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Physicochemical profiling of tomato waste streams for valorization: Insights from discarded market and industrial residues

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Abstract
Tomato market and industrial processing activities generate significant waste, including overripe, damaged, or pomace residues, which are often discarded despite containing valuable nutrients. This study evaluated the physicochemical characteristics of two tomato waste streams: market waste (MW) from the Koyambedu Wholesale Market, Chennai, and industrial processing waste (IW) from ketchup production in a Food processing plant to explore valorization potential. MW exhibited higher moisture content (95.57±0.40%), total soluble solids (4.50±0.00 °Brix), and pH (4.10±0.00), whereas IW showed higher titratable acidity (0.32±0.01%), reflecting differences in origin and processing. Both wastes require stabilization, such as drying, prior to practical applications. Their compositional profiles indicate suitability for direct food incorporation, bioactive extraction, and fermentation-based products. Recovering and transforming these by-products exemplifies a circular economy approach, converting potential losses into high-value functional ingredients, promoting sustainability, and mitigating food loss and waste.

Keywords: Tomato market waste, tomato industrial waste, valorization

1. Introduction
Food loss and waste (FLW) refer to reductions in food quantity or quality along the supply chain, with losses occurring before retail and waste arising at retail and consumer stages (FAO, 2019). [11]. FLW remain a significant global challenge, with the scale and causes varying between regions. In developed countries, most food waste occurs in the end of the supply chain, particularly at retail and consumption. In contrast, developing countries experience higher food loss during early and intermediate stages, including production, post-harvest handling, storage, and processing (FAO, 2011) [10]. In this context, in India, the 2020-2022 NABCONS study covering 54 crops estimated post-harvest losses at ₹1,52,790.42 crore, equivalent to 39.19 million metric tonnes (MT) of food, with perishable commodities such as fruits and vegetables contributing most to this loss.

Against this backdrop, tomatoes stand as the second most important vegetable crop worldwide, and their by-products contain large amounts of bioactive compounds, including carotenoids, flavonoids, polyphenols and pectins (Radić *et al.*, 2024) [20]. Specifically, tomatoes are the primary dietary source of lycopene (> 85% in diet) and are regarded as the most cost-effective raw material for industrial extraction (Tufail *et al.*, 2024) [22]. However, in India the post-harvest losses of tomato are estimated at 11.61% and the issue is compounded by considerable price fluctuations. (NABCONS, 2022) [17]. Additionally, industrial tomato processing produces a wet by-product called tomato pomace (TP), composed of peel, pulp, and seeds, which constitutes roughly 5-30% (w/w) of the raw material. Globally, the food industry generates an estimated 5.4-9.0 million tons of TP each year (Chabi *et al.*, 2024) [8]. Despite this, in India, these waste streams remain largely untapped, resulting in the loss of valuable lycopene and bioactives.

To tackle this issue, the international community has set a target under the United Nations' Sustainable Development Goal 12.3 to cut global per capita food waste by half and minimize food losses across supply chains by 2030 (United Nations, 2015) [23]. Realizing sustainability targets, therefore, demands comprehensive strategies that address FLW reduction, recovery

and specifically, valorization, which converts unusable waste streams into new value-added products (Salas - Millán and Aguayo, 2024) [21]. In this regard, valorization is key to improving resource efficiency and advancing circular economy approaches within food systems. Consequently, there is a growing interest in plant-derived FLW owing to its abundance of organic and bioactive constituents (Aït-Kaddour *et al.*, 2024) [1]. For instance, the value-added products derived from tomato waste include bioactive compounds such as lycopene, β-carotene, and phenolics, along with pectin and tomato seed oil. These components and derived powders are incorporated into various food systems (e.g., bread, meat products, microcapsules) to serve as functional ingredients, antioxidants, natural colorants, and dietary fiber (Almeida *et al.*, 2024 [2]; López-Yerena *et al.*, 2024) [15].

Nevertheless, the utilization of tomato waste streams for food applications faces several practical challenges, with physicochemical factors such as moisture content, pH, TSS and titratable acidity playing a critical role. For instance, tomato waste is characterized by a high moisture content, measured at approximately 81.3±1.87% in the fresh by-product. As a result, removing moisture via drying is a fundamental step to increase shelf life and facilitate handling (Valle - Castillo *et al.*, 2025) [24]. Additionally, the pH and titratable acidity of dried tomato peel are naturally acidic, with a measured pH value of approximately 4.50. This must be considered during valorization because it can inhibit pH-sensitive biological treatments and decrease the overall sensory acceptability when incorporated into food products (Almeida *et al.*, 2024 [2]; Azmi *et al.*, 2025 [6]).

