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Exploring the nexus of innovation management, ultraviolet irradiation, and business scale: implications for sustainable fruit and vegetable preservation during the COVID-19 era

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Abstract

Innovation management stands as a pivotal driver in attaining enduring sustainability in livelihoods. However, its progress can face formidable obstacles, encompassing the complexities arising from human perceptions. This research delved into the realm of innovation management within the context of fruit and vegetable preservation, with a keen focus on the potential impact of the COVID-19 pandemic and the perceptual evaluations surrounding the viability of utilizing ultraviolet (UV) irradiation for this purpose. The perceived effectiveness of UV irradiation in fruit and vegetable preservation was found to be significantly influenced by factors, such as cost, safety, and limited understanding. The respondents' preference for preserved fruits and vegetables was most significantly influenced by the elimination of pathogenic microorganisms, as indicated by a mean score of 4.6. Notably, around 50.9% of the participants demonstrated a lack of understanding regarding the use of ultraviolet irradiation as a preservation technology. In addition, approximately 21.6% of the respondents expressed disinterest in adopting ultraviolet irradiation for preserving fruits and vegetables. In contrast, a smaller percentage of participants, merely 12.3%, showed a positive inclination towards employing ultraviolet irradiation in the preservation process. Interestingly, approximately 15.2% of respondents remained undecided and did not express a definitive preference concerning their willingness to utilize ultraviolet irradiation for preserving fruits and vegetables. Notably, the analysis has revealed a compelling trend, with a substantial portion of participants (63%) perceiving medium-sized enterprises involved in fruit and vegetable processing technologies as displaying notably low levels of motivation for innovation during the COVID-19 era. A similar viewpoint was shared by 51% of respondents regarding large-scale businesses. In stark contrast, the survey has illuminated a striking disparity, as small-scale businesses exhibited significantly heightened innovation motivation at 28%, surpassing the modest 10% observed in both medium-sized and large-scale counterparts. This pronounced variation in innovation motivation across diverse business scales highlights the multifaceted impact of the pandemic on their inclination towards embracing innovation. These

findings offer invaluable insights into the intricacies governing innovation management within the fruit and vegetable preservation sector amidst the challenging COVID-19 period.

Keywords: COVID-19, Questionnaire survey, Innovation management, Fruits and vegetable preservation, Food security

Introduction

The COVID-19 pandemic has left an indelible mark on various aspects of society, including business practices and innovation management. Among the sectors significantly impacted is the realm of fruit and vegetable preservation, where novel approaches have been sought to ensure food safety and security during these challenging times (Litton & Beavers, 2021). Innovation management has emerged as a critical factor in navigating the uncertainties brought about by the pandemic, and its impact on attitudes towards preservation methods, such as ultraviolet (UV) irradiation, has garnered considerable attention (Melendez et al., 2019). Fruits and vegetables play a pivotal role in promoting overall health and well-being, making their consumption of paramount importance (Pocol et al., 2021; Silva et al., 2020; Wu et al., 2021). Rich in essential vitamins, minerals, antioxidants, and dietary fibers, these nutrient-packed foods offer a wide array of health benefits. Consuming fruits and vegetables regularly is well-known for reducing the risk of chronic diseases, such as heart disease, stroke, and various cancers (Dauchet et al., 2006) (Hu et al., 2014) (Oyebode et al., 2014). Furthermore, the inclusion of fruits and vegetables, in a balanced diet holds value due to their low-calorie content. They can aid in weight management and contribute to maintaining a body weight (Tohill et al., 2004).

The wide array of colors and flavors found in these foods enhances the eating experience encouraging individuals to adopt a more diverse and balanced dietary approach. These nourishing foods play a role in supporting an active lifestyle providing not just energy for the body but also contributing to digestion, immunity, and skin health (Hendrix et al., 2008). By incorporating a range of fruits and vegetables into meals individuals can establish a strong foundation for improved overall well-being. However, it is important to note that the fruit and vegetable industry has faced challenges due to the impact of COVID-19. This has resulted in consequences (de Paulo Farias & de Araújo, 2020; Ridley & Devadoss, 2021; Ridley et al., 2023). As businesses strive to navigate through shifting market demands disruptions in supply chains and changes, in consumer behavior caused by the crisis effective innovation management has become increasingly crucial for their survival and growth (Kutieshat & Farmanesh, 2022).

In a relentless pursuit of sustaining competitiveness, enterprises operating within the fruit and vegetable preservation domain have been compelled to undertake a comprehensive reassessment of their strategies while wholeheartedly embracing innovative paradigms. Amongst the methodologies that have captured considerable attention stands the application of ultraviolet (UV) irradiation as a preservation technique, as highlighted by the insightful research of (Kutieshat & Farmanesh, 2022). It has been expounded by Yemmireddy et al. (Yemmireddy et al., 2022) that UV irradiation possesses the inherent capacity to effectively curtail microbial contamination and substantially prolong the shelf life of freshly harvested produce. However, the adoption of UV irradiation in the industry has been subject to diverse influences, encompassing multifaceted considerations,

such as cost dynamics, safety apprehensions, and perceptions concerning its overall efficacy. In light of the ongoing pandemic, there's a fascinating and crucial area that has not received much attention—how it has impacted innovation management and attitudes towards innovative preservation methods. This makes it a captivating subject that deserves more scholarly exploration.

Preserving the nutritional goodness of fruits and vegetables is incredibly important. It ensures that when we consume them, we get all the health benefits they offer. As highlighted by Tylewicz and colleagues (Tylewicz et al., 2019), these foods are packed with essential vitamins, minerals, antioxidants, and dietary fibers that contribute significantly to our overall well-being. Khokhar et al.'s (Khokhar et al., 2021) authoritative research in 2021 reinforces this fact. Not only does preserving these nutritious foods extend their shelf life, but it also helps reduce food waste and enhances food security, a critical concern in today's world. While traditional methods such as canning, freezing, and drying have been widely used, they come with limitations when compared to the transformative potential of ultraviolet (UV) irradiation. Traditional preservation methods are effective but often energy-intensive, contributing to greenhouse gas emissions and potentially compromising the nutritional content of the preserved foods. For example, canning, which involves high heat and preservatives, can degrade heat-sensitive nutrients and change the flavor and texture of fruits and vegetables, as explained by Pursito et al. in 2020 (Pursito et al., 2020). Freezing, another popular method, can damage produce if not stored correctly, leading to harmful ice crystal formation and nutrient loss, as pointed out by Xin et al. in 2015 (Xin et al., 2015). Drying, while widely used, can result in nutrient loss and may not be suitable for fruits and vegetables that require specific moisture levels for preservation, as discussed by Sirui et al. in 2021 (Sirui et al., 2021). In contrast, UV irradiation stands out as a promising alternative. It effectively reduces microbial contamination in fruits and vegetables without the need for chemicals or high temperatures. Unlike traditional methods, it minimizes heat exposure, which helps preserve the nutritional content of the produce. Moreover, UV irradiation is a safer choice for consumers and the environment, as it does not introduce harmful chemicals or residues, in line with Lopez-Malo and Palou's findings in 2004 (Lopez-Malo & Palou, 2004).

Adopting UV irradiation for preserving fruits and vegetables offers numerous advantages and could overcome some limitations of conventional methods, making it a more efficient and sustainable approach. However, to ensure the efficacy and safety of UV irradiation in the realm of food preservation, a judicious amalgamation of further research and meticulous implementation stands as an indispensable imperative. The spoilage of fruits and vegetables can have significant environmental consequences, leading to increased waste generation and greenhouse gas emissions (Alegbeleye et al., 2022). When fruits and vegetables rot and are discarded, they end up in landfills, where they decompose anaerobically, releasing methane gas—a potent greenhouse gas that contributes to climate change. To minimize the environmental impact caused by fruit and vegetable spoilage, addressing food spoilage through improved storage, transportation, and distribution processes, as well as reducing consumer food waste, is crucial. By adopting more sustainable practices, we can contribute to a more environmentally responsible approach to food consumption and help mitigate the environmental consequences of fruit and vegetable spoilage. As stated by Karanth et al. (Karanth et al., 2023), enhancing

and upholding sustainability have involved prominent goals, such as minimizing food waste during harvest, postharvest stages, food processing, and at the consumer level.

