic, kitchen, industrial, and commercial mixed food residues that are intended for human consumption. Conversely, "organic waste" encompasses the waste not suitable for human consumption such as peels and rapeseed meals. FW essentially comprises all cooked and uncooked food including rotten fruits and vegetables, fish and poultry organs, soup pulp, eggshells, cheese, ice cream, yogurts, tea leaves, tea bags, coffee grounds, bread, cakes, biscuits, desserts, jam, cereals of all types (e.g. rice, noodles, oats), plate scrapings and leftover cooked food and various pet foods.[5] Unfortunately, FW is often considered a resource of zero value worldwide and is discarded without much ado. On an interesting note, it has been observed that, chemically, FW contains lipids, carbohydrates, amino acids, phosphates, vitamins, minerals, and other carbon-containing macromolecules.[6]

The utilization of FW as raw material presents logical challenges, with collection being the primary hurdle. Both, the collection of FW from multiple places and treating it post-collection pose difficulties. Moisture and soluble sugars in FW make it susceptible to rapid degradation by microorganisms. Additionally, the heterogeneity of FW is greatly influenced by the source from which the waste is derived. Moreover, nutritional habits and the season of the collection can also impact FW composition. Generally, cereals, fruits, and vegetables constitute a significant portion of the FW worldwide.[7] Consequently, sampling procedures were derived to address those challenges and arrive at the most reliable results.

Worldwide, Municipal solid waste (MSW), comprises degradable, non-degradable, and inert waste, with management typically overseen by local governments and waste management systems. Procedures and methods of segregation in waste management are generally similar across regions.[8-12] Conventional practices involve collection, and segregation of waste into subcategories like bio-degradable, inert, recyclable material and medical waste. Bio-degradable waste primarily consisting of FW/kitchen waste, is often treated through methods like bio-methanation or composting.[13] On the other hand, non-biodegradable waste is commonly recycled, incinerated, or disposed of in landfills in most countries.

Global trends in solid waste management indicate that approximately 2.01 billion MT of waste are generated in total and out of this, organic or biodegradable waste accounts for 44%, recyclable waste for 37%, and inert waste for around 14%.[14] As seen in Pune, another exemplary model of waste management can be found in Kerala, a state situated in the southern part of India. Kerala stands out among other Indian states in terms of human and social development. However, including Kerala, all over the world, MSW management remains challenging.[7]

The common practice of disposal of FW in the European Union is landfill or its usage as animal feed and soil conditioner. Analysis reveals that 129 million metric tons (MT) of FW were generated in the European Union in 2011. representing 20% of the food produced. Vegetables, fruit, and cereals are the food groups that contribute the largest amount of FW. Interestingly, most of FW is generated during the consumption stage (46%), almost equaling the amounts generated during primary production (25%) and processing and manufacturing stages (24%) combined.[14] Distribution and Retailing contribute only small fraction of the FW generated in the food supply chain. This highlights significant FW problem worldwide, emphasizing the urgent need of optimal FW management programs that can repurpose the nutritional benefits for better purposes. To determine the fate of FW, it's essential to understand nutritionally important parameters both qualitatively and quantitatively.[15]

FW worldwide

Valorization initiatives worldwide

To address the challenges of limited feedstock, there is global effort to explore the biological conversion in to value-added products. FW is easily available in houses, restaurants and food industries worldwide. At the industrial scale, FW streams are present in large, concentrated, and homogeneous quantities, making them highly suitable for valorization. The technological, economic feasibility and environmental impact of these potential products are being assessed to select the most appropriate processes and products. Scientists are committed to ensure sustainability and safety throughout the value chain following optimal valorization techniques.[16] Efforts are ongoing globally to utilize FW for the production of bio-chemicals, bioenergy and products like Bio CNG.

The demand for renewable resources for energy production has increased globally as most fossil fuels continue to be consumed at a high rate.[13] Lipids extracted from FW can be transformed into biodiesel. Providing a greener alternative to conventional fuels.[17,18] Furthermore, complex carbohydrates like cellulose and starch found in FW can be hydrolyzed into simpler sugars such as glucose.[19] These sugars are fermentable, offering opportunities to create value-added products. This utilization is viable because studies have shown that FW not only possesses significant nutritional value but also hold potential as an industrial raw material.[20] This underscores the importance of FW as both an environmental asset and a sustainable resource for industrial applications.

For decades, the utility of FW from multiple angles has been explored. The citrus processing industry uses byproduct residue to extract pectin, essential oils, and enzymes.[21] Similarly, in the food processing industry, waste is used for separating high value plant and animal-derived products.[22] The identification, isolation, and characterization of bioactive molecules derived from olive mill waste (OMW) have proven useful as plant growth stimulator and defend against pathogens.[23] The utilization of FW as feedstock for producing microbial fuel cell that produces electricity has been demonstrated.[24] FW is nutrient rich and can be converted into solid feed for solid state fermentation, where it is used to produce the enzyme glucoamylase.[25] The process of biomethanation to produce biogas, a gaseous fuel, has been practiced globally for a long time and is now taking shape with technological advancements. These improvements aim to achieve higher biogas yields and facilitate further conversion to compressed biogas which can power turbines to generate electricity.[16,26-32] Eventually, the focus is also on enhancing commercial attractiveness through improved technology and engineering.[33-36]

In addition to sugary, starchy, and cellulosic feedstock, utilizing FW to produce ethanol presents another viable option due to its global abundance.[17,37-39] Although FW composting is an age-old process requiring minimal technological expertise, recent explorations aim to enhance its efficiencies.[40,41] Fermentative products are critical as biochemical intermediates, such as lactic acid, succinic acid, 2,3 butanediol, and bioplasticisers.[19,37,42-46] Other important notable fermentation products include polymers like poly lactate, and poly hydroxyl butyrate.[47]

Non-biological processes resembling thermochemical treatments, such as the pyrolysis of FW, are employed to produce bio oil and biochar.[18] Waste bread with appropriate pretreatment and fortifying it with essential micronutrients can serve as a nutrient medium for preparing starter culture in the food industry.[48]

To assess the potential of FW for conversion into any of these value-added products, the first step is to understand its chemical composition. This knowledge determines its faith and suitability for biotechnological valorization.

