ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2710-6012 (Online)
CODEN: JWBMAO

Journal of Wastes and Biomass Management (JWBM)

DOI: http://doi.org/10.26480/jwbm.01.2025.16.21

CrossMark

RESEARCH ARTICLE

POTATO PEEL-DERIVED WAX: A SUSTAINABLE SOLUTION FOR ORANGE EXPORTATION IN PAKISTAN

Kokab Naz, Farrah Khalid, Sana Jamshaid*

Department of Chemistry, Rawalpindi Women University, Rawalpindi 46300, Pakistan
****Corresponding Author Email:sana.jamshaid@f.rwu.edu.pk***

ARTICLE DETAILS

Article History:

Received 15 February 2025
Revised 19 February 2025
Accepted 25 March 2025
Available online 07 April 2025

ABSTRACT

In Pakistan, the agricultural sector is undergoing significant changes towards more sustainable practices and efficient waste utilization. This study investigates the innovative concept of repurposing discarded potato peels as fruit wax to facilitate the export of oranges, a vital agricultural commodity in Pakistan. By embracing this eco-friendly approach, the research not only tackles the pressing issue of waste management but also introduces a valuable solution to boost the orange export industry. Through a rigorous experimental inquiry, the effectiveness of potato peel wax in preserving the freshness and extending the shelf life of oranges during transportation was thoroughly examined. This research underscores the importance of adopting creative waste utilization strategies to promote sustainability in the Pakistani agricultural sector. By utilizing potato peel waste as fruit wax, the study proposes a practical solution to waste management challenges while simultaneously enhancing the quality and marketability of exported oranges. Through meticulous experimental evaluation, the study confirms the effectiveness of potato peel wax in prolonging the freshness and durability of oranges, positioning it as a compelling and environmentally friendly alternative to traditional fruit wax. Ultimately, this research provides valuable insights into the integration of sustainability, waste management, and economic development within the Pakistani agricultural industry.

KEYWORDS

Shelf life; bio-based coating; waste management, post-harvest loss reduction

1. INTRODUCTION

Most of the Pakistan's territory is characterized by aridity, with approximately 80% located in arid and semi-arid zones (Ahmad et al., 2019). Out of the total geographical area of 79.6 million hectares, only 23 million hectares are under cultivation. The national economy heavily relies on irrigation, which sustains approximately 75% of cultivated land, with the remaining 4.0 million hectares dependent on rainfall (Idrees, et al., 2022). Agriculture serves as a cornerstone of Pakistan's economy and society, contributing approximately 20–25% to the GDP and providing employment to over 60% of the rural population (Muhammad et al., 2016). Over recent years, the agricultural sector's share of GDP has gradually declined, contributing 21.4%, 20.9%, and 19.53% in 2015, 2016, and 2017, respectively, while engaging a decreasing portion of the workforce during the same period. In 2018, citrus fruit cultivation in Pakistan (Figure 1) spanned 200,461 hectares, yielding 2,247,956 tons at a rate of 112,139 hectograms per hectare (Cheem et al., 2021). Despite outperforming Afghanistan in citrus yield, Pakistan lags regional competitors like Iran, China, and India. This gap in productivity is primarily attributed to high costs, price instability, limited capital, technological deficiencies, and pest-related challenges (Memon et al., 2017).

The agriculture sector in Pakistan has historically pursued an unsustainable trajectory due to the degradation of agricultural resources (Zulfiqar et al., 2017). Post-harvest losses, quality deterioration, and nutrient depletion in stored fruits further exacerbate this issue. Changes in the nutritional quality of fresh produce during storage underscore the importance of ensuring product safety and extending shelf life (Pott et al., 2020). Research in post-harvest management is critical to mitigating these losses, preserving quality, and enhancing the sustainability of the agricultural system (Naseer, et al., 2019). A key aspect of sustainability is the development of innovative technologies and practices that minimize environmental harm, improve food productivity, and provide accessible solutions for farmers (Al-Agele et al., 2021). The global rise in environmental awareness and consumption rates has intensified research into renewable and biodegradable materials to replace petrochemical-based and non-biodegradable substances (Malagurski et al., 2017; Regubalan et al., 2018).