The acceptance of technology, especially advancements in fruit preservation, is greatly influenced by how people perceive it (Delhove et al., 2020). People's attitudes, convictions, and opinions towards emerging preservation technologies can have a big impact on whether or not they choose to employ them. The acceptability and implementation of new fruit preservation technologies are likely to be influenced by favourable views, such as those of improved food safety, a longer shelf life, and increased convenience. Its general acceptability, however, could be hampered by unfavourable impressions, such as worries about potential effects on nutritional value, potential adverse effects, or lack of knowledge with the technology. Building customer trust and addressing any concerns is essential for overcoming these obstacles. Accurate and honest information regarding the advantages and safety of these technologies must be distributed. Some communities may be more open to adopting novel technology, while others may show greater resistance to change; therefore, cultural and sociological issues may also be important (Bellamy, 2019). Innovative fruit preservation methods must be introduced and integrated successfully to ensure widespread adoption, effectively increase food security while minimising food waste, and to ensure that human perceptions are understood and addressed.

The central objective of this study is to explore the intricate interplay between the COVID-19 pandemic and innovation management within the fruit and vegetable preservation industry. The research question focuses on how has COVID-19 impacted innovation in the fruits and vegetables sector, and what is the influence of perceptions on the adoption of UV radiation for their preservation More specifically, the research delves into the shifting perspectives and sentiments regarding the prospective utilization of UV irradiation as a preservation technology. Unraveling these developments assumes paramount significance in addressing the disruptions faced by the food supply chain and ensuring a consistent flow of fresh and secure commodities. In its pursuit of elucidating these dynamics, the study aspires to furnish invaluable insights into the ever-evolving landscape of innovation management amid the backdrop of global disruptions and uncertainties. By scrutinizing the repercussions of the COVID-19 pandemic on innovation management practices within this sector, and analyzing the evolution of attitudes towards UV irradiation, the research endeavors to shed light on critical aspects of adaptation and resilience in the face of unprecedented challenges. Ultimately, this investigation strives to contribute to the advancement of knowledge, thereby fostering more informed decision-making and strategic approaches to navigate the complexities of contemporary times.

Materials and methods

Description of the case study

Kazakhstan, situated in Central Asia, shares its borders with Kyrgyzstan, Uzbekistan, Turkmenistan, Russia, China, and the Caspian Sea. Boasting an expansive territory, it reigns as the largest country in the region and ranks a formidable ninth globally in terms of land area, stretching approximately 1,820 miles from east to west and 960 miles from north to south. Intriguingly, despite its geographical affinity with other Central Asian nations, Kazakhstan did not formally fall under the Central Asia classification during the

Soviet era. While Kazakhstan has laid the groundwork to regulate innovation, questions linger regarding the efficacy of its innovation-related policies and initiatives on both a national scale and within specific industries, regions, and enterprises. Cognizant of the pivotal role innovation plays in diversifying its resource-centric economy and propelling socioeconomic advancement, Kazakhstan has actively pursued the construction of a modern research and innovation ecosystem since the early 2000s. These endeavors have borne fruit, yielding noteworthy strides in scientific research and witnessing some successful ventures in technological commercialization. However, to fully harness its potential, Kazakhstan must fortify its innovation capabilities even further. To achieve this, additional reforms are required, focusing on improving the governance of the research and innovation system, enhancing the funding model for universities, expanding knowledge transfer, and increasing the effectiveness of innovation incentives and policies. Emphasizing implementation and evaluation is critical in this endeavor (OECD, 2022). By addressing these areas, Kazakhstan can bolster its capacity to innovate and drive progress in various sectors, propelling the nation towards sustained development and prosperity.

Perceptions regarding the use of ultraviolet technology for preserving fruits and vegetables

The primary objective of this study was to gauge Kazakh consumers' perspectives on ultraviolet (UV) irradiated food, particularly focusing on fruits and vegetables. In addition, the research aimed to explore the potential impact of providing educational resources on UV irradiation to influence consumer attitudes. The survey, carried out between July 2022 and January 2023, involved a custom-designed questionnaire created by the researcher. It encompassed various aspects, such as sociodemographic details, such as gender, age, location, and educational background. In addition, it delved into attitudes towards preserved food, including purchasing habits, perceived benefits of food preservation, and the frequency of buying foods treated with different preservation methods. Moreover, the survey investigated respondents' knowledge and attitudes towards food irradiation, including their ability to recognize the irradiated food symbol, purchasing preferences, and comprehension of the advantages it offers.

To accomplish this, a multimedia presentation was utilized, which covered topics, such as global food-related diseases, the purpose and impact of food irradiation on nutrients, and visual representations of both irradiated and unirradiated food products after storage. Participants were questioned about irradiated food both before and after reviewing the educational materials. The survey was conducted voluntarily and anonymously online using Google Forms, given the prevailing epidemic situation, and was disseminated through social networks. The study employed random sampling techniques, specifically targeting residents of Kazakhstan, and adhered to a specific formula (Eq. 1) to determine the minimum sample size, ensuring statistical validity.

$$N_{min} = \frac{N_p \times (\alpha^2 \times f(1-f))}{N_p \times e^2 + \alpha^2 \times f(1-f)} \tag{1}$$

By utilizing the provided equation, the minimum sample size (Nmin) was determined to be 384, taking into account the population size (N_p), a confidence level (α) of 95%, an

assumed fraction size (*f*) of 50%, and a maximum error (e) of 0.05. However, considering the lack of comparable surveys conducted in Kazakhstan, it was decided to expand the study group. Consequently, a total of 584 questionnaires were successfully filled out and included in the analysis.

Survey on the possible disturbances arising from the pandemic

In this section of the study, we delved deep into the intricate relationship between the social and economic consequences arising from the disruptive force of COVID-19 and their subsequent influence on the future orientation of innovation within organizations. In addition, our objective was to evaluate how the widespread social and economic ramifications of COVID-19 have shaped the financial resources allocated towards nurturing innovation in companies associated with the fruits and vegetables industry. To achieve this, our study embarked on a comprehensive questionnaire survey involving 54 enterprises operating in this sector. We carefully crafted the survey questions to extract essential data and gain pertinent insights. The questionnaire was meticulously structured into four distinct sections, each precisely tailored to address specific aspects aligned with our research objectives:

1) Firm-specific information: This section gathered details about the size and scope of activities of each organization, providing a foundational understanding of the surveyed companies.
2) Motivating Factors for Innovation: Here, we explored the driving forces that led each company to embark on innovation initiatives, with a specific focus on innovations related to water. We aimed to uncover how these motivations were shaped by the profound social and economic impacts triggered by the COVID-19 disruption.
3) Allocation of Funding: This section probed the extent to which the social and economic implications of COVID-19 have influenced the allocation of financial resources dedicated to innovation within the respective firms. It sought to reveal shifts in funding priorities in response to the pandemic's challenges.
4) Rating the Impact of COVID-19: Respondents were asked to rate the influence of COVID-19 on various facets of innovation management within the preservation of fruits and vegetables. Using a scale ranging from 1 (indicating no significant impact) to 5 (indicating a strong impact), this comprehensive rating system aimed to capture nuanced variations in the pandemic's effects on innovation-related aspects within the industry.

By structuring the research in this way, the study aimed to gain a holistic and detailed understanding of how COVID-19 has reshaped innovation dynamics within the fruits and vegetables industry, shedding light on the challenges and opportunities that have arisen during these unprecedented times.

Emphasizing the indispensability of a questionnaire as an invaluable research instrument, it exemplifies a meticulously curated array of inquiries strategically devised to solicit comprehensive data from respondents during the conduct of surveys or intricate statistical analyses. It serves as the quintessential conduit for garnering profound insights and nuanced perspectives. In this contextual milieu, the respondent-represented

corporate entities have been judiciously classified into three discrete cohorts, each bearing unique characteristics and implications deserving discerning scrutiny. The ensuing categorization endeavors to distill the multifaceted intricacies underpinning innovation management, thus manifesting as a cogent framework that effectively informs strategic decision-making in the quest for sustainable fruit and vegetable preservation strategies amidst the formidable backdrop of the COVID-19 epoch. As previously elucidated, the classification of business scales encompassed three well-defined categories, delineated on the basis of the number of employees within each enterprise. Small-scale enterprises constitute those establishments harboring a workforce ranging from 1 to 20 employees, indicative of their compact operational size and localized focus. In contrast, medium-scale enterprises encompass a more considerable contingent of personnel, comprising 21 to 1000 individuals, thereby showcasing a measured expansion in both organizational outreach and complexity. Finally, the large-scale enterprises surpass the threshold of 1000 employees, emblematic of their expansive corporate structures and consequential global influence. Employing this meticulous stratification framework affords a nuanced and comprehensive examination of the diverse business scales, thus engendering a profound comprehension of their individual contributions and responses in the realm of innovation management and sustainable fruit and vegetable preservation, particularly amid the unprecedented challenges posed by the COVID-19 era. The general Firms' distribution is presented in Fig. 1.