Solid waste characterization practices worldwide

Characterization of waste material composition typically consists of three phases. The first phase encompasses sampling of the waste itself, followed by sorting it into various material fractions such as paper, plastic, organics, combustibles, etc. This initial step is crucial for obtaining accurate waste compositional data. However, the absence of reliable international standards for solid waste characterization has resulted in a variety of sampling and sorting approaches, complicating the comparison of results between studies.

Once the waste has been sampled and sorted, the next phase involves handling, interpreting, and applying the obtained data. Researchers worldwide have developed study protocols based on available resources and convenience. Samples are collected from different public groups such as residences, shops, hotels/ restaurants and institutes to represent diverse waste sources. Accurate and reliable data on waste composition are vital for both waste management planning and environmental assessments.

Solid waste sampling can take different forms, often involving direct sampling either at the source (e.g. households) or from vehicle loads.[49] Vehicle load sampling is commonly preferred for its efficiency in capturing a representative sample waste. As part of routine practice, waste is collected from designated areas every morning by pick up vehicles and transported to processing plants. Samples were then collected from these loads for further studies and analysis.[50]

MATERIALS AND METHODS

Solid waste management practices in Pune city

Pune (Figure 1) the seventh most populous city located on the Western region of India and the second-largest city in the state of Maharashtra, with an estimated population of 7.4 million as of 2020. Considering diverse metropolitan population, Pune was selected for said study.[51] Alongside two municipal corporations and three cantonment towns, Pune forms the urban core of the Pune Metropolitan Region (PMR). Renowned as the 'Oxford of the East', Pune boasts a plethora of educational institutions.

The Pune Municipal Corporation overseas the systematic collection of kitchen waste from multiple locations every morning, transporting it to treatment plant nearby.[52-54] In Pune city, approximately, 2000-2500 MT of solid waste is generated at various locations which include biodegradable as well as non-biodegradable This waste is collected from various spots and stored at proximity sites for segregation, with recyclable materials separated for reuse, and the reminder transported for processing

The composition of solid waste in Pune is roughly 45-50% organic matter, 35-40% recyclable matter, and 10-15% inert material. Around 150 MT per day of hotel waste, a subset of organic waste fraction, is collected separately processed at 25 decentralized bio-methanation plants. The remaining biodegradable waste is utilized for composting and vermicomposting in residential complexes.[55]

Despite the challenges posed by its growing population, Pune has effectively managed its solid waste through systematic organizational planning. This paper focuses on the compositional and nutritional evaluation of FW samples collected and analyzed from Pune, shedding light on the city's waste management practices.[56] FW study procedures taking place worldwide, for, sampling, laboratory analysis and statistical analysis were taken into consideration.[19,53,57]

Specifically, the study delves in to kitchen waste generated by hotel across Pune, highlighting a specific research project within the border context of municipal solid waste management.

Sample collection

The activity started with identifying key locations in Pune city with collection centers, considering atmospheric conditions, sampling frequency, and procedures. Biogas plants for processing FW are situated at various sites across the city from which samples were collected. To

Table 1. Analytical parameters, procedures and major instruments used

No.	Parameters	Analytical procedure	Laboratory equipment
A	**Physico-chemical analysis**		
1	Bulk density	IS,2306 (Part III) 1964	Weighing balance
2	Total solids	AOAC 18th Ed. 32.1.02	Vacuum oven,
	Ash	AOAC 18th Ed. 32.1.05	Muffle furnace,
	Fat	AOAC 18th Ed. 32.1.14	Soxhlet apparatus,
	Proteins	AOAC 18th Ed. 32.1.22C	Digestion apparatus, Steam distillation
	Crude fibre	AOAC 18th Ed. 32.1.17	Soxhlet apparatus
	Starch	AOAC 18th Ed. 32.2.07, AACC	Incubator shaker, Vacuum filtration, HPLC-Agilent 1200
	Pectin	Analysis and quality control for fruit and vegetable products. 2nd ed. By Ranganna. Page no. 40-42	Vacuum filtration unit, hot air oven
B	**Free sugars, carbohydrates and lignin**		
1	Free sugars	AOAC 18th Ed.32.2.07	HPLC-Agilent-1200
2	Carbohydrate Lignin	NREL, Determination of structural carbohydrates and lignin, Laboratory analytical procedures, version 2012.	HPLC-Agilent-1200
C	**Organic by-products**		
	Organic byproducts by HPLC		
	Lactic acid, Glycerol, Ethanol	Bio-Rad: Food and Beverage biotechnology and Bio-Organic analysis. Page: 18	HPLC 1260/1200 series (Agilent), Column-Aminex HPX (300 x 7.8 mm)
	Organic volatile byproducts by GC		
	Methanol, higher alcohols, esters etc.	ASTM D4815	GC-Agilent 7890A
	Organic volatile acids by GC		
	Acetic acid, butyric acid, propionic acid	Altech Association Inc. 2004, GC section. Page No. 340	GC-Agilent 7890A
D	**Elemental analysis by ICP**		
	Zn, Fe, Mn, Cu, Mg, Ca, Na, K, S, P	50.1.15, AOAC official method, 984.27, 18 th edition.2006	Perkin Elmer procedures, Perkin Elmer optima 2100 DV

address comprehensive observation, four diverse locations were chosen. to represent all regions adequately.

Sampling was conducted across three seasons, with samples collected in May 2019, September 2019, and February 2020 covering a full year. Before sample collection, consultations were held with senior authorities from the Pune City MSW Department to gain insights into the city's solid waste management procedures. The samples were collected from waste heaps (Figure 2) as part of this project.

Each heap yielded approximately 1 kg of sample, gathered from five distinct parts and stored in food grade plastic bags, securely sealed to prevent contamination. During collection, protective gear including hand gloves and face masks were worn. Upon collection, the sealed sample bags were promptly transported to the laboratory and placed in the deep freezer section to prevent microbial activity and preserve composition. This preservation method was applied uniformly to samples from all locations. Collected samples from all locations were preserved in the same manner from all locations. Locations selected for sampling included Aundh & Ghole road depot in central zone and Katraj and Yerawada depot from South and North regions, respectively. Samples were collected thrice from the same locations to ensure compositional averages were representative.

