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A REVIEW OF POMEGRANATE PEEL EXTRACTS FOR PLANT DISEASE CONTROL AND ENHANCED FRESH PRODUCE SHELF-LIFE

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Abstract

Despite the fact the Green Revolution was a turning point, its extensive use of synthetic pesticides harms human and environmental health. The need for safer, more ecologically friendly plant disease control and food spoilage prevention solutions is developing. Pomegranate peel extracts (PPEs) are exceptional alternatives due to their effects. In this review, PPEs are examined for their direct antibacterial activity, induction of resistance in treated plant tissues, and how their composition affects their activity. Due to their adaptability, effectiveness, and wide spectrum of activity against bacterial, fungal, and viral plant diseases, PPEs may have a market outside of organic and integrated farming. Since PPEs are non-chemical leftovers of the pomegranate industry, they are typically considered innocuous and can be used in circular economy efforts. This may prompt the agro-pharmaceutical business to rush to register and formulate their goods.

Keywords: Food by-products, polyphenols, foodborne pathogens; coatings; shelf-life.

1. Introduction

Modern, high-yielding crop varieties, which emerged during the Green Revolution, have contributed to increased disease susceptibility, loss of biodiversity, and intensive monoculture farming systems [1, 2]. Issues related to climate change, globalization of markets, and the development and dissemination of diseases with resistance have recently emerged as major concerns [3]. The Green Revolution has been accompanied for decades by the heavy use of pesticides, which has undermined the sustainability and stability of agricultural output. The use of chemical pesticides is fraught with peril because of the damage they do to non-target microbes and the rise in the prevalence of antibiotic-resistant strains [5, 6]. The development of safe and environmentally acceptable alternative management methods to control plant diseases is now urgently needed due to recent regulatory limits in Europe and the growing awareness of consumers regarding food safety and healthy living [7-9]. The use of plant extracts, either alone or as part of an integrated pest management program, is one of several alternate approaches that have been suggested. To that end, antimicrobial compounds derived from pomegranate peel have recently emerged as a potential tool for the management of plant and food-borne diseases. The numerous beneficial chemicals found in pomegranate peels have made them a staple in traditional medicinal practises dating back to ancient times [14]. Pomegranate peel extracts (PPEs) have antioxidant and therapeutic properties that have been demonstrated in several scientific studies to combat serious diseases and conditions, such as cancer, inflammation, diabetes, cardiovascular disease, and more [15]. This article delves into the topic of personal protective equipment (PPEs) as an all-natural way to prevent the spread of plant and food-borne diseases that can infect produce. Biological activity, action mechanism, activity range, and possible practical applications of PPEs are described, along with the primary active chemicals responsible for these activities. People are becoming more and more negative toward chemical pesticides & food additives, and PPEs, being natural goods, are expected to gain a lot of attention and approval from this demographic. More sustainable food and farming systems are being moved towards by-product valorisation, which includes things like pomegranate peel. The numerous beneficial components found in pomegranate peels have made them a staple in traditional medicinal practises dating back to ancient times. Pomegranate peel extracts (PPEs) have shown antioxidant and therapeutic efficacy against a variety of serious diseases and conditions, including cancer, inflammation, diabetes, cardiovascular dis-

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ease, and more, according to several scientific studies. This article delves into the topic of personal protective equipment (PPEs) as an all-natural way to prevent the spread of plant and food-borne diseases that can infect produce. The consumer, who views chemical pesticides and food additives with a more negative light, is likely to pay close attention to and embrace PPEs because of their natural nature. More sustainable food and farming systems are being moved towards by-product valorisation, which includes things like pomegranate peel [16].