To uphold the statistical rigor of the investigation, the establishment of an appropriate minimum sample size was executed via a preliminary calculation. In the domain of research, the notion of "sample size" pertains to the number of individuals encompassed within the study to effectively mirror the characteristics of the intended target population. This aggregate of participants is frequently stratified based on various demographics to ensure that the final sample accurately represents the entirety of the community under scrutiny. The selection of an optimal sample size constitutes a pivotal facet of the subsequent statistical analysis, as it directly influences the precision and reliability of the study's findings. The specific formula employed for ascertaining the sample size in this segment of the study is succinctly encapsulated within Eq. 2. This formula takes into account several critical factors, including the desired level of confidence, the acceptable margin of error, and the variability within the population. The careful consideration of these parameters ensures that the sample size is not only adequate but also statistically

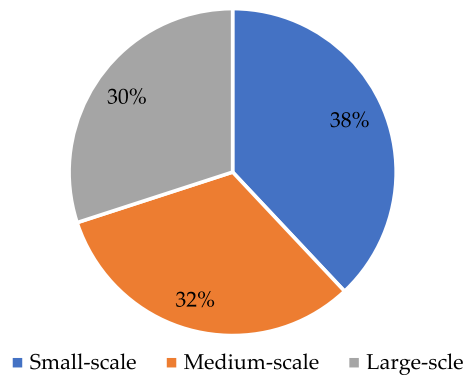

Fig. 1 Firms' distribution in the questionnaire survey

significant. Furthermore, it's essential to note that determining the appropriate sample size is a critical step in ensuring the study's results can be generalized to the broader population. In this context, a larger sample size can enhance the study's external validity, allowing for a more confident extrapolation of findings beyond the surveyed group of participants. Conversely, an excessively small sample size may lead to results that are less reliable and less applicable to the population as a whole.

$$Sample\ size = \frac{(z - score)^2 \times StdDev \times (1 - StdDev)}{(margin\ of\ error)^2} \quad (2)$$

The acknowledgment of the margin of error, or confidence interval, is of paramount importance as a metric that quantifies the potential divergence of data from the population mean. This critical value serves as an indicator of the survey result's proximity to the true population value, instilling confidence in the reliability of the findings. Concurrently, the standard deviation plays an equally pivotal role in assessing the extent of data dispersion from the mean, providing a measure of absolute variability within the distribution. As the data's spread or variability increases, both the standard deviation and the magnitude of the deviation correspondingly expand, underscoring the level of data heterogeneity.

On a similar note, the Z-score assumes its role as a crucial statistical measure, gauging the proximity of a specific value to the mean of a set of values. Calculated by determining the number of standard deviations from the mean, the Z-score furnishes an objective assessment of how each data point deviates from the central tendency. When the Z-score amounts to zero, it signifies that the data point's score is precisely identical to the mean score, suggesting a complete absence of deviation. In essence, the Z-score illuminates the relative position of a data point within the distribution, facilitating the identification of outliers and aiding in the interpretation of data significance.

Results

Consumers' attitudes towards the applicability of UV irradiation on the preservation of fruits and vegetables

Respondents characteristics

In this comprehensive study encompassing a total of 584 participants, gender distribution revealed that 65.4% ($n = 382$) were identified as female, while 34.6% ($n = 202$) were identified as male. The average age of the respondents stood at 25.2 ± 8.5 years, indicative of the sample's age profile and variability. Focusing on age categories, the cohort between 21 and 30 years represented the largest and most prominent group, comprising 55.8% ($n = 326$) of the total participants. This notable majority was deemed statistically significant ($P < 0.05$) when compared to other age groups, underscoring the significance of this age bracket in the study's demographic composition. Educationwise, the participants exhibited a notable level of attainment, with approximately 70% possessing either a university degree ($n = 208$; 35.6%) or secondary/professional education ($n = 215$; 36.8%). This reflects a considerable level of educational achievement within the sample, providing valuable insights into the participants' academic backgrounds. Residence distribution demonstrated that the majority of respondents inhabited urban centers with a population exceeding 100,000 inhabitants, accounting for 75.7% ($n = 342$) of the

total sample. Conversely, a smaller proportion of the participants, representing 24.3% ($n = 142$), resided in villages, highlighting the predominantly urban-centric nature of the study's population.

The general respondents' perceptions about fruit and vegetable preservation

Based on the data presented in Fig. 2a, it is evident that a significant majority of male respondents, around 93.6%, expressed a tendency to frequently purchase preserved fruits and vegetables. In contrast, only a small portion, approximately 6.4%, of male respondents reported not buying preserved fruits and vegetables. Among the female respondents, approximately 84.6% stated that they primarily purchase preserved fruits and vegetables, while approximately 15.3% showed a lack of interest in such products. In terms of age demographics, individuals between the ages of 29 and 39 demonstrated

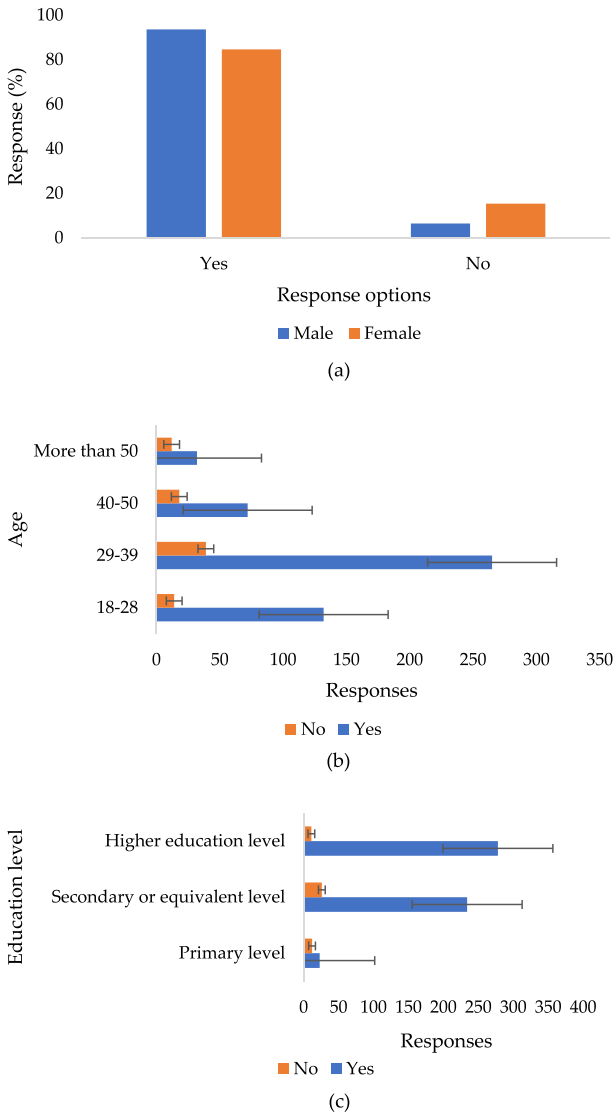

Fig. 2 Purchase of preserved food declaration (**a**) based on gender (**b**) based on age (**c**) based on educational level

a higher level of interest in preserved fruits and vegetables. Approximately 87.2% of respondents within this age category indicated a frequent purchase of preserved fruits and vegetables, regardless of the preservation method used. When considering the level of education, individuals with a "higher learning education level" displayed greater interest in preserved fruits and vegetables compared to those with secondary or primary education. In addition, the results indicate that as people receive more education, they tend to become more comfortable with consuming preserved fruits and vegetables. This phenomenon can be attributed to increased awareness and a decrease in misconceptions surrounding these products.