Figure 1: Citrus Export in Pakistan (https://www.jmbexporters.com/fruits/orange)

Fruits and vegetables, vital for human nutrition, face significant challenges due to their limited post-harvest lifespan. As living tissues, they are susceptible to physiological and biochemical changes caused by physical or pathological factors, leading to financial losses (Palou et al., 2015). Consumer demand for fresh and healthy produce has increased globally, with preferences influenced by appearance, texture, color, aroma, freshness, and flavor (Saba et al., 2018). Most fruits and vegetables, containing 70–90% water, experience rapid respiration and moisture loss upon detachment from their nutrient source, which degrades quality, nutrients, and shelf life while increasing the risk of microbial spoilage (Parajuli et al., 2019). Although fruits naturally possess waxy surfaces to reduce water loss, these natural defenses are often insufficient for prolonged storage and transport (Zhang et al., 2021).

Quick Response Code	Access this article online	
	Website: www.jwbm.com.my	**DOI:** 10.26480/jwbm.01.2025.16.21

Cite the Article: Kokab Naz, Farrah Khalid, Sana Jamshaid (2025). Potato Peel-Derived Wax: A Sustainable Solution for Orange Exportation in Pakistan. *Journal of Wastes and Biomass Management, 7(1): 16-21.*

2. LITERATURE REVIEW

Food packaging serves to protect food products from various deteriorating factors, such as dust, temperature fluctuations, light exposure, microorganisms, physical impacts, shocks, and environmental contaminants. Additionally, it ensures food safety and quality, prolongs shelf life, and reduces food waste (Mangaraj et al., 2019). According to statistician's statistical findings, the annual growth rate of petroleum-based packaging production globally stands at 8%, with less than 5% of it being recycled. Consequently, there is a gradual buildup of plastic waste in the environment, with millions of tons of plastic packaging materials ending up in landfills annually, posing a significant challenge for the planet. The escalating worries regarding plastic-induced environmental pollution have spurred the innovation of biodegradable packaging films (Sedayu, et al., 2019; Cazón et al., 2017). The strong connection between hydrogen and carbon atoms within the polymer molecules found in petrochemical-based films renders them resistant to biodegradation (Dhegihan et al., 2018). Polypropylene, ethylene, and polyolefin are popular packaging materials because of their favourable properties and affordability. However, their non-biodegradable nature presents a major drawback (Tavassoli-Kafrani et al., 2016). Polysaccharides and proteins have the potential to serve as viable alternatives to plastic material in succession (Hassan et al., 2018).

Edible coating is a technique employed to prolong the shelf life and maintain the freshness of fresh fruit and minimally processed fruit and vegetables (Kumar et al., 2019). These coatings function as protective barriers, enhancing the skin's resistance to the diffusion of oxygen, carbon dioxide, and water vapor. This delay in the natural physiological ripening process and reduction in microbial growth in foods and their key effects (Basiak et al., 2019). Edible coatings are made using biodegradable large molecules like carbohydrates, proteins, and lipids (Mohamed et al., 2020). As per the literature, edible coating creates a thin layer on food applied in liquid form. On the other hand, edible films, which utilize similar macromolecules, require pre-formation prior to application, forming solid sheets that encircle food products (Suhag et al., 2020). Starch, abundant in nature, serves as the primary energy source for plants due to its prevalence among natural carbohydrates (Thalmann et al., 2017). This macromolecule has been widely utilized in the production of edible films and coatings because of its capacity to create a seamless structure. Additionally, its abundance, safety, affordability, and rheological characteristics make it highly favorable for such applications (Versino et al., 2016). The global starch market is segmented into four main sources: corn, potato, sweet potato, and cassava. Corn starch has been the most utilized for producing biodegradable plastic, likely because corn accounts for the largest share of starch production globally; approximately 65% of sweet potatoes and cassava follow behind, comprising 13% and 11% of the starch market (Luchese et al., 2017). Starch-based coatings that are colorless and oil-free are ideal for extending the shelf life of various products, such as fruit and vegetables. Various methods, including panning, dipping, spraying, and fluidizing beds (figure 2) can be employed to apply these coatings. The choice of technique depends on factors such as the nature of the product, its surface characteristics, and the desired outcomes of the coating (Suhag et al., 2020).

