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Traditional and Microbubble cleaning technologies for fruits and vegetables: A Review

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Abstract

In India, fruits and vegetables are often transported to markets without proper sorting, grading, or washing, which results in contamination by dust, microorganisms, and residual pesticides. In many cases, traders wash produce with impure pond or canal water, further increasing microbial risks. Such practices not only reduce quality but also pose serious health hazards to consumers. Washing is therefore a critical primary operation in the food processing industry, essential for removing dirt, harmful chemicals, and surface microbes, as well as for preventing post-harvest diseases and food-borne illnesses. This review summarizes existing fruit and vegetable cleaning technologies and highlights the limitations of conventional washers, which are often inadequate for handling diverse produce. Emerging approaches, particularly bubble and microbubble technologies, show great promise for cleaning delicate fruits and vegetables with minimal damage. Future research should focus on developing flexible, multi-produce washing systems that integrate bubble technology with other methods while ensuring cost-effectiveness for marginal farmers, farmers Producer Company and small enterprises.

Keywords: Fruits and vegetable cleaning, post-harvest technology, conventional washer, bubble technology

1. Introduction

India's diverse agro-climatic conditions support extensive fruit (7.05 million ha) and vegetable (11.35 million ha) cultivation, making it the second-largest producer globally after China. According to the National Horticulture Database (2021-22), the country produced 107.24 MMT of fruits and 204.84 MMT of vegetables, providing strong potential for both domestic consumption and export. In 2022-23, India exported fresh produce worth ₹13,185.30 crores, including ₹6,219.46 crores in fruits and ₹6,965.83 crores in vegetables (APEDA, 2023). Despite this, its global market share remains modest 1.7% for vegetables and 0.5% for fruits mainly due to inadequate post-harvest handling, cleaning, storage, and packaging systems.

Cleaning is a vital preliminary step in food processing, as it reduces surface microbes and removes dirt and pesticide residues. Regular intake of fresh fruits and vegetables is linked to reduced chronic disease risk and stronger immunity (Van Duyn & Pivonka, 2000) ^[45], owing to their rich content of phytochemicals, antioxidants (Kalt, 2005) ^[22], and bioactive compounds (Vincent *et al.*, 2010; Kaur & Kapoor, 2001; Slavin & Lloyd, 2012) ^[46, 23, 42]. Increasing health awareness has driven greater demand for fresh-cut and minimally processed produce, which retain better nutritional and sensory qualities and offer a more natural alternative to fully processed foods (Kader, 2002) ^[21].

Despite the increasing production and demand, India continues to face serious challenges in reducing post-harvest losses and meeting international quality standards for fresh produce. A major gap lies in the absence of affordable and effective cleaning technologies suitable for small-scale farmers, entrepreneurs, self-help groups, and rural industries. Traditional manual washing methods are labour-intensive, inconsistent, and often unhygienic, while most existing commercial washing machines are expensive and not adaptable to the wide variety of fruits and vegetables cultivated in India.

There is therefore a strong need to design and develop fruit and vegetable cleaning machines that are affordable, efficient, and capable of handling multiple produce types. Incorporating more than one cleaning technology such as water spray, brush rollers, and microbubble systems will not only improve cleaning efficiency but also ensure reduced microbial contamination and pesticide residues with minimal damage to delicate produce. Hence, this review emphasizes the importance of developing innovative fruit and vegetable cleaning systems that combine traditional and advanced technologies, thereby enhancing food safety, supporting value addition, and improving India's competitiveness in domestic and global markets.

2. Methodology

A comprehensive literature survey was conducted to gather relevant information on traditional and microbubble technologies used for cleaning fruits and vegetables. Online databases and search engines including Google Scholar, Science Direct, and Yahoo were explored for research articles, review papers, patents, reports, and theses published up to August 2023. The search was carried out using combinations of keywords such as: “vegetable crop washing,” “washer,” “fruit crop washing machine,” “farm produce washing,” “agricultural produce washing,” and “microbubble cleaning technology”. These keywords were applied in different permutations to ensure broad coverage of available literature. The collected materials were critically reviewed to identify existing washing methods, their limitations, and the potential advantages of microbubble-assisted cleaning. This methodology enabled the compilation of scientific evidence necessary to achieve the objective of this review.

2.1 Techniques of Washing Fruits and Vegetables

A literature survey was conducted to examine various types of vegetable washers developed for cleaning fresh produce. The efficiency of each washing method largely depends on its mechanical action and compliance with food safety

standards.

a) Cabinet with Sprayer type washer

This washer uses high-pressure water jets to clean vegetables placed on a stationary mesh tray. Its limitation lies in the absence of relative motion between the produce and the container, reducing washing effectiveness.

b) Stirrer-Type Washer

This model employs stirrers, rotors, or paddles to agitate water and the produce. Although effective for some crops, it can damage delicate vegetables and requires significant manual operation, making it unsuitable for large-scale food processing

c) Roller-Brush Washer

Equipped with rotating brushes and continuous water flow, this washer cleans produce surfaces through gentle scrubbing. However, it is inefficient for spherical or irregularly shaped crops.

d) Conveyor-Type Washer

This continuous-flow system uses a conveyor to transport produce through different cleaning stages. It is reliable and cost-effective but may not fully clean some fruits due to limited movement between the produce and the conveyor.

e) Bubble type washer:

Based on bubble technology, this washer releases fine bubbles (smaller than 1 mm) that generate a large interfacial area and high internal pressure, effectively removing soil and pesticide residues. It ensures food safety and hygiene while maintaining product quality <https://www.lonkiamachinery.com>.