Factors affecting the respondents' choice of fruits and vegetables that have been preserved

The factor that had the greatest impact on respondents' preference for preserved fruits and vegetables, with a mean score of 4.6, was the elimination of pathogenic microorganisms. This finding underlines the paramount importance consumers place on food safety when it comes to choosing preserved products. Knowing that the preservation process effectively safeguards them against harmful bacteria and other pathogens provides a sense of reassurance, making these items a popular choice among health-conscious individuals and those seeking peace of mind in their dietary choices. Similarly, the survey revealed that protection against microbial growth and prevention of physical alterations to fruits and vegetables also received high average scores as influential factors. People appreciate that preserved produce can maintain its fresh appearance, taste, and texture for longer periods, minimizing food waste and offering convenience in meal planning. This aspect is particularly appealing in today's fast-paced world, where busy schedules often necessitate longer-lasting food options without sacrificing nutritional value. However, intriguingly, a portion of the respondents mentioned that buying preserved fruits and vegetables was simply part of their daily routine or habit. This finding suggests that familiarity and comfort play a significant role in shaping consumer behavior. For many individuals, incorporating preserved items into their regular grocery shopping becomes a customary practice they have grown accustomed to over time. It could be driven by a combination of factors, including the convenience of having pantry-staple foods readily available and the peace of mind that comes from knowing they will not spoil quickly. Moreover, the preference for preserved fruits and vegetables might also stem from their flexibility in various culinary applications. With preserved options at hand, consumers can effortlessly add fruits to smoothies, create vibrant salads, or use vegetables as a flavorful addition to various dishes year-round. This adaptability can further reinforce their attractiveness to those who enjoy experimenting with recipes and maintaining a diverse diet. It is essential to note that while certain factors stood out as significant influencers, individual preferences can still vary widely. Some respondents might prioritize convenience and shelf life, while others might focus on the taste, nutritional content, or even environmental impact of preserved food options. As food preservation technology continues to advance and consumer awareness grows, the landscape of preferences is likely to evolve, with new factors coming into play in shaping purchasing decisions (Table 1).

The analysis of the data illustrated in Fig. 3 reveals insightful patterns regarding the respondents' perceptions of ultraviolet irradiation for fruit and vegetable preservation. Notably, a substantial proportion of participants, approximately 50.9%, demonstrated a

Table 1 Factors influencing the respondents' preference for preserved fruits and vegetables

Protection	Min.	Max.	Mean	Median	STD
Protection against microbial growth	3	5	4.5	5	0.707107
Preventing physical alterations to fruits and vegetables	3	5	4.25	4.5	0.829156
Elimination of pathogenic microorganisms	3	5	4.625	5	0.695971
Halting biological reactions in fruits and vegetables	2	5	3.625	4	0.856957
Aesthetic reasons	1	5	2.875	2.5	1.268611
Just a habit with no specific reason	1	5	2.75	2.5	1.391941

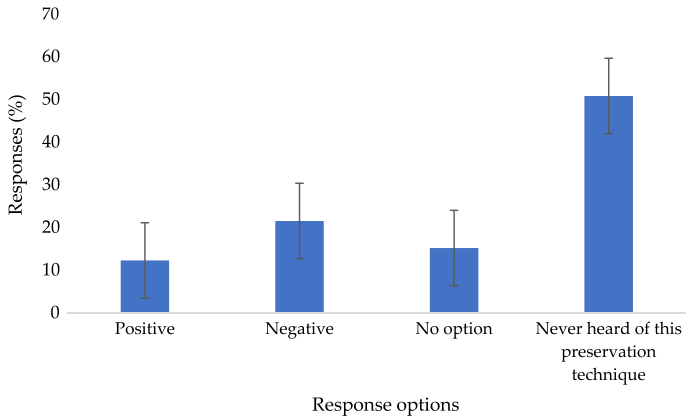

Fig. 3 Knowledge on UV utilization for the preservation of fruits and vegetables

lack of understanding regarding the utilization of ultraviolet irradiation as a preservation technology. Furthermore, about 21.6% of respondents expressed disinterest in adopting ultraviolet irradiation for preserving fruits and vegetables. In contrast, a relatively smaller percentage of participants, comprising only 12.3%, exhibited a positive inclination towards the application of ultraviolet irradiation in the preservation process. Interestingly, approximately 15.2% of respondents remained undecided and did not provide a definitive preference regarding their willingness to utilize ultraviolet irradiation for preserving fruits and vegetables. This nuanced breakdown of responses provides valuable insights into the awareness, receptiveness, and hesitations surrounding the potential adoption of ultraviolet irradiation as an innovative preservation approach in the fruits and vegetables industry.

Factors believed to make UV irradiation less applicable for preserving fruits and vegetables

Regarding the factors influencing the perceived applicability of UV irradiation in fruit and vegetable preservation, the survey respondents highlighted cost, safety, and limited knowledge as the most significant determinants. For the purpose of assessment, participants were asked to provide a rating on a scale of 1 to 5, with 1 denoting the least influence and 5 indicating the highest level of influence. This meticulous scoring approach allowed for a nuanced understanding of the relative importance attributed to each factor by the respondents. The analysis of these scores provides valuable insights into the prevailing attitudes and perceptions surrounding the use of UV irradiation techniques in

the preservation of fruits and vegetables, shedding light on critical considerations that may impact the adoption and acceptance of such preservation methods in the industry (Table 2).

Despite the knowledge available as of September 2021, it was not common for COVID-19 to be transmitted through fruits and vegetables. The primary mode of COVID-19 transmission remained through respiratory droplets when an infected person talked, coughed, or sneezed. Nevertheless, practicing proper hygiene when handling fruits and vegetables was essential to minimize the risk of potential contamination. Experts recommended thoroughly washing fruits and vegetables under running water before consumption, even if peeling them, to remove any potential surface contaminants. In addition, it was crucial to wash hands thoroughly with soap and water before and after handling fruits and vegetables, and adhere to general hygiene practices to prevent the spread of COVID-19. In light of this knowledge, the study also aimed to explore how the pandemic has influenced perceptions regarding the potential use of UV irradiation as a method to ensure food safety and preservation. The following assumptions were made while selecting the factors:

1) Increased public attention to food safety: The COVID-19 pandemic significantly increased public attention to food safety. The likelihood of viruses and other pathogens spreading across the food supply chain raised increasingly serious concerns. To secure the safety of food products, people and businesses started investigating and investing in cutting-edge technology-like UV irradiation.
2) Demand for safer food preservation techniques: The uncertainty caused by the epidemic around the virus increased demand for safer food preservation techniques. Customers expressed a significant demand for food products that would maintain their nutritious value over an extended period of time. As a result, one of the possible methods to meet this expanding demand was UV irradiation.
3) UV applications in food facilities: During the pandemic, cleanliness and sanitation were stressed in a variety of contexts, including food production and processing facilities. These establishments' use of UV technology for surface, air, and water disinfection significantly improved food safety measures.
4) Research and development: Companies and researchers have stepped up their efforts to explore and advance UV irradiation technologies in response to the urgent need

Table 2 Perceived factors leading to less applicability of UV irradiation on the preservation of fruits and vegetables

Factor	Responses				
	Min.	Max.	Mean	Median	STD
Competitive factors and process effectiveness	1	4	2.6	2	1.02
Costs	3	5	4.5	5	0.67
Safety	3	5	4.6	5	0.66
Lack of awareness/knowledge	2	5	4.4	5	0.92
Regulatory consequences	1	5	3.3	3.5	1.42
Consumer acceptance	2	5	3.5	3.5	1.02
Insufficient innovative ideas in the field	3	5	4	4	0.77

to battle COVID-19 and improve food safety. The efficiency of it in neutralising different viruses and its prospective uses in guaranteeing food safety have been thoroughly understood as a result of this research.

5) Regulatory factors: As interest in UV irradiation for food safety rose, regulatory organizations and health authorities closely observed its application and discussed standards and approvals for it in the food business. The pandemic may have sped up talks and analyses about the practicality and safety of UV irradiation as a food preservation technique.
6) Consumer acceptance: Given that UV irradiation's safety and efficacy are well-established, the pandemic's increased attention to health and safety may have made consumers more receptive to novel technologies. The pandemic's effects on consumer choices and behaviour may have an impact on whether UV irradiation is ever used as a food safety strategy.