The panning technique involves placing the product into a spacious revolving bowl known as the pan. The fluidized bed technique is widely studied across industries such as chemical, pharmaceutical, and food for coating applications. The method aims to achieve a uniform coating with specific qualities largely influenced by droplet formation and their physical state. Essentially, it involves spraying a coating solution onto fluidized powders to form a shell-like structure (Wentzlaff et al., 2019). The dipping technique is widely favored for its convenience, enabling thorough and uniform coverage of surfaces, even those that are uneven or complex (Miteluț et al., 2021). The spraying technique is highly utilized for coating material deposition because of the extensive range of macromolecules available and its versatility in handling irregular shapes and various sizes (Ambaw, et al., 2017).

In recent times, there has been a notable rise in the production of fruits and vegetables to satisfy the growing demand from consumers. Around 0.9 billion tons of fruit and over 1 billion tons of vegetables were cultivated in 2017. According to the FAO report, we generate an estimated 1.3 billion tons of food waste and losses annually. Food waste and product generation have adverse environmental, economic, and social effects globally. Initiatives such as the EU's Farm to Fork Strategy aim to reduce waste, which can lower production costs and improve food system efficiency. Additionally, waste reduction efforts promote sustainability, enhance food security, and improve nutrition (Poyatos-Racionero et al., 2018). Waste valorization, integral to the pursuit of a circular economy, involves converting food waste into value-added products like fuels and fertilizers. This approach, prioritized by the government and the food sector, offers economic, social, and environmental benefits by reducing waste and maximizing resource efficiency (Garcia-Garcia et al., 2019; Sindhu et al., 2019). Recent research suggests that leveraging advancements in food packaging technology can effectively mitigate food waste and byproducts by incorporating natural materials derived from waste and byproducts into packaging solutions, representing a progressive move toward eco-conscious waste valuation (Tumwesigye et al., 2016; Torres-León et al., 2018). Fruit and vegetable peels, pomace, and seeds are rich in bioactive compounds like proteins, fibres, colorants, and phytochemicals, offering various health benefits such as antioxidants, antimicrobial properties, and anti-inflammatory effects (Baiano et al., 2014; Sagar et al., 2018; Ran et al., 2019).

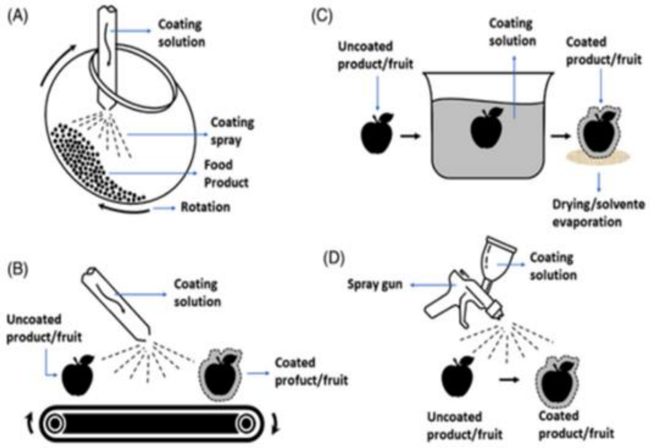

Figure 2: Different method of coating a) panning b); fluidized bed c); dipping d); and spraying (DOI: (10.1002/star.202100279))

The growing global plastic consumption has spurred interest in using biopolymers derived from agricultural and food processing waste to make biodegradable materials, particularly for food packaging applications (Matheus, et al., 2013). Alongside the rising need for recycling and waste minimization, it is imperative that food maintain high quality and safety standards, ensuring extended shelf life (Basumatary, et al., 2020). Packaging made from fruit and vegetable waste is gaining attention for its unique properties. When used in packaging, these waste materials offer benefits like increased antioxidant and antimicrobial activity, improved mechanical strength, and better quality for preserved fruits.

Our research aims to address many challenges by achieving the following objectives:

- To develop an innovative and sustainable solution for post-harvest fruit preservation by repurposing potato peels to extract starch as a biodegradable wax coating for oranges.
- To address the critical challenges of agricultural waste management by providing a practical approach to recycling and reusing waste materials.
- To enhance the shelf life and export potential of citrus fruits in Pakistan while reducing reliance on synthetic and petrochemical-based coatings.
- To contribute to sustainable agricultural practices by integrating waste recycling and environmental conservation into post-harvest management strategies.