Moreover, the TSS content (sugars), indicated by °Brix values, dictates the commercial quality, sweetness, and acidity of fresh tomato by-product. It varies between 4.1 and 4.7 °Brix for different stages of tomato maturation (Valle - Castillo *et al.*, 2025) [24]. TSS and TA are particularly important for the processing industry, as sugars and acids are key contributors to tomato flavor (Bhandari *et al.*, 2016) [7]. Therefore, this study assessed the physicochemical characteristics of two common tomato waste streams: market waste (MW) and industrial processing waste (IW) to determine their potential for valorization in food applications.

2. Materials and Methods

2.1 Preliminary processing of tomato waste streams

Tomato waste was collected from two sources: market waste (MW), consisting of discarded produce from the Koyambedu Wholesale Market Complex (KWMC), Chennai, and industrial processing waste (IW) pomace, comprising peel, pulp, and seeds generated during ketchup production at the Food processing plant, College of Food and Dairy Technology, TANUVAS, Koduveli, Chennai. Both sources of tomatoes *Solanum lycopersicum* L., are local variety (known as nattu thakali), commonly cultivated in Tamil Nadu. The MW was washed, pulverized, and homogenized into a purée using an Ultra-Turrax blender, while the IW was ground in a domestic blender to obtain a paste and stored at 4 °C. The physicochemical parameters of both waste streams were subsequently analyzed.

Fig 1: Tomato market waste (MW)

Fig 2: Tomato industrial waste (IW)

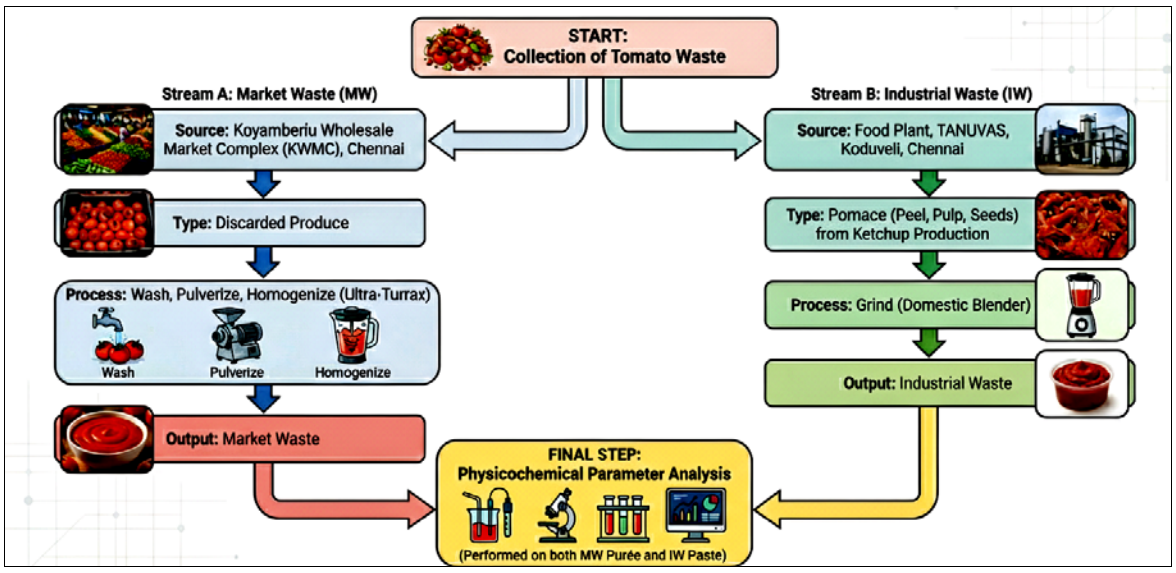

Fig 3: Tomato waste collection and preparation protocol

2.2 Physico-chemical characterization

Moisture content (MC) (%) was estimated using a Shimadzu MOC63u Unibloc Moisture Analyzer. 1 G of the MW and IW samples was loaded, and the moisture percentage was recorded. The TSS was measured at 20 ºC using a hand refractometer (RHB-32ATC, ERMA, Tokyo, Japan) and expressed in °Brix. The pH of the samples was measured using a handheld pH meter (EcoTestr pH1, Eutech Instruments, Singapore).