2.1 Pomegranate Fruit's Bioactive Substances

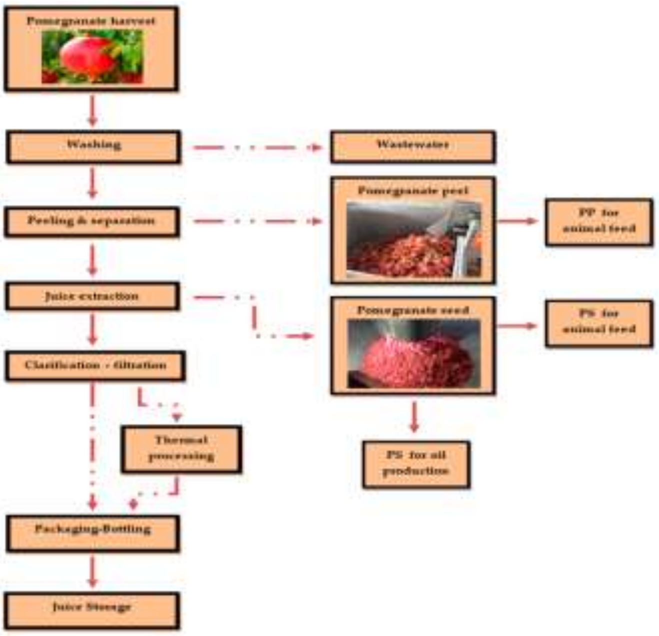

Fig1: Extraction Methods of Pomegranate peel

Traditional medicine has long made use of the pomegranate's (*Punicagranatum L., Punicaceae*) curative and defensive properties. Pomegranates are rich in ellagitannins, the most prominent of which is punicalagin, a phenolic chemical found in just a small number of plant species. With numerous beneficial nutraceutical effects, including antioxidant, anti-inflammatory, antimicrobial, and anti-carcinogenic capabilities, etc., ellatannins are hydrolyzable tannins that are well-known free radical scavengers. Although punicalagins are the most important component, the chemical synergy of the total fruit phytoconstituents, not a single component, determines the high biological value of the fruit, according to various studies that focused on isolating and characterizing the active components of pomegranates. Researchers are now looking at the complete extract instead of only punicalagins due to these findings. The peel of the pomegranate fruit contains a significant concentration of polyphenols, according to phytochemical screenings conducted on several portions of the fruit, including the arils and seeds. That is why the peel is very valuable in traditional medicine (Fig.1) [17]. The pomegranate's peel is a treasure trove of bioactive compounds since it makes up over half of the fruit's weight. Biological activity, action mechanism, activity range, and possible practical applications of PPEs are described, along with the primary active chemicals responsible for these activities. Nevertheless, it is imperative to establish a precise standardization of PPE preparations due to the potential significant variation in polyphenolic concentration caused by various variables. For example, the selection of solvent was found to have a substantial influence on the concentration of polyphenols that an 80% methanolic extract had a higher concentration of polyphenols compared to hot water and diethyl ether extracts. As a result, it exhibited stronger antibacterial effects against Listeria monocytogenes, *Staphylococcus aureus, Escherichia coli, and Yersinia enterocolitica*. In a similar vein, Tayel et al. discovered that a methanolic peel extract was superior to ethanol and water extracts in managing Penicillium digitatum. However, Romeo et al. ethanolic extract had a greater content of anthocyanins and phenols compared to other extracts. Additionally, they recommended the utilization of a non-toxic chemical (food grade ethanol) for extractions as crucial in acquiring environmentally friendly and safe antimicrobial treatments. Factors such as maturity stage, variety, growth region, and environmental circumstances can significantly influence the polyphenolic composition and antibacterial activity of pomegranate extracts, similar to the extraction process. Glazer et al. observed varying concentrations of punicalagins in the peel extracts obtained from different types of pomegranate accessions. Recently, the significance of different types of pomegranate cultivars was confirmed as their chemical makeup substantially varied and had a significant impact on the antifungal activity of the extracts [18-19].

2.2 Action Mechanisms

The precise processes via which the bioactive components of PPEs exercise their effects have not been fully understood. However, a substantial amount of evidence already exists, indicating that these components have both direct antibacterial properties and the ability to stimulate resistance responses in the plant tissues they are applied to. The direct antibacterial activity of personal protective equipment (PPE) has been extensively studied, with a particular focus on microorganisms associated with humans. Results from in vitro trials demonstrated strong inhibitory activity against the germination of conidia and the growth of mycelium in major plant fungal pathogens, including Botrytis cinerea, Penicillium digitatum, Penicillium expansum, Penicillium italicum, Alternaria alternata, Stemphylium botryosum, Colletotrichum acutatum sensu stricto, Fusarium oxysporum, Aspergillus parasiticus, Monilinia laxa, and Monilinia fructigena. The antifungal activity level can significantly vary depending on the type of extract and the species of the infection [20]. For example, a PPE solution including ethanol totally prevented the germination of conidia of B. cinerea and C. acutatum. However, it was not as efficient against P. digitatum and P. expansum, reducing their growth by 91.0% and 82.7% correspondingly. A water-based PPE suppressed the growth of mycelium in A. alternata, S. botryosum, and Fusarium spp., but it had no effect on P. expansum, P. digitatum, and B. cinerea.