This study introduces a novel approach to enhance post-harvest fruit preservation, combining environmental sustainability and economic benefits. By repurposing potato peels, a commonly discarded waste material into a biodegradable fruit wax, this research not only reduces waste but also provides an eco-friendly alternative to conventional coatings. These advancements align with the global shift towards sustainable practices while addressing the unique challenges faced by Pakistan's agricultural sector.

3. MATERIALS AND METHOD

This study was conducted in department of chemistry (February 2024 to June 2024), Rawalpindi Women University by undergraduate students for their graduate research thesis project. Fresh oranges (*Citrus sinensis*) from the *Rutaceae* family were purchased at a local market and selected for their consistent size, color, and free of visible defects. First, we got some fresh potatoes and properly washed them to remove any dirt or contaminants. The potatoes were subsequently peeled, and the skins weighed approximately 20 g. A predetermined amount of water, about 250 ml, was measured and poured into a boiling pot. We added the collected potato peels to the water and heated the mixture until it boiled. The boiling process continued until the water quantity was reduced to approximately half of the original volume. Care was taken to ensure that the water did not evaporate completely and that the potato peels were adequately submerged throughout the boiling process.

After boiling, the pot was removed from heat, and the water was allowed to cool slightly to achieve a semi-hot temperature. We monitored the temperature with a thermometer to ensure it stayed within the desired range. The presence of starch extracted from potato peels was determined using the Fehling test. A few millimeters of extracted starch solution were taken into test tubes, and the Fehling test was performed. Since starch is a non-reducing sugar, it gives negative results in the test. The oranges were dipped into the semi-hot water containing the potato peel extract for a brief period, ensuring that each orange was evenly coated with the extract. The starch extracted from the potato peels formed a protective coating on the orange surface. Finally, we placed both coated and uncoated oranges in separate storage containers and kept them in a controlled environment at room temperature. The shelf life of the oranges was monitored regularly for 30 days.

3.1 Color

Color evaluation was performed by visualizing the mobile camera photos with human eye taken over the period of 30 days observations.

3.2 Firmness

Firmness was measured using an FT-011 fruit pressure tester by pressing both coated and uncoated oranges over a 30-day period.

3.3 Statistical Analysis

Data were analyzed using MS Excel.

4. Results and Discussion

4.1 Visual and Physical Observations

The oranges coated with potato peel wax exhibited remarkable preservation over time. Coated oranges maintained their firmness and visual appeal much longer than uncoated oranges (Table 1). By March 12, uncoated oranges began to show signs of aging such as surface softening and discoloration. By March 22, uncoated oranges displayed significant spoilage, including discoloration, shriveling, and a mushy texture. In contrast, the coated oranges showed minimal signs of aging. By April 1, uncoated oranges were nearly entirely spoiled, while coated oranges retained most of their quality.

Table 1: Qualitative study of potato waxes coated oranges with uncoated oranges in 30 days.

Days	Coated	Uncoated
1st day (March 3rd, 2024)		
5th day (March 7th, 2024)		
10th day (March 12th, 2024)		

Table 1 (cont): Qualitative study of potato waxes coated oranges with uncoated oranges in 30 days.

15th day (March 17th, 2024)		
20th day (March 22nd, 2024)		
25th day (March 27th, 2024)		
30th day (April 1st, 2024)		

4.2 Quantitative Observations

The quantitative results of the study, including weight loss, firmness, and spoilage percentage, confirmed the positive impact of the potato peel wax on prolonging the shelf life of oranges (Table 2). Below are the detailed observations:

4.2.1 Weight Loss

Coated oranges exhibited only a 5.6% weight loss after 30 days, compared to 18.3% for uncoated oranges. This indicates reduced moisture loss, which is critical in preventing spoilage.

4.2.2 Firmness

Firmness measurements in Newtons (N) revealed that on Day 0, both coated and uncoated oranges had an initial firmness of 35 N. By Day 30, coated oranges maintained a firmness of 29 N, whereas uncoated oranges dropped to just 12 N.

4.2.3 Decay Percentage

By Day 30, 70% of the uncoated oranges were completely spoiled, while only 20% of the coated oranges showed signs of decay.

Table 1: Quantitively study of potato waxes coated oranges with uncoated oranges in 30 days.