Sample preparation for compositional analysis

After removal from the deep freezer, all four sample bags were thawed to room temperature. Thawed FW samples were assessed for bulk density and processed individually using food pulverizer (Figure 3). This process resulted in the creation of a slurry as depicted in Figure 4.

The slurry was then homogenized appropriately and from each slurry matter around 150 g sample was analyzed.

Analytical procedures

Given the extensive analytical work load, rigorous standard operating procedures (SOPs) were adhered throughout. All the analytical procedures were conducted at the ISO-recognized Praj Matrix R&D Center. Analytical protocols outlined in the Praj analytical manual, derived from standards such as AOAC, ASTM, and ICUMSA, were followed, ensuring suitability for FW analysis. Utilizing standard and industry-recognized laboratory equipment and instruments coupled with SOPs and regular calibrations, maintained precision and accuracy. Analytical parameters were categorized based on their nature, as detailed in Table 1.

Physico-chemical composition

Analytical procedures mainly involved gravimetric, titrimetric, and distillation techniques. These techniques were utilized to estimate bulk density and chemical components, focusing on biological macro molecules like starch, proteins and fats on as-is basis

Figure 1. Map of India[51]

Carbohydrates and lignin

For carbohydrates and lignin, the sample underwent distinct preparation methods before analysis. Carbohydrate analysis involves initial drying followed by acid hydrolysis, with the resulting hydrolysate subjected to analysis via High-Performance Liquid Chromatography (HPLC). To collectively access the free and hydrolyzed sugars. Lignin analysis, on the other hand after drying, utilized solvent extraction as the method of choice.

Organic by- products analysis

Organic by-products, such as glycerol, lactic acid, and ethanol were determined using high performance liquid chromatography (HPLC) on as-is basis.

For organic volatile by-products, including aldehydes, esters, and higher alcohols, gas chromatography (GC) was employed for analysis, also on an as-is basis.

Similarly, organic volatile acids like acetic acid, butyric acid, and propionic acid were determined using gas chromatography (G.C) again on as-is basis.

Inorganic elemental analysis

Trace inorganics elements were quantified using inductively coupled plasma atomic emission spectroscopy (ICP) Before analysis, the samples were subjected to digestion using nitric acid.

RESULTS

The results revealed that the constituents analyzed in FW predominantly originated from their own content and the source where the waste was generated and collected. However, a

Figure 2. Heap of Food Waste

Figure 3. Pulveriser Machine

Figure 4. Slurry after pulverisation

few constituents generated during collection and transportation eventually contributed to the FW.

Physico chemical composition

The figures illustrate more or less consistent levels of ash, crude fiber, starch, and free sugars across sample collected during all seasons and from all locations. However, solid content appears relatively higher in samples collected in February 2020 from all four reasons. Particularly, samples from Katraj consistently exhibit elevated solid content across all three seasons. Additionally, fat content emerges as predominant in all four samples collected during May 2019 (Figure 5).

Carbohydrates and lignin

These estimations were conducted on dry basis, revealing that glucose is notably prominent in samples collected from all locations across seasons. The glucose detected in the samples comprises both free glucose and the hydrolyzed product of starch, suggesting that starchy materials such as cereal products, are the primary contributors to carbohydrates. This indicates that starchy materials like cereal products are the main contributors to carbohydrates. Xylose and arabinose are negligible, indicating that cellulosic material has minimal contribution to FW. Notably, vegetables and fruit market waste was not included in the sample collection. Unexpectedly, lignin has contributed more, indicating that seeds and vegetable structural material became part of the samples (Figure 6).

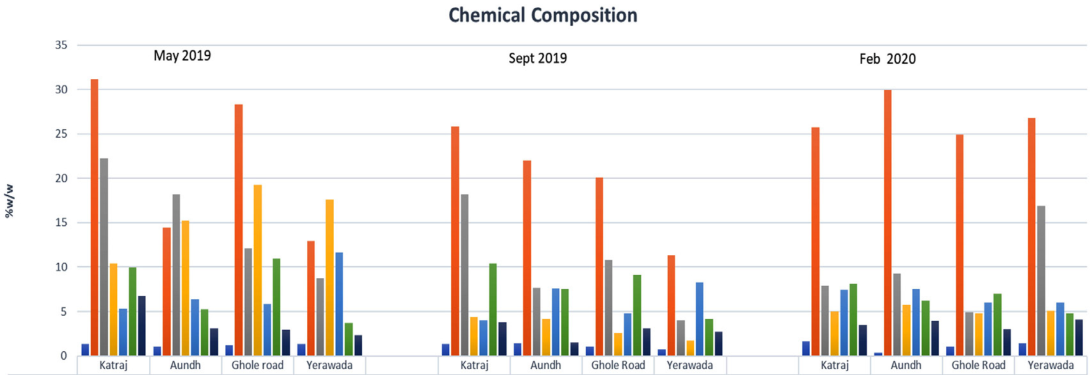
Organic By- products

Organic by-products by HPLC

Lactic acid naturally occurring in plants as a product of cellular metabolism, is also found in animal tissue and can therefore be present in FW. Additionally, lactic acid, along with glycerol and ethanol, is a fermentation by-product produced by microorganisms during the collection and transportation of FW. These microorganisms utilize sugary substrates present in FW for fermentation. Analysis of the samples indicates a prevalence of lactic acid in all samples, particularly notable in September 2019, where levels are higher in samples Katraj and Aundh. The presence of these fermentation byproducts suggests the existence of variety of active bacteria and yeasts in the FW samples (Figure 7).