Furthermore, due to their ability to both directly combat fungal growth and prevent the production of toxins, PPEs can be effectively employed against fungi that produce mycotoxins. A recent study found that a methanolic PPE had a significant effect on the germination of conidia and the rate of hyphal extension in Aspergillus flavus and Fusarium proliferatum. In addition, the extract alone resulted in a 97% reduction in the generation of aflatoxins. Furthermore, when the extract was combined with the azole fungicide prochloraz (PRZ), the production of aflatoxins was totally prevented. In addition, it has been observed that PPEs exhibit strong antibacterial action against both Gram-positive and Gram-negative bacteria. These substances have been shown to be successful in combating significant plant pathogens like Clavibacter michiganensis subsp. michiganensis, Pseudomonas syringae pv. actinidiae, Pseudomonas syringae pv. syringae, Erwinia carotovora, and Xanthomonas campestris, as well as food-borne pathogens such as Salmonella spp. and Listeria monocytogenes, Belgacemetal. shown potent and rapid bactericidal and bacteriostatic effects against L. monocytogenes. The efficacy of PPE treatments in combating bacteria was further confirmed through the analysis of the epiphytic population of olive drupes and citrus fruits [21-22].

Multiple investigations have established a connection between the antifungal and antibacterial properties of PPEs and their abundant polyphenol content, including punicalagins and ellagic acids. Rongai et al. discovered that punicalagins are the active compounds that hinder the growth of Fusariumoxysporum f. sp. lycopersici. They also emphasized that PPEs (pomegranate peel extracts) are highly effective in suppressing the germination of F. oxysporum. The conidial germination and hyphal growth of the mycotoxigenic fungus A. flavus and F. proliferatum yielded comparable findings, as stated in a previous study. The microscopic examination of Fusarium sambucinum mycelium treated with methanol PPE showed distinct changes in hyphal morphology, such as curling, twisting, and collapsing. Additionally, the presence of vacant spaces within the cell and the breakdown of cytoplasmic organelles were also noted. Furthermore, a deviant mycelium formation of M. laxa and M. fructigena was observed after a PPE treatment. Moreover, the examination of the sterol composition of A. flavus revealed that PPE has the potential to suppress the manufacture of ergosterol. This is a pathway that is responsible for the fluidity and permeability of the fungal cell membrane, and is necessary for hyphal extension [23]. PPE polyphenolic chemicals interact with proteins in the fungal cell membrane, leading to cell death by enhancing permeability. In addition, PPEs can reduce the pH gradient surrounding the cell membrane and induce cell death by enhancing permeability. However, it emphasized that the interaction between polyphenols and sulfhydryl groups can lead to enzymatic inhibition and microbial starvation. Sudharsan et al. found that personal protective equipment (PPE) can hinder the development of aflatoxin in A. flavus by blocking certain enzymes involved in the creation of aflatoxin. Furthermore, a dedicated investigation into the proteome impacts of punicalagin on S. aureus revealed that it negatively affects bacterial growth by disturbing iron homeostasis and generating SOS responses, potentially by inhibiting DNA biosynthesis. While several research indicated that the outer lipopolysaccharide membrane found in Gram-negative bacteria can hinder the ability of PPEs to modify and impact cells, other studies have demonstrated a strong effectiveness against Gram-negative bacteria such Salmonella Enteritidis. In addition to their direct antimicrobial effects, there is compelling evidence demonstrating that personal protective equipment (PPE) triggers resistance in plant tissues. Pangallo et al. showed indirectly that PPE can trigger the plant's defense mechanisms in olive drupes infected with C. acutatum and in citrus fruits infected with P. digitatum and P. italicum. This was observed by a decrease in disease occurrence even without direct contact between the pathogens and the extract [24-26].