Date	Weight Loss (%)	Firmness (N)	Spoilage (%)
March 3 (Day 0)	0.0	35	0
March 12 (Day 10)	Coated: 1.2 / Uncoated: 5.7	Coated: 33 / Uncoated: 28	Coated: 0 / Uncoated: 10
March 22 (Day 20)	Coated: 3.5 / Uncoated: 12.4	Coated: 31 / Uncoated: 20	Coated: 5 / Uncoated: 50
April 1 (Day 30)	Coated: 5.6 / Uncoated: 18.3	Coated: 29 / Uncoated: 12	Coated: 20 / Uncoated: 70

4.3 Contribution to Sustainability

The use of potato peel wax significantly reduced spoilage and food waste, promoting sustainable agricultural practices. This aligns with eco-friendly solutions, as agricultural by-products like potato peels are converted into valuable resources, helping reduce environmental waste and supporting the circular economy.

4.3.1 Fehling Test Validation

The Fehling test confirmed that the potato peel extract contains non-reducing starch, which, despite giving a negative result in the test, effectively contributed to the preservation of oranges by forming a protective coating.

4.4 Effectiveness Of Potato Peel Wax As A Coating Material

The results clearly demonstrate that potato peel wax provides an effective and sustainable means of extending the shelf life of oranges. The starch extracted from potato peels forms a protective layer that minimizes moisture loss, thus preventing spoilage and maintaining fruit firmness. These findings corroborate similar studies on biodegradable coatings, supporting the notion that natural, plant-based alternatives can reduce post-harvest losses effectively (Yousefi et al., 2023; Khan et al., 2023). The preservation of fruit quality over extended storage periods suggests that this approach could be beneficial for the export of citrus fruits from Pakistan, where the agricultural sector plays a vital role in the economy.

4.4.1 Post-Harvest Loss Reduction and Export Potential

One of the major challenges for the citrus export industry in Pakistan is the high post-harvest losses, especially due to spoilage during transit. By utilizing potato peel wax as a coating, these losses can be significantly reduced, enhancing the competitiveness of Pakistani oranges in international markets. This solution also lowers reliance on synthetic coatings, which are often costly and non-biodegradable, offering an economic advantage. Moreover, as Pakistan produces a large quantity of potato products, this method can help address waste management issues. The recycling of potato peel waste not only provides an eco-friendly alternative to synthetic waxes but also contributes to the local economy by turning food industry waste into a valuable product.

4.4.2 Sustainability and Environmental Implications

This study addresses two critical environmental concerns: food waste and synthetic waste. The potato peel, typically discarded by the food processing industry, is a readily available by-product in Pakistan, where a large amount of potato-based products are produced. By converting this waste into a functional fruit wax, this study offers a sustainable solution that reduces the environmental burden of both food waste and the use of petroleum-based synthetic coatings. The recycling of potato peel into a valuable agricultural resource aligns with circular economy principles, where waste is transformed into a resource, reducing environmental impact and promoting resource efficiency (Liu et al., 2023; Hameed et al., 2022).

4.4.3 Waste Management and Recycling in Pakistan

Waste management is a growing concern in Pakistan, particularly in the agricultural and food processing sectors. The potato peel, which is often discarded, constitutes a large proportion of food waste generated in the country. By tapping into this waste stream for fruit preservation, this study not only provides a functional coating solution but also contributes to addressing Pakistan's pressing waste management challenges. The concept of recycling potato peel waste for creating biodegradable coatings can inspire further innovations in utilizing agricultural by-products for sustainable applications. This strategy could reduce landfill waste, minimize environmental pollution, and offer a local, scalable solution for food preservation in Pakistan's agricultural sector.

5. Conclusion

This study reveals the potential of reusing potato peel waste as an eco-friendly fruit wax to enhance the export quality of oranges from Pakistan. Extensive research demonstrated that oranges coated with potato peel-derived starch had a significantly longer shelf life and better preserved freshness compared to uncoated ones. This innovative approach not only addresses waste management challenges by transforming agricultural waste into a valuable resource but also supports sustainable agricultural practices by reducing the reliance on synthetic packaging materials. The results indicate that potato peel wax can effectively protect and preserve the quality of oranges during transit, boosting their marketability and economic value. Furthermore, the use of potato peel wax as a fruit coating offers a sustainable solution to both environmental and economic concerns in Pakistan. By recycling agricultural waste, this study presents a promising solution to fruit preservation and waste management issues, positioning Pakistan as a leader in sustainable agricultural practices. Future research should focus on scaling this solution and exploring its application to other fruit types, ensuring broader environmental and economic benefits for the region.