According to the data presented in Fig. 4, all the factors examined in the study received an average score of at least 4 points, indicating their considerable significance in influencing the potential application of UV irradiation for preserving fruits and vegetables in the context of COVID-19. The results highlight the overall importance respondents placed on these factors when considering the adoption of UV irradiation as a viable method to enhance food safety and prolong the shelf life of perishable produce during the pandemic. The high average scores given to each factor underscore the collective recognition of their impact on the use of UV irradiation as a preservation technique. These findings suggest that respondents recognize the potential benefits of UV irradiation in mitigating the risks associated with foodborne pathogens and extending the freshness and safety of fruits and vegetables in the face of the pandemic's challenges. The study's findings can be a useful resource for researchers, legislators, and anyone working in the food sector who wants to promote and implement safer and more environmentally friendly food preservation techniques. By identifying these influential factors, stakeholders can tailor educational initiatives and communication strategies to emphasize the

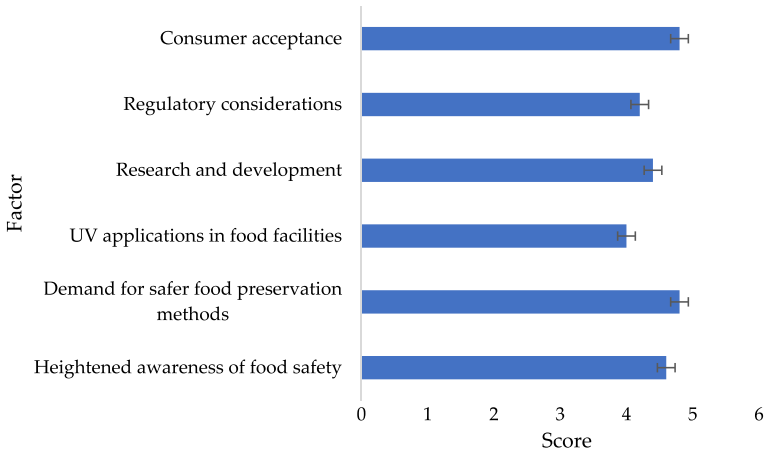

Fig. 4 COVID-19 potential influence on the adoption of UV irradiation for preservation of fruits and vegetables

advantages and effectiveness of UV irradiation in ensuring food safety and enhancing consumer confidence in preserved produce.

Innovation disruptions amidst the pandemic

Influential external factors impacting innovation in fruit and vegetable preservation

The systems view of innovation encompasses a comprehensive understanding of the intricate interplay between political, social, organizational, and economic systems, and how these external influences interact with the creative endeavors of businesses. This approach underscores the significance of external forces in shaping a company's incentives, efforts, capabilities, and ultimate outcomes in the realm of innovation. These external influences can arise from diverse sources, such as strategic business initiatives, political directives, or well-organized social movements championed by advocacy organizations. Measuring the impact of external influences on innovation can be done through both direct and indirect methodologies. Indirect measurement focuses on how external factors impact businesses without explicitly referencing innovation. It involves data collection and rigorous analysis, often leveraging econometrics, to examine the effects of external influences on innovation across firms of varying levels of innovativeness. On the other hand, direct measurement methods involve direct questioning of respondents to assess the importance and influence of external factors on specific innovation-related traits. However, it's important to recognize that direct questioning may introduce cognitive biases and may not allow respondents enough time to thoroughly assess how external factors affect an organization's innovation activities or outcomes. In examining the data presented in Fig. 5a, a notable observation emerges—governance quality appears to exert a more pronounced impact on medium-sized enterprises compared to smaller ones. Conversely, small businesses exhibit a higher willingness to experiment with creative approaches. Moving to Fig. 5c, the results indicate that large-scale businesses are more affected by factors, such as the availability of local expertise, the quality of governance, and their readiness to embrace novel ideas. These intriguing findings highlight the intricate connections between external factors and the innovation efforts and outcomes of different types of firms, prompting the need for further in-depth investigation into these matters. By delving deeper into the complexities of these interactions, valuable insights can be gleaned to better understand and optimize the innovation dynamics within various organizational contexts.

The investigation concerning the effects of COVID-19

The data depicted in Fig. 6 reveals a striking and noteworthy pattern concerning the innovation motivation of enterprises within the fruits and vegetable processing technologies amidst the COVID-19 era. Remarkably, 63% of the participants identified medium-sized businesses as manifesting conspicuously low levels of innovation motivation during this period. Similarly, 51% of the respondents shared the same perspective regarding large-scale businesses. However, the survey results brought to light a significant contrast, showcasing small-scale businesses' exceptional display of higher innovation motivation at 28%, which notably surpassed the comparatively modest 10% observed in both medium-sized and large-scale counterparts. These marked disparities in innovation motivation across different business scales signify the varying impacts

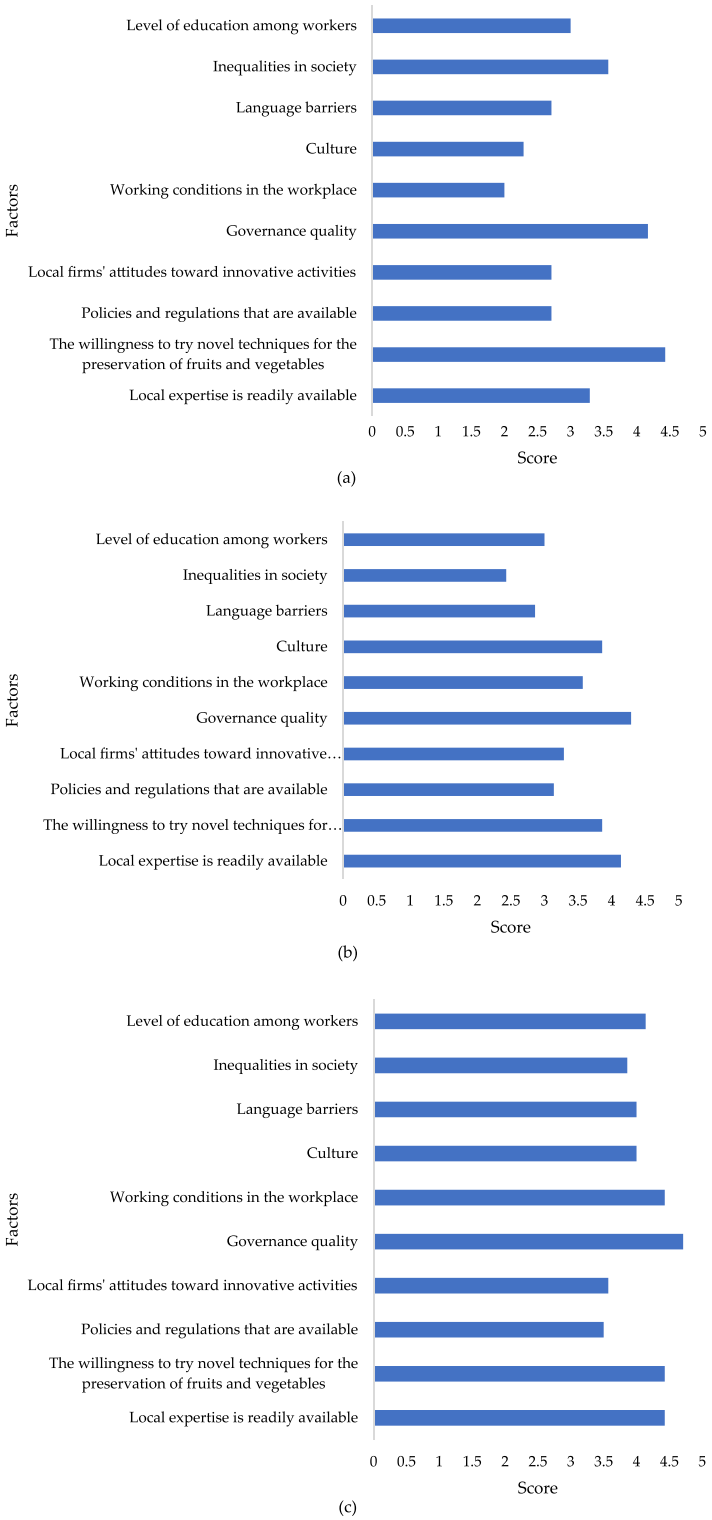

Fig. 5 Score of social factors affecting innovation in the fruits and vegetables preservation sector (**a**) small scale (**b**) medium scale (**c**) large scale