Additionally, the application of PPE treatment on grapefruit resulted in the detection of elevated levels of reactive oxygen species (ROS), which reached their highest point 24 hours after the treatment. The study also found that various genes related to plant defensive responses, such as CHI, CHS, MAPK, MAPKK, and PAL, were activated. A recent study on orange fruit conducted transcriptome studies and discovered the activation of numerous genes and pathways associated with plant defense responses. The study specifically demonstrated the activation of nine enzymes involved in the production of antibiotics. The scientists proposed that the activation of this pathway could be a primary mechanism by which PPE combats microbial infections. They further linked the activation of these enzymes to the composition of the extract, as polyphenols have been shown to increase resistance in plant tissues. The prolonged effectiveness of PPEs treatments may be attributed to the activation of resistance responses, as suggested by previous studies [27-29]. However, it is necessary to conduct specific investigations to ascertain the duration of host resistance responses after PPE treatment and the rate at which they degrade inside the host tissues. Preventive and curative measures PPEs are highly effective in both preventing and treating many conditions. Controlling existing infections is crucial because most alternative methods of control are only effective when implemented prior to the occurrence of the infection. When olives were intentionally infected with C.acutatum sensustricto, treatments with PPE applied 6, 12, and 24 hours after the infection significantly decreased the occurrence of rots. This indicates that PPE treatments may be effective in controlling infections that have already developed. Comparable results were acquired about apples.

The study involved the inoculation of P. expansum on grapefruits and lemons, as well as the inoculation of P. digitatum and P. italicum on the same fruits. Additionally, field trials have confirmed a potent therapeutic effect in controlling anthracnose in olive orchards with a high prevalence of latent infections. Authors have hypothesized about the significance of this characteristic, as latent infections play a crucial role in the epidemiology of olive anthracnose. The results also indicated the possible application of PPEs to extend the lifespan of fresh fruits and vegetables. By applying treatments shortly before or after harvest, latent infections can be reduced and fruits can be protected during the processes of harvesting, packaging, and storage. The precise processes through which PPE performs its therapeutic effects are not fully comprehended. The extract's capacity to promptly trigger plants' resistance response and stimulate the synthesis of antifungal chemicals is expected to have a significant impact. Furthermore, it is probable that the extract has a direct antifungal effect on the fungi that colonize, although there is currently no information about the ability of the active components of PPE to penetrate and spread throughout the tissues of the host [30].

3.Practical Applications

3.1 Management of Fungal Field Diseases

Currently, there is limited research on the use of Personal Protective Equipment (PPE) to manage fungal illnesses in the field. However, the strong effectiveness and wide range of antifungal activity shown by several PPEs in laboratory trials have motivated scientists to conduct further investigations in this area. Field findings strongly indicate that Personal Protective Equipment (PPE) may be effective in managing a wide variety of diseases caused by necrotrophic, hemibiotrophic, and biotrophic fungal pathogens. For example, the addition of personal protective equipment (PPE) to soils that were intentionally contaminated with F. oxysporum f. sp. lycopersici resulted in a significant decrease in the quantity of the harmful pathogen and an increase in the number of healthy tomato plants. The results demonstrated a notable efficacy of the extract, comparable to the commercial fungicide dicloran (Marisan 50 PB). Another study found that using a methanolic PPE as a treatment for tomato seeds or soil significantly reduced the occurrence of pre- and post-emergence damping off caused by F. oxysporum in a greenhouse setting [31-32]. The efficacy of soil treatment surpassed that of seedling therapy. It should be noted that there have been reports indicating that a significant amount of the extract can cause allelopathic effects in tomato plants. Field trials conducted in commercial olive orchards to manage olive anthracnose indicated a very high efficacy of an ethanolic PPE, which proved significantly more effective than copper, normally employed to control this disease. Specifically, the use of the extract during the initial stage of the illness epidemic totally prevented the growth of natural rots. The authors hypothesized that their extract, which is derived using harmless chemicals that do not harm the olive fruit, can be considered a safe and efficient natural antifungal preparation. A patent has been granted for the use of an ethanolic PPE to manage the grape powdery mold fungus Uncinula necator. This patent emphasizes the potential application of PPEs against biotrophic infections as well (Fig. 2). Three treatments were applied to grapevine cv. Aglianico at 15-day intervals during the phenological phases of fruit set, pre-bunch closure, and bunch closure. These treatments resulted in a 71% reduction in disease incidence, which was equivalent to the effectiveness of the systemic fungicide Spiroxamine [33].