Acknowledgements

The author is thankful to Higher Education Commission (HEC) Pakistan for IPFP fellowship and to Department of Chemistry of Rawalpindi Women University, Rawalpindi for the support to conduct this study.

Reference

Ahmed, K., Shahid, S., Wang, X., Nawaz, N., and Khan, N., 2019. Spatiotemporal changes in aridity of Pakistan during 1901–2016. Hydrology and Earth System Sciences. https://doi.org/10.5194/HESS-23-3081-2019.

Al-Agele, H., Nackley, L., and Higgins, C., 2021. A Pathway for Sustainable Agriculture. Sustainability, 13, 4328. https://doi.org/10.3390/SU13084328.

Ali, M., 2022. Eco-friendly fruit coatings: Trends and challenges in citrus preservation. Postharvest Biology and Technology, 195, 112115. https://doi.org/10.1111/j.1541-4337.2012.00186.x

Ambaw, A., Dekeyser, D., Vanwalleghem, T., Hemelrijck, W., Nuyttens, D., Delele, M., Ramon, H., Nicolai, B., Bylemans, D., Opara, U., and Verboven, P., 2017. Experimental and numerical analysis of the spray application on apple fruit in a bin for postharvest treatments. Journal of Food Engineering, 202, Pp. 34-45. https://doi.org/10.1016/J.JFOODENG.2017.01.026.

Baiano, A., 2014. Recovery of biomolecules from food wastes-A review. Molecules, 19 (9), Pp. 14821-14842. https://doi.org/10.3390/molecules190914821

Basiak, E., Linke, M., Debeaufort, F., Lenart, A., and Geyer, M., 2019. Dynamic behaviour of starch-based coatings on fruit surfaces. Postharvest Biology and Technology, 147, Pp. 166-173. https://doi.org/10.1016/j.postharvbio.2018.09.020

Basumatary, I., Mukherjee, A., Katiyar, V., and Kumar, S., 2020. Biopolymer-based nanocomposite films and coatings: recent advances in shelf-life improvement of fruits and vegetables. Critical Reviews in Food Science and Nutrition, 62, Pp. 1912-1935. https://doi.org/10.1080/10408398.2020.1848789.

Cazón, P., Velazquez, G., Ramírez, J.A., and Vázquez, M., 2017. Polysaccharide-Based Films and Coatings for Food Packaging: A Review. Food Hydrocolloids, 68, Pp. 136-148. https://doi.org/10.1016/j.foodhyd.2016.09.009

Cheem, I., and Jamali, H., 2021. Growth of Citrus Fruits in Pakistan. Artificial Intelligence, 9, Pp. 74-81. https://doi.org/10.34069/ai/2020.35.11.6.

Chen, Y., Yang, J., Mujumdar, A., and Dave, R., 2009. Fluidized bed film coating of cohesive Geldart group C powders. Powder Technology, 189 (3), Pp. 466-480. https://doi.org/10.1016/j.powtec.2008.08.002

Dave, R.K., Ramana Rao, T.V., Nandane, A.S., 2017. Improvement of post-harvest quality of pear fruit with optimized composite edible coating formulations. J. Food Sci. Technol., 54, Pp. 3917-3927. https://doi.org/10.1007/s13197-017-2850-y

Dhegihan, S., Hosseini, S.V., and Regenstein, J.M., 2018. Edible films and coatings in seafood preservation: A review. Food Chemistry, 240, Pp. 505-513. https://doi.org/10.1016/j.foodchem.2017.07.034

Fan, X.J., Zhang, B., Yan, H., Feng, J.T., Ma, Z.Q., Zhang, X., 2019. Effect of lotus leaf extract incorporated composite coating on the postharvest quality of fresh goji (Lycium barbarum L.) fruit. Postharvest Biol. Technol., 148, Pp. 132-140. https://doi.org/10.1016/j.postharvbio.2018.10.020

FAOSTAT (FAO Statistics). Food and Agriculture Organization of the United Nations. 2017. Available on: http://www.fao.org/faostat/en/#data/QC/visualize (accessed on 1 May 2021).