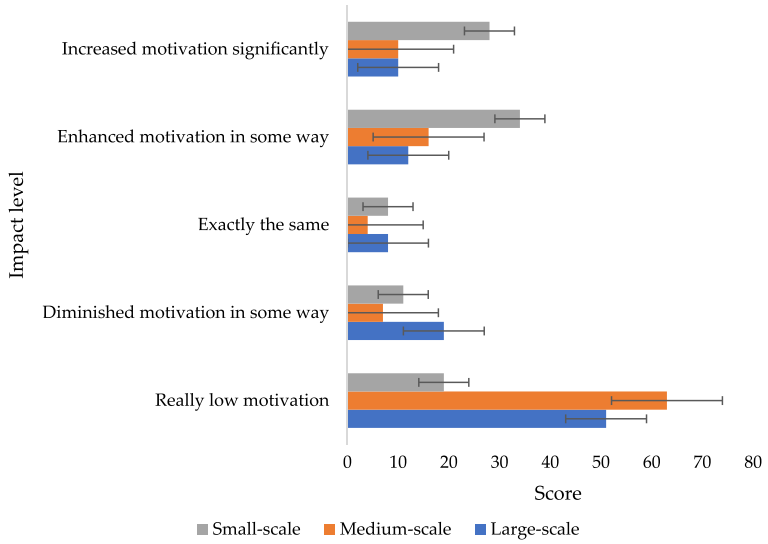

Fig. 6 Impact on motivation for innovation

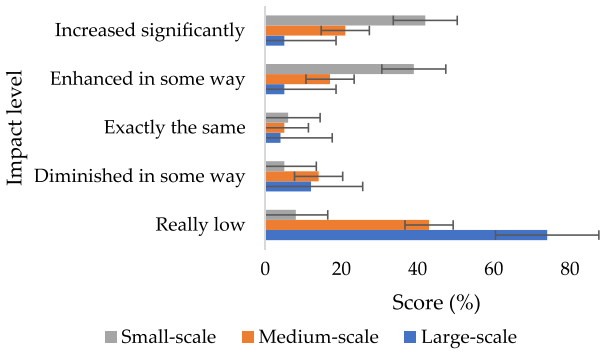

Fig. 7 Impact on investment level as influenced by funding

of the pandemic on firms' proclivity for embracing innovation in the fruits and vegetables preservation sector. Such insightful findings shed light on the intricate dynamics of innovation management within the industry during the challenging COVID-19 period, offering valuable perspectives on how various enterprises navigated the unprecedented circumstances and approached innovation in response to the pandemic's disruptions.

In addition to investigating the influence of the COVID-19 pandemic on various innovation-related parameters, the research also delved into the financial aspects of enterprises, particularly in relation to their investment activities. Figure 7, a pivotal component of our study, presents the survey results pertaining to the impact of COVID-19 on investment levels. As observed, a notable distinction emerged in investment trends between large corporations and small businesses. During the COVID-19 period, a substantial 74% of respondents from large enterprises indicated remarkably low investment levels. This decrease in investment among large corporations can be attributed to several factors, including economic uncertainties, disrupted supply chains, and the need to conserve resources amidst the pandemic's uncertainties. In contrast, only 21% of medium-sized businesses and a mere 5% of large-scale organizations reported experiencing a

similar decline in investment. The relatively resilient investment behavior of medium-sized firms could be attributed to their adaptability and ability to pivot in response to market changes. Interestingly, the findings revealed that 42% of respondents from small-scale firms reported a noteworthy increase in their investment levels during the same period. This surge in investment among small businesses may be indicative of their agility and capacity to identify opportunities even during challenging times. These research findings illuminate the significant disparities in investment behavior among enterprises of different sizes in the context of the COVID-19 pandemic. The data sheds light on the varying responses of businesses in navigating the financial challenges brought forth by the pandemic, providing valuable insights into the dynamics of investment decisions and their implications across diverse business scales. Furthermore, these findings underscore the importance of agility and adaptability for businesses, as they face and respond to unprecedented disruptions, and highlight the need for tailored strategies that align with an organization's size and resilience.

Figure 8 presents a comprehensive and all-encompassing overview of the research outcomes, elucidating the far-reaching impact of the COVID-19 pandemic on various innovation-related parameters, irrespective of the firm's size. Notably, the COVID-19 situation has exerted a profound influence on several critical facets, encompassing funding allocation, market availability, goods transportation, and overall profitability in recent times. Of particular importance is the study's comprehensive definition of "goods transportation," which encompasses the intricate processes involved in the movement of cargo or goods utilizing diverse transportation modes, such as trucks, cars, trains, ships, and airplanes. The pandemic's multifaceted repercussions on these pivotal aspects of innovation management underscore the pressing need for a more holistic and systematic approach to comprehending and addressing the complex challenges that have surfaced in the fruits and vegetables preservation industry during this unprecedented period. Deeper exploration and thorough examination of these research findings carry the potential to offer valuable insights and perspectives that can be harnessed in formulating strategies and policies aimed at bolstering resilience and sustainability within the sector amidst the prevailing global uncertainties. As the fruits and vegetables preservation

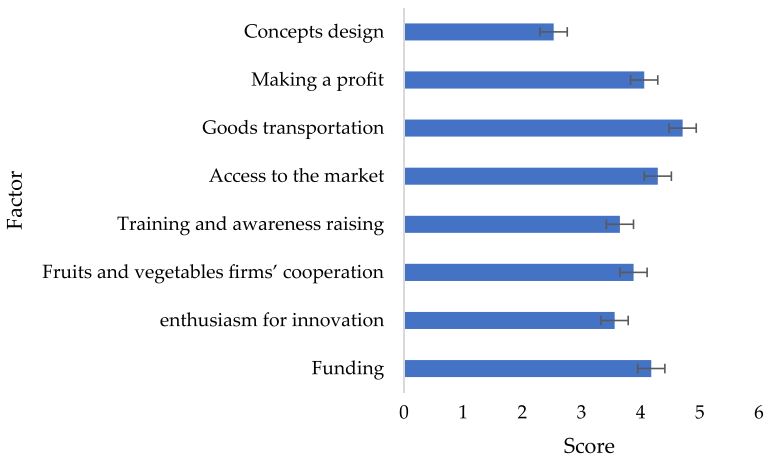

Fig. 8 Impact of the pandemic on diverse facets of innovation

industry navigates through these turbulent times, a well-informed understanding of the pandemic's impacts on innovation-related parameters will undoubtedly play a pivotal role in charting a path towards recovery, growth, and enhanced adaptability.

Implications of the findings on sustainable production and consumption

Regarding the problems with the environment on a worldwide scale, sustainable production and consumption are essential. The direct and indirect effects of our discoveries on sustainable production and consumption, particularly in relation to advancements in food preservation, are covered in this paragraph.

Direct implications

Our study shows that consumer perceptions about UV-irradiated food have a big impact on what they buy. Customers are more inclined to select these products when they are aware of the advantages of UV irradiation, such as the prolonged shelf life and less food waste. By decreasing food deterioration and lowering the carbon footprint associated with food production and delivery, this shift towards UV-irradiated foods can directly contribute to sustainable consumption. In addition, UV irradiation can take the place of conventional chemical preservatives, supporting sustainable and healthy food production ideals.

Indirect implications

Our findings have wider, indirect consequences for sustainable farming and agriculture in addition to the immediate consumer decisions. Food producers may be encouraged to use cutting-edge, resource-saving preservation techniques by the rising demand for UV-irradiated items. In turn, this may encourage the food business to adopt sustainable manufacturing methods. Longer shelf lives reduce food waste, which reduces the use of resources such as water, energy, and agricultural inputs in the manufacture of food that will not be eaten. As a result, this promotes agriculture's primary objective of resource conservation.

Resource conservation

Fruit and vegetable post-harvest losses could be considerably reduced by advances in food preservation, including UV irradiation. The requirement for excessive agricultural inputs such as water, fertilizer, and pesticides is reduced due to crop conservation. In addition, it eases the strain on agricultural land use, assisting in the preservation of biodiversity and natural habitats. UV irradiation aligns with sustainable production practises, where resource conservation is a key concept, by reducing resource-intensive practices and improving resource utilization.