Organic volatile by-products by GC

The origin of acetaldehyde in food can be traced back to fruits and dairy products. Acetone, naturally found in plants, trees, and animal tissues, arises from the breakdown of fats. Methyl acetate,



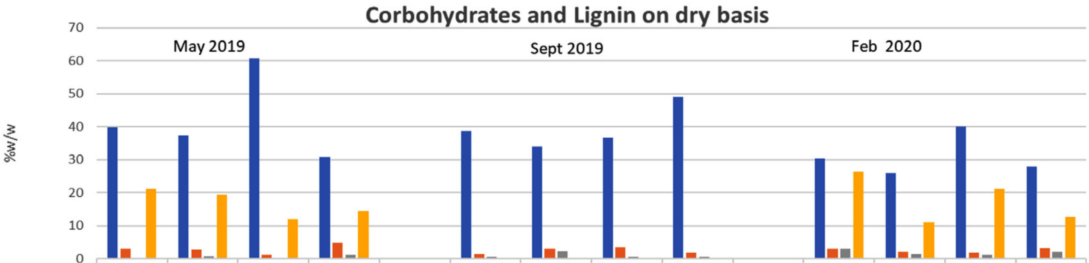
	Katraj	Aundh	Ghole road	Yerawada	Katraj	Aundh	Ghole Road	Yerawada	Katraj	Aundh	Ghole Road	Yerawada
Ash	1.36	1.01	1.21	1.34	1.34	1.42	1.03	0.75	1.67	0.36	1	1.41
Total solids	31.16	14.46	28.38	12.91	25.8	22.02	20.14	11.36	25.77	29.92	24.91	26.8
Fat	22.27	18.18	12.08	8.72	18.21	7.65	10.82	4	7.9	9.3	4.9	16.9
Proteins	10.38	15.23	19.23	17.59	4.4	4.18	2.59	1.71	5	5.75	4.75	5.09
Crude fiber	5.29	6.39	5.82	11.6	3.97	7.6	4.79	8.25	7.45	7.51	6.01	5.97
Starch	9.97	5.26	10.96	3.68	10.44	7.51	9.14	4.15	8.12	6.23	6.98	4.76
Free sugars	6.73	3.12	2.97	2.35	3.74	1.5	3.11	2.7	3.5	3.9	2.98	4.1

Figure 5. Physicochemical Composition

used as food additive for flavor enhancement, and ethyl acetate, naturally occurring in fruits, contribute to the mixture. Methanol, present in fresh fruits, vegetables, and fermented beverages, emerges as major constituent in all samples. Additionally, n-amyl alcohol, utilized in ice cream, bakery products, and pudding as additives, is detected. The presence of N-propanol and iso-butanol is attributed to microbial activity. Besides their natural occurrence, all the mentioned by-products are produced during fermentation with methanol notably produced after pectin breakdown (Figure 8).

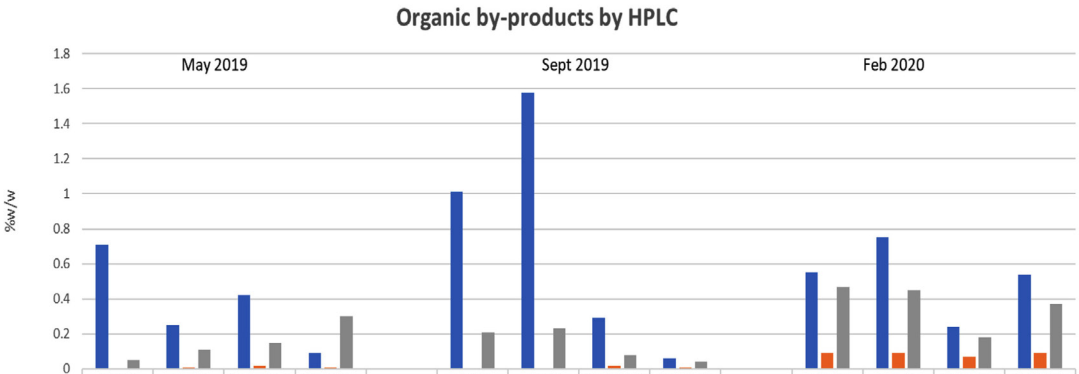
Organic volatile acids by GC

The presence of organic acids in FW includes acetic acid, naturally occurring in fruits like apple, grapes and oranges, and commonly used as preservative in the form of vinegar. Butyric acid and iso-butyric acid are naturally present in butter, cheese, yogurt, and fermented food products. Valeric acid and iso-valeric acid occur naturally in both plant and animal tissue as metabolites. Propionic acid in FW results from bacterial activity. Across all samples collected and analyzed from various locations and seasons, acetic acid concentration stands out notably higher than all other volatile acids by-products. This suggests the abundance of acetic acid bacteria. However, such high concentration of acetic acid may inhibit the desired microbial reaction when FW is used as a fermentation medium (Figure 9).



	May 2019 Katraj	Aundh	Ghole road	Yerawada	Sept 2019 Katraj	Aundh	Ghole road	Yerawada	Feb 2020 Katraj	Aundh	Ghole road	Yerawada
Glucose	39.89	37.4	60.72	30.76	38.74	34.07	36.67	49	30.45	25.98	40.03	27.99
Xylose	3.1	2.85	1.24	4.78	1.45	2.92	3.55	1.93	2.98	2.09	1.87	3.27
Arabinose	0	0.65	0.3	1.29	0.45	2.24	0.48	0.45	2.98	1.45	1.09	2.01
Lignin	21.27	19.29	11.97	14.43	0	0	0	0	26.29	10.98	21.25	12.65

Figure 6. Carbohydrate and lignin



	May 2019 Katraj	Aundh	Ghole road	Yerawada	Sept 2019 Katraj	Aundh	Ghole road	Yerawada	Feb 2020 Katraj	Aundh	Ghole road	Yerawada
Lactic acid	0.71	0.25	0.42	0.09	1.01	1.58	0.29	0.06	0.55	0.75	0.24	0.54
Glycerol	0	0.01	0.02	0.01	0	0	0.02	0.01	0.09	0.09	0.07	0.09
Ethanol	0.05	0.11	0.15	0.3	0.21	0.23	0.08	0.04	0.47	0.45	0.18	0.37