3.2 Management of Bacterial Field Diseases

The potential application of Personal Protective Equipment (PPE) for managing plant bacterial infections is particularly intriguing, as copper is now the sole permitted and effective bactericide in many countries, but often fails to provide adequate protection. Copper therapies function as protectants, lacking curative or systemic properties, and hence should be administered before any infection occurs. Moreover, copper can pose significant ecological disadvantages. It builds up in the soil and poisons the normal microbial population and fauna. It could potentially have adverse impacts on human beings as well. As a result, it was included in the list of compounds designated as "candidates for substitution" by the European Commission according to Regulation (EC) No 1107/2009. The proposal to utilize Personal Protective Equipment (PPE) for the purpose of managing plant microorganisms was initially put up in 2013.

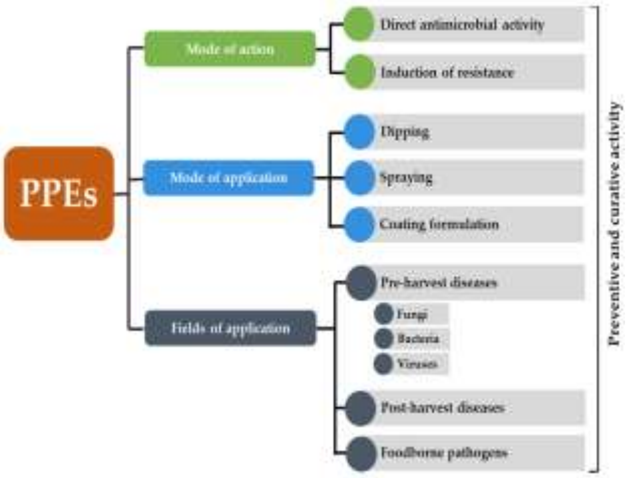

Fig 2: Mode of action and Application of Pomegranate Peel extract

The authors documented a significant effectiveness in combating tomato bacterial speck, which is caused by Pseudomonas syringae pv. They also discussed the significance of their findings, given the absence of viable alternative chemicals and the unavailability of commercially resistant tomato varieties. A hydroalcoholic personal protective equipment (PPE) was recently employed to combat Xylella fastidiosa, a systemic bacterium that inhabits the xylem tissues of olive trees. Conducted over a span of four years (2016-2019), experiments demonstrated an overall enhancement in the plant's well-being following trunk injections. The activation of resistance in plant host tissues treated with PPEs and the wide spectrum of antibacterial activity observed in laboratory experiments indicate the possible application of PPEs as a safe method of controlling bacterial diseases in many plant systems [34-35].

3.3 Management of Viral Field Diseases

A recent Italian patent has been granted for the utilization of an alcoholic extract derived from pomegranate peel for the purpose of managing plant viruses. The application of the extract on tobacco and carnation plantlets through artificial inoculations effectively prevented the infection of tomato spotted wilt virus (TSWV). As per the authors, the extract triggers specific defense mechanisms in the plant and inhibits viral infections. While additional research is required to verify the potential use of Personal Protective Equipment (PPE) in plant virus control tactics, these first findings hold significant importance. Plant viruses are highly resistant diseases that are difficult to control. In rare instances, they can be managed by using pesticides or other chemical treatments. Hence, it is imperative to conduct thorough research to examine the utilization of Personal Protective Equipment (PPEs) for the management of plant virus illnesses [36-37].

3.4 Foodborne Pathogens Linked to Fresh Fruits and Vegetables

A significant amount of resources is dedicated to studying plant-associated diseases due to their impact on the well-being and productivity of numerous crucial crops. Nevertheless, certain diseases have the ability to directly infect humans, leading to cross-kingdom pathogenicity. The likelihood of transmission of infections from humans is extremely elevated, resulting in human sickness and, in certain instances, fatality. Although there are numerous preservation procedures available, foodborne illnesses continue to be a significant worldwide health issue. Instances of severe food-borne outbreaks and food recalls were documented in relation to fresh produce, leading to acute cases of food poisoning and significant economic losses [38].