The titratable acidity was expressed as % of citric acid following the method described in FSSAI manual, 2016 with modifications (FSSAI, 2016) [12]. 1 G of the sample was diluted in 9 mL of distilled water and 1 drop of phenolphthalein was added as indicator. Following this, the solution was titrated with 0.1 N NaOH to pink end point persisting for 30 seconds and the titratable acidity was determined using the equation,

$$\text{TA (\% citric acid)} = \frac{Eq.\ wt.\ of\ acid \times N \times T}{W} \times 100$$

Where, Equivalent weight of citric acid (anhydrous) is 0.064 G/mL of 0.1 N NaOH, N is normality of NaOH, T is the titre value in mL, W is the weight of sample in G.

2.3 Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics 31.0.1.0. All measurements were performed in triplicate, and the results were recorded as the mean ± standard deviation (SD).

3 Results and Discussion

3.1 Comparison of physicochemical properties of MW and IW

Table 1: Physico-chemical properties of tomato market waste and processing residue

Tomato waste streams	MC (% f.w.)	TSS (°Brix f.w.)	pH (f.w.)	TA (% f.w.)
MW	95.57±0.40^{a}	4.50±0.00^{a}	4.10±0.00^{a}	0.26±0.01^{a}
IW	91.50±0.50^{b}	4.07±0.06^{b}	3.90±0.05^{b}	0.32±0.01^{b}

The data are expressed as Mean ± S.E (n=3). The values bearing different superscripts in a column represent significantly different mean values (P<0.05). MW - Market waste; IW - Industry waste; MC - Moisture content; TSS - Total soluble solids; pH - Potential of hydrogen; TA - Titratable acidity expressed as % of citric acid; fw - Fresh weight of samples.

The MC, TSS, pH, and TA of MW) and IW are presented in Table 1. The MC, TSS, and pH of MW were significantly higher than those of IW ($p < 0.05$). This difference can be attributed to the nature of the waste: MW consisted of cracked, overripe, bruised, and visually damaged whole tomatoes that retained their inherent moisture, soluble sugars (TSS), and organic acids, resulting in values closer to fresh tomatoes. In contrast, IW represents the by-product obtained after pressing during juice or ketchup production, where a substantial portion of water and soluble solids is removed, leaving a drier residue with lower sugar content. The lower TA observed in MW is likely due to the dilution of organic acids by the higher moisture content and the buffering effect of sugars, which also contributes to its comparatively higher pH.

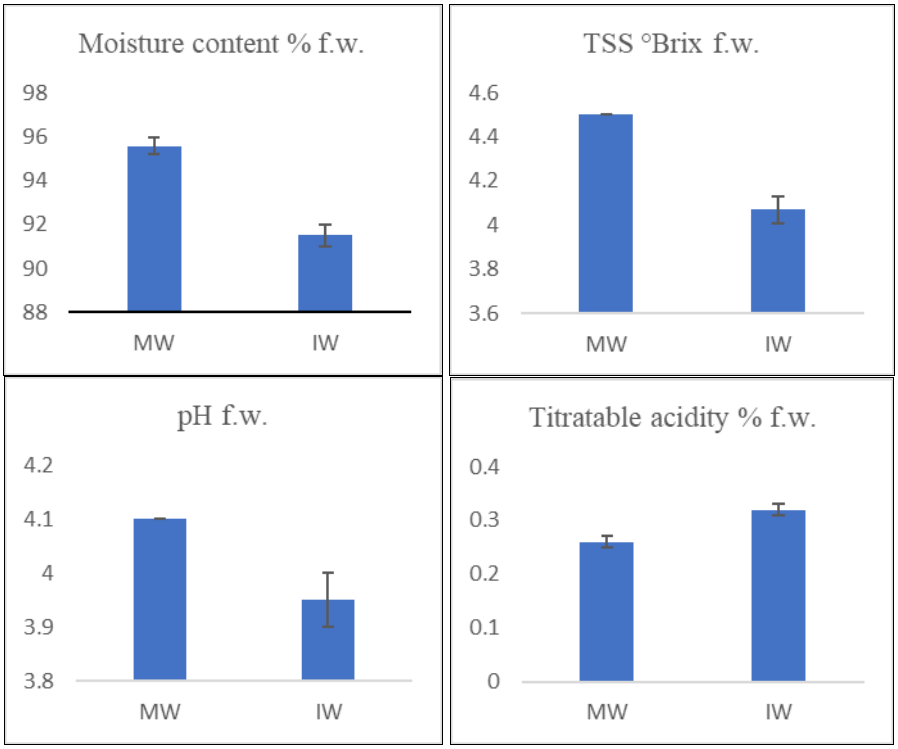

Fig 4: Graphs showing differences in MC, pH, TSS, and TA between MW and IW

(Bars represent mean±SD, f.w. is fresh weight)