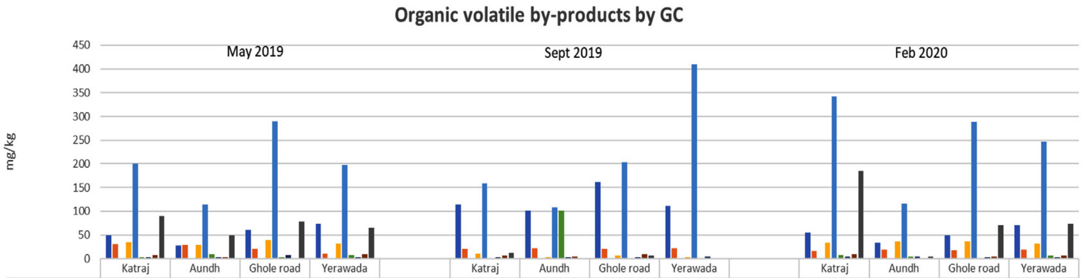
Figure 7. Organic By-products by HPLC

Inorganic elemental analysis

Zinc (Zn), manganese (Mn), magnesium (Mg) serve as crucial co-factors in enzymatic reactions and are found in FW, although Zn is notably absent in samples collected in May 2019. Copper (Cu) is absent in all samples, suggesting that inhibition due to Cu will not occur if FW is utilized as a fermentation medium. Calcium(Ca), sodium (Na), and potassium (K) are predominantly present in all samples as major constituents. These salts may occur naturally in food or could have been added during cooking. However, their excess presence can induce osmotic stress on microorganisms, thereby slowing down their growth. The presence of sulfur (S) and phosphorous (P) in FW serves as essential building block elements for the production of amino acids and nucleic acids (Figure 10).

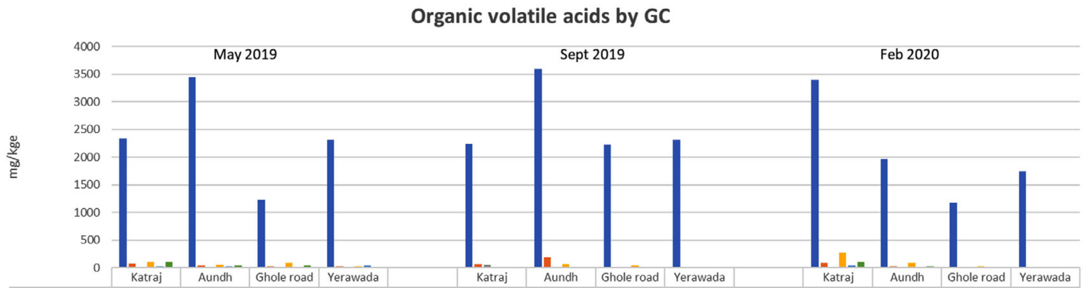
Average compositional analysis

Average compositional analysis of all samples, regardless of the sampling location or season is presented in Table 2 alongside standard deviations. Few to mention – total solids average 22.80% with standard deviation 7.71, fat average 12.72% w/w, with standard deviation 6.24, proteins average 6.72% w/w with standard deviation 6.07, starch average 7.27% w/w with standard deviation 2.51, likewise, the presence of numerous deviations in most constituents highlights the diversity in analytical values. These deviations are crucial in determining the physico-



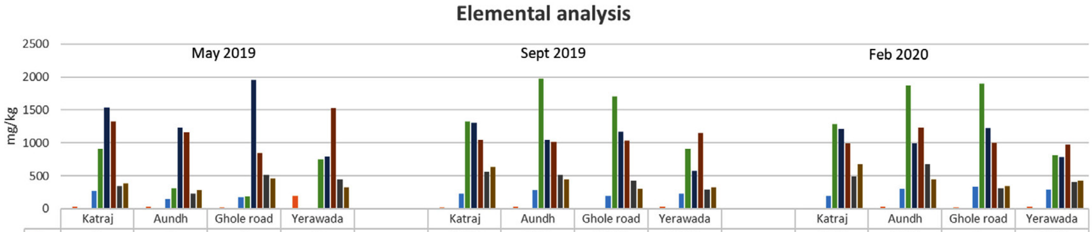
	May 2019 Katraj	May 2019 Aundh	May 2019 Ghole road	May 2019 Yerawada	Sept 2019 Katraj	Sept 2019 Aundh	Sept 2019 Ghole road	Sept 2019 Yerawada	Feb 2020 Katraj	Feb 2020 Aundh	Feb 2020 Ghole road	Feb 2020 Yerawada
Acetaldehyde	49.3	28.2	61.3	73.3	114.67	101.21	162	111.68	54.51	33.78	50.05	70.73
Acetone	31.3	29.3	20.4	10.3	20.66	21.3	21.01	22.21	15.55	19.59	18	19.78
Methyl Acetate	0	0	0	0	0	0	0	0	0	0	0	0
Ethyl Acetate	34.9	29.7	39.2	31.4	9.83	3.46	6.82	3.82	33.43	36.41	36.07	32.47
Methanol	200.1	114.3	290.3	198.3	159.51	108.98	203.1	409.23	342.22	114.93	288.08	246.1
N-Propanol	3.9	9.4	2.9	8.3	0	101.55	0	0	7.43	5.38	2.36	6.53
Iso-Butanol	2.9	3.7	8.3	3.1	3.8	3.9	2.7	4.2	4.25	4.02	3.59	3.78
Isi-Amyl Acetate	8.3	3.9	1.8	9.3	5.9	4.5	9.2	1.4	9.5	0	4.5	5.87
Iso-Amyl Alcohol	89	49.3	78.28	65	11.77	0	5.57	0	184.66	4.12	71.16	73.89

Figure 8. Organic Volatile By-products by GC



	May 2019 Katraj	May 2019 Aundh	May 2019 Ghole road	May 2019 Yerawada	Sept 2019 Katraj	Sept 2019 Aundh	Sept 2019 Ghole road	Sept 2019 Yerawada	Feb 2020 Katraj	Feb 2020 Aundh	Feb 2020 Ghole road	Feb 2020 Yerawada
Acetic acid	2343	3454	1232	2312	2242.43	3600	2225.54	2318.32	3398.65	1969.79	1182.67	1745.65
Propionic Acid	80.4	40.3	23.4	30.1	71.07	183.68	0	0	89.45	25.11	17.59	20.28
Iso- Butyric Acid	12.3	3.4	4.9	0	48.5	0	0	0	17.52	0	0	0
Butyric Acid	103	49.4	87	29.1	0	61.31	41.92	0	274.56	92.84	23.98	13.76
Iso- Valeric Acid	29.4	30.4	0	39.2	0	0	0	0	35.9	11.57	0	0
Valeric Acid	100	39.4	36.4	20.1	0	0	0	0	98.29	29.07	0	0