The primary causes of this phenomenon are cross contamination, mechanical injury, and the emergence of antibiotic-resistant foodborne bacteria, which pose a growing concern to public health. Due to the great susceptibility of processed foods to physical and biological deterioration, there is a strong demand from consumers who are transitioning to a healthy diet for the development of natural preservation techniques. PPEs have been found to have potent bactericidal and bacteriostatic effects on various Gram-positive and Gram-negative foodborne bacteria, such as Salmonella spp., L.monocytogenes, E. coli, Pseudomonas aeruginosa, Clostridia, S. aureus, Y. enterocolitica, Bacillus subtilis, Bacillus cereus, and Vibrio parahaemolyticus (Table 1). Research has shown that the use of personal protective equipment (PPE) can prolong the shelf-life of food products and preserve their microbiological, chemical, and sensory quality. This is achieved when PPE is used alone or in conjunction with other antimicrobial agents. For example, PPE shown significant effectiveness against L. monocytogenes on fresh-cut pear, melon, and apple fruits. This suggests that PPE might be used in the ready-to-eat fresh-cut products business to ensure a high degree of control and safety [39-40].

Notably, personal protective equipment (PPEs) shown a synergistic effect when combined with several additional substances such as chitosan, alginate, biocontrol agents, and plant extracts. In addition, the potential utilization of Personal Protective Equipment (PPEs) in edible coating formulations is particularly intriguing given the growing interest of food companies in novel active packaging materials. The addition of personal protective equipment (PPE) to a gelatine film-forming solution enhanced the antioxidant characteristics and antibacterial activity of the active packaging against S. aureus, L. monocytogenes, and E. coli. Furthermore, the addition of personal protective equipment (PPE) and sodium dehydroacetate to a polyvinyl alcohol (PVA) film resulted in an enhanced antioxidant activity and bacteriostatic action against E. coli and S. aureus [41].

S. No	Field of Application	Pathogens
1	Pre-harvest diseases	• *Fusarium oxysporum* • *Colletotrichum acutatum* • *Uncinula necator* • *Pseudomonas syringae pv. tomato* • *Xylella fastidiosa* • *Tomato Spotted Wilt Virus Tobacco.*
2	Post-harvest diseases	• *Fusarium sambucinum* • *Botrytis cinerea* • *Monilinia laxa* • *Monilinia fructigena* • *Penicillium digitatum* • *Penicillium italicum* • *Penicillium expansum* • *Colletotrichum gloeosporioides* • *Colletotrichum acutatum*

Table 1: Overview of different applications of PPEs to control plant diseases and foodborne pathogens

Recently, researchers suggested using PPE immobilized electrospun active nanofibers as a high-quality food wrapping material. This material helps to maintain the sensory characteristics of meat and other food products and also prolongs their shelf-life. This proposal was documented in reference. Currently, numerous industries are considering incorporating Personal Protective Equipment (PPE) into their food products as a functional ingredient. This is due to the remarkable antioxidant, anti-inflammatory, and antibacterial effects of PPE, as well as its versatility in various food products such as fresh fruits, vegetables, meat, sausages, fish, bread, juice, and more. Research has shown that applying PPEs to food products has a dual benefit. Firstly, it helps to prevent the growth of harmful bacteria that cause foodborne illnesses. Secondly, it promotes the growth of beneficial microorganisms in the human gut. One important discovery about PPEs is their possible prebiotic effect. This is primarily because they are rich in polyphenols, including ellagitannins, which have been found to preferentially influence the growth of vulnerable microbes. According to reports, PPEs have been found to promote the growth of Bifidobacterium and Lactobacillus strains. These strains are among the most significant types of bacteria engaged in food microbiology and human nutrition Neyrinck et al. discovered that the combination of PPE and the probiotic Lactobacillus rhamnosus effectively decreases the buildup of lipids, indicating its potential use in diets aimed at preventing obesity [42].

4 Conclusions

Although the current review, use of natural treatments to control plant diseases and foodborne pathogens associated with fruit and vegetable is gaining great interest from the scientific community as well as consumers, many of the investigated methods are associated with major limitations including the lack of curative or preventive effects, impersistent efficiency, risk of fruit injury and incompatibility with other treatments. Regarding this, pomegranate peel extracts are shown to be an effective and multipurpose natural substitute that can be used for a variety of tasks. Additional research is necessary to confirm that PPEs are safe for plants, human health, and the environment, even though there have been no reports of phytotoxicity thus far. Given this environment, the public's interest and approval of PPEs' established therapeutic effect would drive pharmaceutical companies to study these areas and expedite the time-consuming and expensive process of registering them as a natural antibacterial and fungicide. The broad availability of peels from pomegranate fruits as a waste product from processing industries could also help in obtaining affordable formulations that can hold their own against more conventional chemical compounds.