Food and Agriculture Organization (FAO). The State of Food and Agriculture 2019. Ministry of Finance of Pakistan. Economy Survey of Pakistan 2015. Available on:

http://www.finance.gov.pk/survey/chapters_16/03_Manufacturing.pdf (accessed on 21 September 2022).

García-Betanzos, C.I., Hernández-Sánchez, H., Bernal-Couoh, T.F., 2017. Total phenols and pectin methylesterase changes on quality maintenance on guava fruit (Psidium guajava L.) coated with candeuba wax solid lipid nanoparticles-xanthan gum. Food Res., 101, Pp. 218-227. https://doi.org/10.1016/j.foodres.2017.08.065

Garcia-Garcia, G., Stone, J., and Rahimifard, S., 2019. Opportunities for waste valorisation in the food industry–A case study with four UK food manufacturers. Journal of Cleaner Production, 211, Pp. 1339-1356. https://doi.org/10.1016/j.jclepro.2018.11.269

Ghidelli, C., and Pérez-Gago, M., 2018. Recent advances in modified atmosphere packaging and edible coatings to maintain quality of fresh-cut fruits and vegetables. Critical Reviews in Food Science and Nutrition, 58, Pp. 662 - 679. https://doi.org/10.1080/10408398.2016.1211087.

Grujić, R., Vujadinović, D., and Savanović, D., 2017. Biopolymers as food packaging materials. Advances in Applications of Industrial Biomaterials, Pp. 139-160. https://doi.org/10.1007/978-3-319-62767-0_8

Hassan, B., Chatha, S.A.S., Hussain, A.I., Zia, K.M., and Akhtar, N., 2018. Recent advances on polysaccharides, lipids and protein based edible films and coatings: A review. International Journal of Biological Macromolecules, 109, Pp. 1095-1107. https://doi.org/10.1016/j.ijbiomac.2017.11.097

Idrees, M., Ahmad, S., Khan, M., Dahri, Z., Ahmad, K., Azmat, M., and Rana, I., 2022. Estimation of Water Balance for Anticipated Land Use in the Potohar Plateau of the Indus Basin Using SWAT. Remote. Sens., 14, Pp. 5421. https://doi.org/10.3390/rs14215421.

Kumar, N., 2019. Polysaccharide-based component and their relevance in edible film/coating: A review. Nutrition and Food Science, 49 (5), Pp. 793-823. https://www.emerald.com/insight/content/doi/10.1108/nfs-10-2018-0294/full/html

Liu, J., 2023. Valorization of agricultural by-products for sustainable food packaging. Green Chemistry Letters and Reviews, 16 (2), Pp. 93-105. DOI: 10.1016/j.fbio.2024.103751

Luchese, C.L., Spada, J.C., and Tessaro, I.C., 2017. Starch content affects physicochemical properties of corn and cassava starch-based films. Industrial Crops and Products, 109, Pp. 619-626. https://doi.org/10.1016/j.indcrop.2017.09.020

Malagurski, I., Levic, S., Nesic, A., Mitric, M., Pavlovic, V., and Dimitrijevic-Brankovic, S., 2017. Mineralized agar-based nanocomposite films: Potential food packaging materials with antimicrobial properties. Carbohydrate Polymers, 175, Pp. 55-62. https://doi.org/10.1016/j.carbpol.2017.07.064

Mangaraj, S., Yadav, A., Bal, L.M., Dash, S.K., and Mahanti, N.K., 2019. Application of biodegradable polymers in food packaging industry: A comprehensive review. Journal of Packaging Technology and Research, 3, Pp. 77-96. https://doi.org/10.1007/s41783-018-0049-y

Matheus, J., Dalsasso, R., Rebelatto, E., Andrade, K., Andrade, L., De Andrade, C., Monteiro, A., and Fai, A., 2023. Biopolymers as green-based food packaging materials: A focus on modified and unmodified starch-based films. Comprehensive Reviews in Food Science and Food Safety. https://doi.org/10.1111/1541-4337.13107.