Figure 9. Organic Volatile Acids by GC



	May 2019 Katraj	May 2019 Aundh	May 2019 Ghole road	May 2019 Yerawada	Sept 2019 Katraj	Sept 2019 Aundh	Sept 2019 Ghole road	Sept 2019 Yerawada	Feb 2020 Katraj	Feb 2020 Aundh	Feb 2020 Ghole road	Feb 2020 Yerawada
Zn	0	0	0	0	5.185	4.009	2.376	2.962	4.987	3.87	0	3.564
Fe	27.67	27.04	13.98	198.4	22.76	25.89	13.44	25.23	0	27.23	15.98	28.9
Mn	3.361	0	0	0	5.685	3.275	4.078	3.204	3.87	3.98	4.987	2.897
Cu	0	0	0	0	0	0	0	0	0	0	0	0
Mg	265.1	146.4	178.5	0	224	278	199.8	223.9	198	300	329	287
Ca	906	308.3	181.6	754.4	1327	1978	1704	903.6	1289	1876	1900	809
Na	1537	1235	1957	790.2	1307	1048	1173	573.7	1209	989	1222	786
K	1325	1156	842.3	1522	1048	1010	1037	1144	989	1232	998	969
S	341.2	225.9	506.5	449.1	563.2	506.6	430.2	289.3	489	677	309	409
P	384.4	277.7	457.4	326.5	634.4	448.6	300.8	320.9	675	450	342	432

Figure 10. Elemental Analysis by ICP

chemical pretreatment process parameters and conversion methodologies. Understanding these variations is essential for optimizing the treatment and conversion of FW into valuable products.

DISCUSSION

The above results show that the presence of starch, sugar, proteins, fats, and trace elements in all samples indicates that the concentrations of these components are sufficient to support microbial growth and produce desired product. While noticeable variations in almost all components may occur on day-to-day basis, it is expected that average values remain relatively consistent. Therefore, pretreatment parameters can be designed to accommodate these compositional variations. Evaluation and quantification of those important components, which contribute to the nutritional value of the FW become crucial in determining the appropriate treatment methods and subsequent utilization. Understanding carbohydrates, proteins, fats, vitamins, elements, and trace elements content, by and large, is important and useful to decide the potential application of FW.

With a water content of approximately 77%, the need for additional water during FW processing is minimal, primarily required to ensure flowability. Starch and free sugar serve as valuable carbon and energy source while proteins support cell-mass growth. Fiber content can be repurposed as feed for cattle. Comparatively, compositional analysis of FW conducted in other countries, such as the European Union, demonstrate similarities to our findings. However, the relatively high occurrence of acetic acid among other byproducts suggests undesired bacterial activities during handling, collection and transportation. Elevated methanol content, indicative of pectin degrading bacteria presence, highlights potential issue. Elemental analysis reveals the presence of zinc (Zn), manganese (Mn), and magnesium (Mg) ions crucial for enzymatic reaction, further emphasizing the potential value of FW in various applications.

Understanding compositional analytical parameters of FW is crucial for determining enzyme doses, process parameters, and pre-treatment conditions. It's essential to revisit and address why FW is nutritionally rich for microbial growth and product formation. The nutritional requirements of microorganisms are primarily revealed by the elemental composition of cells, consisting of carbon (C), hydrogen (H), oxygen (O) nitrogen sulfur (S), phosphorous (P), potassium (K), magnesium (Mg), iron (Fe), calcium (Ca), manganese (Mn), and traces of zinc (Zn), cobalt (Co), copper (Cu), and molybdenum (Mb). These elements, along with water, inorganic ions, small molecules, and macromolecules, serve structural and functional roles in microbial cells.[56] Organic compounds such as carbohydrates and fats fulfill the carbon, hydrogen and oxygen requirements of microorganisms, providing energy in the form of adenosine triphosphate (ATP) generated during various biochemical pathways.

Table 2. Average values and standard deviation

No.	Parameters	Unit	Average	Std. Deviation
A	**Chemical analysis**	**As is basis**		
1	Ash	%w/w	1.16	0.35
2	Total solids	%w/w	22.80	6.71
3	Fat	%w/w	12.74	6.24
4	Proteins	%w/w	7.99	6.07
5	Crude fiber	%w/w	6.72	1.99
6	Starch	%w/w	7.27	2.51
7	Free sugars	%w/w	3.39	1.27
B	**Carbohydrates & lignin**	**On dry basis**		
1	Glucose	%w/w	37.64	9.61
2	Xylose	%w/w	2.67	1.00
3	Arabinose	%w/w	1.22	0.88
4	Acid Insoluble Lignin	%w/w	17.27	5.53
C	**Organic by-products by HPLC**	**As is basis**		
1	Lactic acid	%w/w	0.54	0.43
2	Glycerol	%w/w	0.04	0.04
3	Ethanol	%w/w	0.22	0.15
D	**Organic volatile by-products by GC**	**As is basis**		
1	Acetaldehyde	mg/kg	75.9	39.3
2	Acetone	mg/kg	20.8	5.5
3	Methyl Acetate	mg/kg	0.0	0.0
4	Ethyl Acetate	mg/kg	24.8	14.2
5	Methanol	mg/kg	222.9	95.5
6	N-Propanol	mg/kg	12.3	28.3
7	Iso-Butanol	mg/kg	4.0	1.4
8	Isi-Amyl Acetate	mg/kg	5.3	3.3
9	Iso-Amyl Alcohol	mg/kg	52.7	54.1
10	n-Amyl Alcohol	mg/kg	24.6	22.7
E	**Organic volatile acids by GC**	**As is basis**		
1	Acetic acid	mg/kg	2335	799
2	Propionic Acid	mg/kg	48	52
3	Iso- Butyric Acid	mg/kg	7	14
4	Butyric Acid	mg/kg	65	75
5	Iso- Valeric Acid	mg/kg	12	16
6	Valeric Acid	mg/kg	27	37
F	**Elemental analysis**	**As is basis**		
1	Zn	mg/kg	4	1
2	Fe	mg/kg	39	53
3	Mn	mg/kg	4	1
4	Cu	mg/kg	0	0
5	Mg	mg/kg	239	57
6	Ca	mg/kg	1161	616
7	Na	mg/kg	1152	366
8	K	mg/kg	1106	184
9	S	mg/kg	433	127
10	P	mg/kg	421	126