Promoting sustainable agriculture

Sustainable agriculture attempts to minimise harmful environmental effects while providing for the rising global food demand. By increasing the freshness of fruits and vegetables, UV irradiation aids in the creation of more resilient agricultural systems. To meet the demand for premium, UV-irradiated food, farmers may be encouraged to embrace environmentally friendly practises, including reduced pesticide use and organic farming.

In addition, UV irradiation can make it possible to use extra or "imperfect" products that would otherwise go to waste, aiding small-scale farmers and boosting sustainable agriculture by lowering food loss.

Economic and social sustainability

The use of UV irradiation for food preservation may have effects on the economy and society's ability to sustain itself. Small-scale farmers may be given the chance to take part in supply chains that put an emphasis on sustainable practises. In addition, UV-irradiated food can support better nutrition and food security by lowering food waste and boosting food safety, which is in line with the Sustainable Development Goals of the United Nations.

Environmental footprint reduction

Because UV irradiation can substitute chemical preservatives, it can lessen the environmental impact of making and disposing of these chemicals. In addition, the decrease in food waste brought on by foods that have undergone UV radiation can lessen the environmental impact of landfills, where discarded food frequently produces methane, a potent greenhouse gas. This is in line with initiatives to lessen global environmental degradation and combat climate change.

Consumer awareness and education

There is a significant need for public knowledge and education about the advantages of UV-irradiated foods to fully understand these indirect consequences. Consumer education about UV radiation's benefits for the environment and resource conservation can increase demand for these goods and encourage companies to use sustainable agriculture and production methods.

Policy and industry collaboration

Through supportive policies and partnerships, governments and industry stakeholders may play a critical role in advancing sustainable production and consumption. Policies that promote the use of UV irradiation and other environmentally friendly food preservation techniques can support sustainable agriculture and resource preservation. Collaboration between industry, academia, and government organisations can also promote advancements in food preservation technology and their incorporation into environmentally friendly production methods. In conclusion, our study emphasises the significant effects consumer perceptions of UV-irradiated foods have on sustainable food production and consumption. Innovations in food preservation, such as UV irradiation, have the potential to be a catalyst for improvement in the quest for sustainability in the food business by reducing food waste, preserving resources, supporting sustainable agriculture, and minimizing environmental footprints. All stakeholders, from consumers and producers to politicians and researchers, must work together to build a more sustainable and resilient food system to realize these benefits.

Discussion

In the realm of food preservation, the significance of employing various techniques cannot be overstated. These methods play a vital role in extending the availability of seasonal produce, curbing food waste, ensuring food security, and enabling efficient transportation of perishable goods across long distances. Moreover, they offer consumers the opportunity to savor a diverse array of food throughout the year while maintaining nutritional value and upholding safety standards. The effectiveness of fruit and vegetable preservation in prolonging shelf life and retaining nutritional content hinges upon the specific preservation method employed. Nevertheless, consumer perception plays a crucial role in determining the acceptability of these methods. The study's findings revealed that a substantial majority of male respondents, approximately 93.6%, expressed a preference for frequently purchasing preserved fruits and vegetables. Conversely, a minor percentage, around 6.4%, indicated that they do not procure preserved food items. Among female respondents, approximately 84.6% reported a primary preference for purchasing preserved fruits and vegetables, while approximately 15.3% displayed minimal interest in these products. Traditionally, fruits and vegetables have been preserved through methods, such as canning, freezing, and drying. However, with their ability to curb microbial growth and delay spoilage, modern technologies such as ultraviolet irradiation and modified environment packaging have gained prominence. In addition, there is a rising demand for natural and environmentally friendly preservation techniques, aligning with consumers' desires for sustainable and healthier food options. The practice of canning fruits and vegetables ensures the year-round availability of a diverse and nutrient-rich diet, contributing to enhanced food security and reduced waste. In an era, where food sustainability and health-consciousness take center stage, the adoption of preservation methods becomes paramount for meeting the needs and preferences of discerning consumers. Furthermore, it is imperative to underscore the transformative trends in food purchasing and consumption, wherein consumers are increasingly prioritizing convenience and the impact of food production and processing on health and the environment. For the food industry, particularly in relation to highly perishable items, such as fruit, this poses a considerable challenge (Janssen et al., 2021). In response, the industry has undertaken significant endeavors to mitigate post-harvest losses by embracing natural preservatives as viable alternatives to conventional chemical fungicides. The adoption of such alternatives has gained momentum due to mounting public and governmental opposition towards chemical treatments (Aday & Aday, 2020).

Examining the preferences across different age groups, individuals aged between 29 and 39 years demonstrated a remarkable inclination towards preserved fruits and vegetables. Approximately 87.2% of respondents within this age bracket indicated frequent purchases of preserved produce, regardless of the preservation method utilized. Furthermore, when considering educational attainment, those with a "higher learning education level" exhibited a heightened interest in preserved fruits and vegetables compared to individuals with secondary or primary education. The results also suggest a positive correlation between higher education and an increased comfort level with consuming preserved fruits and vegetables. This shift in perception can be attributed to heightened awareness and a decrease in misconceptions surrounding these products. In light of these findings, it is crucial to acknowledge that consumer perceptions regarding

preserved fruits and vegetables wield substantial influence over market dynamics, health choices, sustainability initiatives, and economic considerations. These attitudes hold immense importance for both consumers and industry stakeholders, as they play a pivotal role in shaping various aspects of the industry (Rahman et al., 2021). By comprehending and responding to these perceptions, the food industry can better cater to the evolving demands of discerning consumers and align its practices with the broader goals of health, sustainability, and economic viability. When contemplating the factors influencing the perceived limited suitability of UV irradiation for fruit and vegetable preservation, cost, safety, and lack of knowledge emerged as the foremost contributors, garnering the highest average scores among the respondents. In this phase of the study, participants were requested to assign ratings on a scale of 1 to 5 to each factor, where 1 denoted the least influence, and 5 indicated the highest impact.

In their comprehensive investigation, (Darré et al., 2022) observed that ultraviolet (UV) radiation had long been perceived as a harmful agent to be avoided by living organisms. However, recent research has unveiled a transformative revelation, demonstrating that UV radiation can bestow beneficial effects on plant physiology by instigating the synthesis of secondary antioxidant metabolites and natural defense mechanisms. This novel understanding has entirely shifted the perception of UV radiation from being solely deemed a germicide and potentially hazardous agent to an invaluable tool that can be harnessed for its favorable responses when applied to harvested agricultural products.

The application of UV treatments in postharvest scenarios has been an area of intense research and experimentation for over four decades, leading to remarkable successes across various domains. These applications encompass several critical aspects, including the careful selection of premium-grade raw materials, the effective control of postharvest diseases and pathogens, the promotion of nutraceutical compound production, the modulation of ripening and senescence processes, and the enhancement of tolerance to environmental stresses. UV radiation, aside from its well-documented antimicrobial properties, possesses a truly fascinating capability—it can trigger the synthesis of bioactive compounds in plants as a defense mechanism. One of the most striking aspects of UV radiation is its role in stimulating the production of these bioactive compounds. This is particularly significant, because these compounds often contribute to the nutritional and health-promoting aspects of fruits and vegetables. Notably, UV treatments have been shown to induce the accumulation of crucial phytochemicals, which include but are not limited to ascorbic acid (Vitamin C), carotenoids (e.g., beta-carotene), glucosinolates (known for their anticancer properties), and notably, phenolic compounds. These phenolic compounds, which include various subclasses, such as flavonoids and phenolic acids, are of paramount importance. They are recognized for their potent antioxidant properties and their potential to combat oxidative stress in the human body. Moreover, they are closely associated with numerous health benefits, including anti-inflammatory, anti-cancer, and cardiovascular-protective effects. Therefore, the ability of UV treatments to enhance the presence of phenolic compounds in fruits and vegetables is of immense significance, as it contributes to the overall nutritional value and health benefits of these produce. In essence, the postharvest application of UV treatments represents a multifaceted approach with a profound impact. It not only serves to protect

and extend the shelf life of fruits and vegetables by controlling diseases and pathogens but also enhances their nutritional content and health-promoting attributes. This dual functionality positions UV treatments as a valuable tool in the realm of postharvest preservation and underscores their potential in contributing to healthier and more sustainable food practices.