3.2 Moisture content (MC)

The MC of MW (95.57±0.40%) closely aligns with the value reported by Alvarado-Vallejo *et al.* (2024) [3], who observed 96.05% in tomatoes sourced from a traditional market in Mexico. In contrast, the MC of IW (91.50±0.50%) is higher than the values reported by Weiss *et al.* (1997) [25] and Islamova (2024) [14], which typically average around 75%, yet it remains comparable to the 93.67% reported by Popescu *et al.* (2022) [19]. Moreover, other studies indicate wet-basis moisture contents ranging from 63% to 92.7% for industrial tomato waste (Nour *et al.*, 2015) [18]. These findings indicate that both MW and IW possess high moisture levels, emphasizing the necessity of a drying or stabilization step prior to valorization in food applications.

3.3 Total Soluble Solids (TSS)

TSS influence tomato flavor, texture, and key sensory attributes such as sweetness and acidity, reflecting the fruit's glucose and fructose content (Bhandari *et al.*, 2016) [7]. TSS of MW (4.50±0.00 °Brix) is consistent with the value of 4.46 °Brix reported by Hussein *et al.* (2016) [13] for fresh tomatoes. In contrast, the TSS of IW (4.07±0.06 °Brix) is lower than the 4.74 °Brix reported by Valle - Castillo *et al.* (2025) [24] for industrial pomace with 81.3% MC. This reduction in TSS in our IW samples is likely due to their higher moisture content (91.5%), which dilutes the soluble solids. These results suggest that MW has a richer soluble solids profile than IW, making it more suitable for value-added applications where higher sugar concentration or natural sweetness is desirable, and importantly, its TSS level remains on par with fresh tomatoes.

3.4 pH

The pH of MW (4.10 0.00) aligns closely with the value of 4.07 reported by Minuye *et al.* (2024) [16] for fresh tomatoes, whereas the pH of IW (3.90±0.05) is comparable to the 3.92 reported by Weiss *et al.* (1997) [25] for industrial tomato residues. This suggests that MW retains characteristics similar to fresh tomatoes, making it more suitable for direct food applications and for the extraction of pH-sensitive bioactive compounds such as carotenoids and phenolics. In contrast, the slightly higher acidity of IW may limit its use in some direct food formulations but could be advantageous for processes where lower pH inhibits microbial growth, such as in fermentations, acidified products. Additionally, the acidic environment of both MW and IW may favor the stability and recovery of certain bioactives, particularly polyphenols and ascorbic acid, during extraction processes.

3.5 Titratable acidity (TA)

TA of MW (0.26±0.01%) is comparable to the range of 0.26-0.36% citric acid reported for organic fresh tomatoes in Spain (Ayuso-Yuste *et al.*, 2020) [5]. In contrast, although Nour *et al.* (2015) [18] reported a lower TA of 0.22% for industrial processing waste with 70% moisture, the IW samples in this study exhibited a higher TA of 0.32±0.01%. This higher acidity is beneficial as it can help inhibit microbial growth and enhance the antioxidant potential of the matrix. Moreover, higher TA in tomato varieties has been associated with a lower incidence of fungal infections (Amraoui *et al.*, 2018 [4]; FAO, 1995 [9]). The measured TA values suggest that both MW and IW not only contribute to flavor but also possess inherent preservative and bioactive-enhancing properties. This makes these waste streams particularly suitable for valorization, as their acidity can improve the stability, shelf life, and functional quality of derived food products or bioactive extracts. However, excessively high acidity may limit direct incorporation into some food products due to potential impacts on taste and consumer acceptability, requiring pH adjustment or blending during formulation.

4 Conclusion

This study evaluated the physicochemical characteristics of two common tomato waste streams—market waste (MW) and industrial processing waste (IW)—to assess their potential for valorization in food applications. MW retained higher moisture, TSS, and pH, reflecting its similarity to fresh tomatoes and making it particularly suitable for direct food incorporation. In contrast, IW exhibited higher acidity, which can enhance microbial stability and preserve bioactive compounds, favoring its use in fermented or acidified products as well as for bioactive extraction. However, both waste streams possess high moisture content, necessitating stabilization through drying or other preservation techniques prior to practical applications. Although currently underutilized and often discarded, these waste streams represent a valuable resource. Their recovery and transformation into functional ingredients exemplify a circular economy approach, converting potential losses into high-value products while contributing to sustainability and the reduction of food loss and waste.

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