The general physiological functions of the elements[4] are outlined in Table 3. Trace elements are metal ions required by certain cells in such small amounts that it is difficult to detect (measure) them, and it is not necessary to add them to fermentation media as nutrients. As metal ions, the trace elements usually act as co-factors for essential enzymatic reactions in the cell example include Mn, Co, Zn, Cu, and Mo. Components of FW selected for analysis, contribute to microbial growth and metabolism as shown in the Table 3. These components play a crucial role as precursors for different enzymatic reactions, while some serve as important substrates in fermentation.[57] Additionally, volatile components were also selected for analysis as they indicate the level of microbial activity taking place in the FW during collection and transportation.

After understanding FW in terms of compositional analysis, constituent deviation ranges and the major component present, the valorisation process is decided. For example, if free sugars and starch is more, such a FW may be considered for converting into fermentation medium leading to ethanol, lactic acid production. FW having particular bioactive compound in greater quantities, can be used for extracting it. Similarly, the FW with required C: N ratio is used for anaerobic digestion.

Although, this paper mentions only domestic kitchen waste, it's also important to understand the food industry and agriculture waste because those have remarkable quantities to contribute in FW globally.

Globally, on an average, fruits and vegetables contributed about 45% of to the total FW. Usually, unavoidable FW, especially peel, skin, and twigs of fruits, contains a greater amount of bioactive compounds than do the edible portions. In addition, it is also reported that food processing waste is rich in protein, lipid, and carbohydrates, thus exhibiting valorization potential in producing animal feed, cosmetics, chemicals, as well as prebiotics, and it can play an important role in reducing problems associated with.[58] The residues of raw agricultural products constitute the agricultural wastes. Such residues are corn stalks, sugar cane bagasse, and culls from fruits and vegetables, pruning are few. The main food groups contributing to nutrient and FW or loss are cereals

Table 3. Major elements, their sources and functions in microbial cells[55]

Element	% of dry weight	Source	Function
Carbon	50	Organic compounds or CO_2	Main constituent of cellular material
Oxygen	20	H_2O, organic compounds, CO_2 and O_2	Constituent of cell material and cell water; O_2 is electron acceptor in aerobic respiration
Nitrogen	14	NH_2, NO_3, organic compounds, N_2	Constituent of amino acids, nucleic acids, nucleotides and coenzymes
Hydrogen	8	H_2O, organic compounds, H_2	Main constituent of organic compounds and cell water
Phosphorous	3	Inorganic Phosphates (PO_4)	Constituent of nucleic acids, nucleotides, phospholipids, LPS, teichoic acids
Sulphur	1	SO_4, H_2S, S, organic sulphur compounds	Constituent of cysteine, methionine, glutathione, several coenzymes
Potassium	1	Potassium salts	Main cellular cation and cofactor for certain enzymes and component of endospores
Magnesium	0.3	Magnesium salts	Inorganic cellular cation and cofactor for certain enzymatic enzymes
Calcium	0.5	Calcium salts	Inorganic cellular cation, co factor for certain enzymes and component of endospores
Iron	0.2	Iron salts	Component of cytochromes and certain iron protein and cofactor for some enzymatic reactions

and pulses, fruits and vegetables, meat and animal products, roots, tubers, and oil-bearing crops. The animal-derived FWs contain fats, lard, blood, internal organs of farm animals, offal, head, tails, scales, shells of marine animals, and dairy products such as cheese whey, curd, and milk sludge. The wastes of vegetables, fruits, cereals, roots and tubers, oil crops, and pulses consist of peels, stems, seeds, shells, bran, germs, cull, pomace, pulp, and other residues obtained from processing. Wheat straw, orange peel, grape pomaces, olive pomace, apple pomace, and potato peel. Those wastes can be used for extracting the bioactive component present in it.[59] Various types of FW, such as waste from fruit, vegetables, grains, and other food production and processing, contain important bioactive compounds, such as polyphenols, dietary fibre, proteins, lipids, vitamins, organic acids, and minerals, some of which are found in greater quantities in the discarded parts than in the parts accepted by the market. These bioactive compounds offer to convert it into value-added products, thus enhancing people's confidence in better utilizing and managing FW. To harness the potential of FW in extracting these compounds, it is possible to create high-quality and functional food ingredients, cosmetic products, and dietary supplements. This approach aims not only to reduce FW but also to create new sources of income and support the greenhouse gas emissions into the environment. The valorization of FW through the production of value-added products based on its bioactive compounds is a pioneering solution for reducing waste and generating new economic possibilities. Nanotechnological approaches are recently used as novel and green applications to valorize agricultural FWs and improve their stability and applicability.[60] Considerable amounts of expired FW are generated every day. They are rich in organic carbon and in other elements, including nitrogen, phosphorus and potassium, which cannot be wasted. The expired FW for biogas production in anaerobic digestion process is known since decades. A database was extrapolated from the tests carried out in order to obtain a complete list of physico-chemical and biochemical methane potential (BMP) of 88 expired FW. The organic composition and other factors such as pH, temperature, C/N ratio of the samples varies considerably with the region, the season and the processing characteristics, resulting in methane yield variations. Therefore, knowledge of the appropriate physical and chemical properties of the feedstock, working conditions and the effects of the inhibition of various components on the anaerobic digestion processes is a key element, necessary to optimize energy production from FW. The anaerobic digestion method converts the energy contained in FW into a useful fuel (biogas) that can be stored. In addition, this method allows the transformation of organic waste into stable soil improvers and valuable products, such as fertilizers. In particular, anaerobic digestion of FW is a complex process that simultaneously digests all organic substrates such as carbohydrates, lipids and proteins.[61]