Literature survey for commercial washing of vegetables includes Cabinet with Sprayer, roller brush type washer, drum type washer, stirrer type washer and bubble washer. Also Literature survey deals with use of bubbling action technology in various field.

Table 1: Specific technique for vegetables cleaning

S.N.	Researcher	Specific Technique for Vegetables Cleaning
1	Moos (2002) ^[34]	This research focused on the conceptualization, construction, and operational evaluation of a mechanical carrot washing unit. However, it did not incorporate a statistical comparison between mechanical and manual washing processes based on quantitative parameters such as soil removal percentage or cleaning efficiency.
2	Capito (2009) ^[6]	The AMDP Root Crop Washer-Peeler, designed at the Institute of Agricultural Engineering, was experimentally evaluated by varying batch load (25-75 kg), drum speed (40-60 rpm), and operation time (5-15 min). Performance indicators such as peeling, cleaning efficiency, throughput capacity, recovery rate, mechanical damage, noise level, and power consumption were assessed, with efficiency ranging from 45% to 95% depending on conditions.
3	Magar <i>et al.</i> , (2010) ^[26]	A prototype mechanical stirrer-type fruit washer suitable for mangoes, tomatoes, and potatoes was designed and developed. The influence of three distinct rotor speeds on the overall performance index was analyzed to determine the optimal operating condition.
4	Dawn <i>et al.</i> , (2013)	A manually operated vegetable washer for carrot and radish was fabricated in Coimbatore using rubber and plastic matting. Experimental findings showed that 3.5 mm plastic matting provided the best results, achieving washing efficiencies of 97% for carrot and 96% for radish, and cleaning efficiencies of 91% and 90%, respectively.
5	Ghuman, <i>et al.</i> , (2014) ^[14]	This research presented a design concept for an automatic root crop washer intended for cleaning vegetables such as radish, carrot, and potato to remove soil and clay prior to marketing.
6	Choi <i>et al.</i> , (2014) ^[9]	The study aimed to meet the cleaning needs of the McGill Student-Run Ecological Garden through a custom-designed root crop washer. By employing modeling and prototype development, the final machine successfully minimized manual cleaning efforts.
7	Kenghe <i>et al.</i> , (2015) ^[24]	A compact mechanical washer was designed for washing potatoes. Tests indicated that the machine achieved washing efficiencies between 96.36% and 98.18%, confirming its effectiveness.
8	Adegbite <i>et al.</i> , (2018) ^[1]	A washing system for tomatoes and oranges was developed in Nigeria with a throughput of 276-320 kg/h for tomatoes and 437-518 kg/h for oranges. Washing efficiency averaged 89.7% for tomatoes and 90.2% for oranges, indicating consistent performance.
9	Tehmena <i>et al.</i> ,	Field evaluations conducted in Pakistan on carrot washers recorded an average washing efficiency of 98% with a