Memon, N.A., and Kasbit, D., 2017. Citrus fruit (Kino): Punjab produced 98% of production. Exclusive on Kino, Pp. 29-31. https://foodjournal.pk/2017/Jan-Feb-2017/PDF-Jan-Feb-2017/Dr-Noor-Kino.pdf

Ministry of Finance of Pakistan. Economy Survey of Pakistan 2016. Available on: http://www.finance.gov.pk/survey/chapters_17/03-Manufacturing.pdf (accessed on 21 September 2022)

Ministry of Finance of Pakistan. Economy Survey of Pakistan 2017. Available on: http://www.finance.gov.pk/survey/chapters_18/Economic_Survey_2017_18.pdf (accessed on 21 September 2022).

Miteluţ, A., Popa, E., Drăghici, M., Popescu, P., Popa, V., Bujor, O., Ion, V., and Popa, M., 2021. Latest Developments in Edible Coatings on Minimally Processed Fruits and Vegetables: A Review. Foods, 10. https://doi.org/10.3390/foods10112821.

Mohamed, S., El-Sakhawy, M., and El-Sakhawy, M., 2020. Polysaccharides, Protein and Lipid -Based Natural Edible Films in Food Packaging: A Review. Carbohydrate Polymers, 238, Pp. 116178. https://doi.org/10.1016/j.carbpol.2020.116178.

Moving Forward on Food Loss and Waste Reduction. 2019.

Muhammad, U., 2016. Contribution of Agriculture Sector in the GDP Growth Rate of Pakistan. Journal of Global Economics, 4, Pp. 1-3. https://doi.org/10.4172/2375-4389.1000184.

Naseer, M., Ashfaq, M., Hassan, S., Abbas, A., Razzaq, A., Mehdi, M., Ariyawardana, A., and Anwar, M., 2019. Critical Issues at the Upstream Level in Sustainable Supply Chain Management of Agri-Food Industries: Evidence from Pakistan's Citrus Industry. Sustainability. https://doi.org/10.3390/SU11051326.

Olivas, G.I.I., and Barbosa-Cánovas, G., 2009. Edible films and coatings for fruits and vegetables. Edible Films and Coatings for Food Applications, Pp. 211-244. https://doi.org/10.1007/978-0-387-92824-1_7

Parajuli, R., Thoma, G., and Matlock, M.D., 2019. Environmental sustainability of fruit and vegetable production supply chains in the face of climate change: A review. Science of the Total Environment, 650, Pp. 2863-2879. https://doi.org/10.1016/j.scitotenv.2018.10.019

Pott, D., Vallarino, J., and Osorio, S., 2020. Metabolite Changes during Postharvest Storage: Effects on Fruit Quality Traits. Metabolites, 10. https://doi.org/10.3390/metabo10050187.

Poyatos-Racionero, E., Ros-Lis, J.V., Vivancos, J.L., and Martinez-Manez, R., 2018. Recent advances on intelligent packaging as tools to reduce food waste. Journal of Cleaner Production, 172, Pp. 3398-3409. https://doi.org/10.1016/j.jclepro.2017.11.075

Saba, A., Moneta, E., Peparaio, M., Sinesio, F., Vassallo, M., and Paoletti, F., 2018. Towards a multi-dimensional concept of vegetable freshness from the consumer's perspective. Food Quality and Preference. https://doi.org/10.1016/J.FOODQUAL.2017.12.008.

Suhag, R., Kumar, N., Petkoska, A., and Upadhyay, A., 2020. Film formation and deposition methods of edible coating on food products: A review. Food Research International, 136, Pp. 109582. https://doi.org/10.1016/j.foodres.2020.109582.

Thalmann, M., and Santelia, D., 2017. Starch as a determinant of plant fitness under abiotic stress. The New Phytologist, 214 3, Pp. 943-951. https://doi.org/10.1111/nph.14491.

Wentzlaff, M., Senz, V., and Seidlitz, A., 2019. Evaluation of the suitability

of a fluidized bed process for the coating of drug-eluting stents. European Journal of Pharmaceutics and Biopharmaceutics, 139, Pp. 85–92. https://doi.org/10.1016/j.ejpb.2019.03.013.

Zhang, M., Yang, H., Zhu, F., Xu, R., and Cheng, Y., 2021. Transcript profiles analysis of citrus aquaporins in response to fruit water loss during storage. Plant Biology, 23 (5), Pp. 819-830. https://doi.org/10.1111/plb.13269.