Although, landfilling is most easy way of disposing of FW, it not only consumes valuable land, it also causes air, water and soil pollution, releasing methane into the atmosphere and releasing chemicals and pesticides into the earth and in the groundwater. When the food becomes not suitable for human consumption and its reuse as animal feed is not possible, it is diverted to energy production systems, which are used for energy recovery in a sustainable and renewable way. Considering the necessity to stabilize the FW from the point of view of environmental protection, biotechnological methods are the most useful and economic methods. Bioconversion technologies, such as ethanol, 2.3 butanediol, and fields including nutritional foods, bioplastics, bioenergy, bio surfactants, bio fertilizers, and single cell proteins are more suitable, compared to thermochemical conversion technologies, such as combustion and gasification, due to the raw material high moisture content. The chemical composition of feed stocks has a great influence on the presence and concentration of system buffering components.

FW valorization aims not only to reduce FW but also to create new sources of income and support the creation of a circular economy. To ensure the environmental and economic sustainability of future FW valorization, it is essential to consider the availability of this waste over time, its techno economic potential, and the environmental assessment of benefits and burdens based on its life cycle, and creation of a circular economy.

CONCLUSION

Traditionally, FW was managed through methods such as sanitary landfilling, incineration, composting, and sometimes as animal feeds or feed ingredients. However, these options can cause secondary pollution and additional energy consumption. In recent years, the concept of circular bioeconomy has gained traction as a way to transform the linear economy of FW as a valuable resource for the production of chemicals, material, and fuels, a practice that has been increasingly adopted in many countries. European Union (EU) has introduced the directive to reduce organic waste gradually, so that it can be either reused for production of biochemical or compost or energy.

Compared to other developing Asian countries, developed nations have showcased learnable models of FW valorization supported by higher utilization rates and policies focused on "zero waste and resource recycling". Recently, nano technological approaches are used as novel and green applications to valorize agricultural food wastes and improve their stability and applicability. Extensive efforts are invested in cultivating vegetables, cereals, nuts, and seeds to ensure they are rich in carbohydrates, proteins, fats, minerals and vitamins, enhancing their nutritional value for human consumption. However, statistics indicate that only one-third of these foods are consumed by humans, with the remainder becoming waste. This so called FW, although enriched with nutrionally significant components, is not fit for human consumption and is thus labeled as waste. It is important to note that, while FW refers to both uncooked and cooked food materials that are unusable for human consumption, this does not imply a reduction in their nutritional value.

FW, derived from various organic sources, is increasing at an alarming rate, impacting the economic conditions of several nations adversely. The study highlights that the recycling of food products can be explored at various stages of food supply chain from post-harvest, through processing, distribution, to consumption. Essential nutrients and vital bacteria present in FW can be effectively utilized to generate recycled raw materials for various industrial applications. This approach not only mitigates waste but also promotes sustainable resource utilization. Another approach is extraction of important bioactive compounds, such as polyphenols, dietary fiber, proteins, lipids, vitamins, organic acids, and minerals, some of which are found in greater quantities in the discarded parts than in the parts accepted by the market. The compositional analysis of all FW samples revealed the presence of free sugar, starch, and crude fiber serve as carbon sources. Proteins, vital for the growth of microorganisms, are also present, fulfilling the nutritional requirement of cell organelles. Being of plant origin, the FW also contains some vitamins and essential trace elements such as Zn, Mn, Mg, which act as co-factors in enzymatic reactions. Fats and oils are present both as part of the original content of the waste and also from external sources like vegetable cooking oil. These fats and oils were extracted using hexane as a solvent, and it has been observed that the extracted oil has potential for biodiesel production.

While the waste contains both carbohydrates and proteins, it may not be readily available to bacteria and yeast in their easily assimilable or fermentable forms. Free sugars such as glucose, fructose, xylose, and sucrose are generally considered fermentable. However, polysaccharides like starch, cellulose, and pectin require enzymatic breakdown before they can be utilized by most microbes, as only certain bacteria and yeasts produce the enzymes needed to convert these complex sugars into simpler forms. To convert polysaccharides into fermentable sugars, enzymatic pretreatment is essential. For starch, enzymes such as amylases are used to liquefy and saccharify it into simpler sugars. Similarly, cellulase and pectinase are employed to breakdown cellulose and pectin, respectively. These enzymes not only facilitate the conversion of complex carbohydrates into simpler sugars but also help reduce the viscosity of the slurry during pretreatment, making the sugar more accessible for microbial fermentation.

To convert proteins into assimilable nitrogen form, proteinase is utilized during pretreatment. The presence of lactic acid glycerol, and ethanol indicates uncontrolled microbial reactions occurring due to spoilage microorganisms during transportation. The wider range of component deviations pose challenges in determining pretreatment parameters; however, overall valorization is still manageable. Higher values can lead to increased spoilage and reduced nutrient availability for composite feedstock. Additionally, if these products persist through pretreatment, they may pass into the feedstock and potentially inhibit the desired fermentation process.

It is recommended to establish a strategic roadmap for the biotechnological valorization of FW at all social levels to optimize resources, reduce waste, and control pollution. The environmental and economic impacts of FW depend on the multiple parameters of waste management systems. Enormous efforts are taken to minimize FW and to valorize it thus to reduce environmental and economic loss. A joint effort from stakeholders is the key to reducing FW and the efficient and effective valorization of FW to improve its sustainability. Continuation of research projects can draw cues from studies exploring microbial routes to recover value from FW into various chemical building blocks. Recycling FW into valuable chemicals directly contributes to transitioning from fossil fuel-based economies to a bio-economy, ultimately aiding in the reduction of food wastage for society as a whole. Not only Pune, but the model can be worked out similarly in other metro cities globally.

Evaluating the nutritional richness of food waste is first step for researchers to understand its composition and potential. This understanding is crucial for furthering research towards sustainable chemistry and establishing bio-economy.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS' CONTRIBUTION

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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DATA AVAILABILITY

All datasets generated or analyzed during this study are included in the manuscript.

ETHICS STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors.

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