	(2018) ^[44]	capacity of 2.75 t/h. The study recommended maintaining drum speed at 20-21 rpm for optimal fuel efficiency and cleaning.
10	Narender <i>et al.</i> (2018) ^[37]	Carrot washer performance was assessed in Haryana, India. Optimal mechanical and microbial cleaning efficiencies were 75% and 90%, respectively, with minimal bruising (7%) at a drum speed of 25 rpm.
11	Susendran <i>et al.</i> , (2019) ^[43]	A continuous rotary drum washer was developed for washing turmeric rhizomes. The prototype achieved high mechanical washing efficiency with consistent performance under continuous operation.
12	Ghobashy, <i>et al.</i> , (2020) ^[13]	A small-scale prototype washer for potatoes was developed in Egypt. Operating at 20 rpm for 4 minutes with a 36 kg batch load yielded a washing efficiency of 93.07%, microbial cleaning of 85.8%, and minimal bruising (5.33%).
13	Olutomilola, (2021)	This review discussed various fruit and vegetable washing systems, emphasizing that parameters such as mechanical efficiency, microbial efficiency, bruising rate, retention time, and throughput are essential in evaluating washer performance.
14	Amin <i>et al.</i> , (2021) ^[31]	A root crop washing unit was developed in Bangladesh for carrots with a batch capacity of 120 kg. The machine achieved washing and cleaning efficiencies of 98% and 99%, respectively.
15	Chatchaphon <i>et al.</i> , (2022) ^[7]	The galangal washing machine replaced traditional manual cleaning, reducing production costs significantly and achieving a payback period of three months while improving worker health and productivity.
16	Shariff <i>et al.</i> , (2022)	A pedal-powered vegetable washer was evaluated for carrots, radishes, potatoes, and ginger. It demonstrated an average washing efficiency of 88.4% and was cost-effective for small-scale use.
Bubble Technology		
17	Shekhawat and Srivastava (2006)	The study investigated dissolved air flotation (DAF) for separating fine suspended solids in water using pressurized air release. Although effective, the vacuum-based flotation method had limitations, including batch operation and equipment complexity.
18	Warapa <i>et al.</i> , (2014) ^[49]	Microbubble technology was tested for washing fresh vegetables to reduce <i>E. coli</i> and <i>Salmonella</i> . At 4.5 L/min for 15 minutes, significant pathogen reduction was achieved. Further, combining microbubbles with sanitizers enhanced microbial safety without notable chemical dependence.
19	Bruna Luiza <i>et al.</i> , (2016)	Dissolved air flotation with cationic polymers was evaluated for removing fibers from paper mill wastewater. Results showed over 90% removal of solids, color, and turbidity, demonstrating high treatment efficiency.
20	Mundi <i>et al.</i> , (2017) ^[35]	This research examined wastewater from post-harvest produce washing and evaluated various treatment options. Decision matrices were created to identify suitable methods like coagulation, DAF, and electrocoagulation for different conditions.
21	Zhang and Tikekar (2021) ^[15]	Air microbubbles were found to improve particulate removal from leafy vegetables but did not significantly increase microbial decontamination. Their main benefit was enhancing visual cleanliness.
22	Botondi <i>et al.</i> , (2021) ^[5]	The review summarized ozone and ozonated water treatments as eco-friendly alternatives for extending shelf life and maintaining the microbial safety of fresh produce.
23	Zhou <i>et al.</i> , (2022) ^[48]	This paper reviewed ultrasonic cleaning applications in fruit and vegetable processing. While effective for microbial removal, drawbacks such as cavitation noise and surface erosion were noted.
24	Yang and Chen (2022) ^[47]	The study explored ozone micro-nano bubble technology for extending the freshness of fruits and vegetables during air transport. Results showed improved moisture retention and a 12% increase in preservation efficiency.
25	Javed <i>et al.</i> , (2023) ^[17]	A comprehensive review on nanobubbles (NBs) highlighted their generation methods and applications in the food industry. Their high surface area and gas dissolution capabilities make them useful for food safety, extraction, and viscosity control.
26	Lu <i>et al.</i> (2023) ^[18]	The article reviewed microbubble generation techniques and their industrial applications, emphasizing their cost-effectiveness and potential for wider use in food cleaning and bioprocesses.
27	William <i>et al.</i> , (2024)	Fine bubble technology (FBT) was shown to reduce fertilizer and pesticide usage by 20%, mitigate methane emissions from rice fields, and enhance productivity in agriculture and aquaculture sectors.
28	Napte, and Biradar, (2024) ^[36]	This study described nanobubble properties, formation techniques, and potential agricultural applications. It emphasized their oxidative strength and ability to improve soil and water conditions but noted limited research in food processing.
29	Rosalinda <i>et al.</i> , (2024) ^[41]	Ozone nanobubble water (ONBW) was developed as a non-chemical sanitizing agent. Tests on broccoli and tomatoes demonstrated effective microbial reduction and prolonged shelf life while preserving color and nutrients.
30	Mallesham <i>et al.</i> , (2025)	This review summarized nanobubble generation methods, including hydrodynamic and electrolysis techniques, and highlighted applications in food processing, freezing, and viscosity control.
31	Malahlela <i>et al.</i> (2025) ^[28]	The study investigated micro-nano bubble water treatments using air, oxygen, and ozone against <i>E. coli</i> and <i>S. aureus</i> . Ozone micro-nano bubbles showed the greatest antibacterial effect, suggesting potential for fruit surface decontamination.

Conclusion

This review emphasizes that washing is a crucial initial operation in fruit and vegetable processing, as it directly affects food safety, product quality, and storage life. Conventional cleaning methods, though common, are often labour-intensive, inconsistent, and unhygienic. Commercial washing machines perform effectively for specific crops but are generally expensive and less adaptable to India's wide variety of produce.

Recent studies indicate that bubble and microbubble-based systems, when combined with water spray or brush-assisted mechanisms, can achieve higher cleaning efficiency, greater microbial reduction, and lower physical damage to produce.

Despite these advantages, research and technological development in this area remain limited. Therefore, there is a strong need to develop cost-effective, flexible, and multi-purpose washing equipment that integrates traditional and modern techniques. Such innovations can reduce post-harvest losses, enhance food hygiene, and support farmers, self-help groups, and small-scale processors in meeting domestic and export quality requirements.

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