Moreover, the study's findings illuminate the varying impacts of governance quality on organizations of different scales. Medium-sized organizations appear to be more significantly influenced by governance quality, while small-scale businesses exhibit a greater propensity to explore creative approaches. Conversely, large-scale firms demonstrate a stronger susceptibility to factors, such as the availability of local expertise, governance quality, and the willingness to experiment with novel ideas. It is crucial to acknowledge that business activities can be both directly and indirectly shaped by societal and environmental factors. The reception of innovations by the public and the implementation of corporate social responsibility programs are influenced by societal considerations (Aghmiuni et al., 2020; Petridis et al., 2020). Notably, transformative shifts in society can catalyze system-wide innovations, such as the transition towards a low-carbon economy. Furthermore, the environmental impact plays a significant role in driving company innovation, with businesses striving to minimize adverse consequences through environmentally conscious inventions (Brasliņa et al., 2021). Similarly, businesses may engage in innovative practices in response to anticipated changes in the natural environment, such as climate change adaptation.

Government programs aimed at supporting businesses involve resource transfers, either directly as financial aid or in-kind donations. These assistance measures can be provided by government agencies themselves or indirectly through consumer subsidies for specific goods (Najib et al., 2021). Companies can derive benefits from government funding targeting their operations, such as investments in research and development or the acquisition of new equipment, as well as the outcomes of these endeavors, leading to revenue streams resulting from past innovation efforts (Teng et al., 2020). Government financing often focuses on activities and outcomes related to innovation. Given the national and international regulations governing the conditions for providing assistance to businesses, there exists a specific demand for evidence regarding the scope and impact of various forms and levels of government support for innovation (OECD/Eurostat, 2019). The research findings shed light on the differential impact of the COVID-19 disruption on the innovation needs of fruit and vegetable businesses, with large-scale enterprises experiencing more pronounced effects compared to their smaller counterparts. Notably, despite the widespread repercussions of the pandemic, most small industrial businesses exhibited resilience, as evidenced by their relatively stable revenue and minimal alterations in business practices, use of open innovation tools, and innovation promotion, as meticulously explored by Harel (Harel, 2021) in the context of small businesses' performance and innovation amidst the COVID-19 era.

Moreover, the study's findings underscore a significant divergence in investment strategies related to innovations in fruit and vegetable preservation between large-scale enterprises and their smaller counterparts. This divergence highlights the overarching motivation of fruit and vegetable businesses to embark on more innovative ventures during the COVID-19 pandemic. This observation aligns with the discoveries of Jin

et al. (Jin et al., 2022), who discerned a more pronounced adverse effect of COVID-19 on innovation within larger organizations when compared to small and medium-sized enterprises. Furthermore, at the corporate level, state-owned enterprises demonstrate heightened vulnerability to the adverse effects of the pandemic in contrast to non-state-owned businesses. These findings collectively emphasize the intricate and multifaceted dynamics that unfolded during the pandemic, influencing innovation endeavors across diverse scales and ownership structures within the fruit and vegetable industry. The COVID-19 pandemic exerted a profound influence on specific industries, with notable repercussions observed in the realms of air travel and long-distance rail travel, as evidenced by substantial declines in passenger numbers and operational disruptions (Suau-Sanchez et al., 2020). A comprehensive study conducted by Sun et al. (Sun et al., 2020) meticulously analyzed shifts in international passenger flights from December 16, 2019, to May 15, 2020, leveraging Flightradar24 data, which encompassed 150 airlines and 2,751 airports worldwide. Their research brought to light a drastic reduction of approximately 75% in the number of served origin–destination airport pairs, commencing from mid-March 2020. This decline was accompanied by a significant decrease of about two-thirds in the count of operational aircraft. Similarly, the long-distance rail travel industry, especially in Asia and Europe, grappled with severe repercussions due to the COVID-19 pandemic (Rothengatter et al., 2021). Major rail operators in Europe, such as Deutsche Bahn (Germany) and SNCF (France), reported substantial losses in passenger numbers and encountered significant financial impacts on their rail lines during the first half of 2020 (Mack et al., 2021). These instances underscore the far-reaching effects of the pandemic on various sectors, including transportation, which underwent substantial transformations and disruptions during this challenging period.

Interestingly, the pandemic spurred divergent trends in various modes of transportation, particularly in the case of road transportation, which displayed different dynamics. In addition, water transportation also encountered considerable challenges. Xu et al. (Xu et al., 2021) conducted a study analyzing panel data from 14 major Chinese ports between January and October 2020. They found that widespread factory closures, coupled with the severity of the pandemic measured by the total number of confirmed COVID-19 cases, significantly and adversely affected both import and export cargo throughputs. The pandemic's far-reaching impacts on transportation industries underscore the intricate interplay of global travel and trade during these unprecedented times. As per the findings of the research conducted by (Sadyrova et al., 2021), the presence of low innovation activity indicators within the economy can be attributed to a confluence of key factors. Among these factors, the inadequacy of knowledge and technology transfer systems stands prominent, hindering the smooth dissemination and application of cutting-edge ideas. In addition, the limited commercialization of the research and development sector further compounds the challenges, hampering the transformation of innovative concepts into tangible market solutions. Furthermore, the absence of robust financial and institutional systems dedicated to fostering innovation and technological advancement serves to exacerbate the situation, constraining the resources and support available for progressive endeavors.

The underdeveloped system for knowledge and technology transfer, combined with a weak domestic demand for novel technological developments, plays a pivotal role in

contributing to the overall decline in technological competitiveness. This deficiency in driving and adopting innovations not only impacts the business landscape but also casts implications on the state's competitive edge in the global arena. Addressing these multifaceted challenges becomes imperative for nurturing a thriving environment of innovation, which is instrumental in propelling economic growth and bolstering the nation's standing in the ever-evolving technological landscape.

Conclusion

This study embarked on a comprehensive inquiry into the perceptions surrounding the utilization of UV irradiation as a preservation method for fruits and vegetables, with an additional exploration into the potential impact of the pandemic on innovations in this specific domain. The participants illuminated cost, safety concerns, and limited understanding as pivotal factors shaping their views on UV irradiation for preserving fruits and vegetables. Furthermore, the research delved into the impact of the pandemic disruption on innovation activities within the fruit and vegetable preservation sector. Intriguingly, the results unveiled those large-scale businesses exhibited a more pronounced need for innovations and investment in this domain compared to their small-scale counterparts. In addition, the study brought to light a notable observation regarding the limited practical considerations evident in existing research. Many studies primarily focused on small-scale laboratory tests, often incorporating costly components and unrealistic working conditions. To foster practical and economical advancements in the field, the study placed emphasis on pilot-scale research employing readily available and cost-effective materials, facilitating a more pragmatic cost–benefit analysis for proposed preservation technologies. Considering the array of suggested techniques, the study underscored the preference for combination methods to enhance fruit and vegetable preservation performance. An integrated approach to technology development was deemed crucial to achieve cost-effective preservation solutions. Achieving cost-effective preservation solutions demands a holistic approach to technology advancement. Within this framework, the thorough understanding and assessment of fruits and vegetables become paramount. The effectiveness of preservation methods is deeply intertwined with the physical and chemical attributes of these products and their intended use. Unfortunately, the investigation has highlighted a significant oversight in these critical domains, underscoring the need for continued efforts to establish widely accepted evaluation systems for characterization and quality appraisal. These endeavors play a vital role in guiding the choice of the most suitable preservation methods for fruits and vegetables, ultimately raising the bar for preservation standards. The survey findings underscore the multitude of factors contributing to the popularity of preserved fruits and vegetables. Key considerations such as the elimination of pathogenic microorganisms, protection against microbial growth, and prevention of physical alterations resonate as vital factors, reflecting the paramount importance consumers place on food safety and quality. Simultaneously, habits and routines play a role in influencing consumer behavior, signifying that longstanding familiarity and ease of use profoundly impact purchase decisions. As we delve deeper into unraveling consumer preferences and integrate

more advanced preservation techniques, the preserved food market is poised to witness continued growth and foster a culture of innovation, elevating the overall landscape of food preservation practices.

Abbreviations

ANOVA	Analysis of variance
HSD	Honestly significant difference
OECD	Organisation for Economic Co-operation and Development
SNCF	The Société nationale des chemins de fer français
StdDev	Standard deviation
USA	The United States of America
WHO	The World Health Organization is a specialized agency of the United Nations

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Availability of data and materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Competing interests
The authors declare no conflict of interest.

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