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Conflict of Interest: Nil

References

[1] Fones, H.N.; Bebber, D.P.; Chaloner, T.M.; Kay, W.T.; Steinberg, G.; Gurr, S.J. Threats to global food

security from emerging fungal and oomycete crop pathogens. Nat. Food 2020, 1, 332–342.

[2] Larsen, A.E.; Gaines, S.D.; Deschênes, O. Agricultural pesticide use and adverse birth outcomes in the San Joaquin Valley of California. Nat. Commun. 2017, 8, 302.

[3] Gill, H.K.; Garg, H. Pesticides: Environmental impacts and management strategies. In Pesticides-ToxicAspects; IntechOpen: Rijeka, Croatia, 2014.

[4] Dilucia, F.; Lacivita, V.; Conte, A.; Nobile, M.A.D. Sustainable use of fruit and vegetable by-products to enhance food packaging performance. Foods 2020, 9, 857.

[5] Popp, J.; Peto˝, K.; Nagy, J. Pesticide productivity and food security. A review. Agron. Sustain. Dev. 2013, 33, 243–255.

[6] Wisniewski, M.; Droby, S.; Norelli, J.; Liu, J.; Schena, L. Alternative management technologies for postharvest disease control: The journey from simplicity to complexity. Postharvest Biol. Technol. 2016, 122, 3–10.

[7] Van Lenteren, J.C.; Bolckmans, K.; Köhl, J.; Ravensberg, W.J.; Urbaneja, A. Biological control using invertebrates and microorganisms: Plenty of new opportunities. BioControl 2018, 63, 39–59.

[8] Mari, M.; Bautista-Baños, S.; Sivakumar, D. Decay control in the postharvest system: Role of microbial and plant volatile organic compounds. Postharvest Biol. Technol. 2016, 122, 70–81.

[9] Shaygannia,E.; Bahmani,M.; Zamanzad,B.; Rafieian-Kopaei,M.AreviewstudyonPunicagranatumL.J.Evid. BasedComplement. Altern.Med.2016, 21, 221–227.

[10] Li, Y.; Ye, T.; Yang, F.; Hu, M.; Liang, L.; He, H.; Li, Z.; Zeng, A.; Li, Y.; Yao, Y. Punica granatum (pomegranate) peel extract exerts potent antitumor and anti-metastasis activity in thyroid cancer. RSC Adv. 2016, 6, 84523–84535.

[11] Stojanovic´, I.; Šavikin, K.; Đedovic´, N.; Živkovic´, J.; Saksida, T.; Momcˇilovic´, M.; Koprivica, I.; Vujicˇic´, M.; Stanisavljevic´, S.; Miljkovic´, Đ. Pomegranate peel extract ameliorates autoimmunity in animal models of multiple sclerosis and type 1 diabetes. J. Funct. Foods 2017, 35, 522–530.

[12] Du, L.; Li, J.; Zhang, X.; Wang, L.; Zhang, W.; Yang, M.; Hou, C. Pomegranate peel polyphenols inhibits inflammation in LPS-induced RAW264. 7 macrophages via the suppression of TLR4/NF-κB pathway activation. Food Nutr. Res. 2019, 63

[13] Bearth, A.; Cousin, M.-E.; Siegrist, M. The consumer's perception of artificial food additives: Influences on acceptance, risk and benefit perceptions. Food Qual. Prefer. 2014, 38, 14–23.

[14] Siegrist, M.; Hartmann, C. Consumer acceptance of novel food technologies. Nat. Food 2020, 1, 343–350.

[15] Rongai, D.; Pulcini, P.; Pesce, B.; Milano, F. Antifungal activity of some botanical extracts on Fusariumoxysporum. OpenLifeSci. 2015, 10, 409–416.

[16] Vora, A.; Londhe, V.; Pandita, N. Herbosomes enhance the in vivo antioxidant activity and bioavailability of punicalagins from standardized pomegranate extract. J. Funct. Foods 2015, 12, 540–548.

[17] Joseph, M.M.; Aravind, S.; George, S.K.; Varghese, S.; Sreelekha, T. A galactomannan polysaccharide from Punica granatum imparts in vitro and in vivo anticancer activity. Carbohydr. Polym. 2013, 98, 1466–1475.

[18] Akhtar, S.; Ismail, T.; Fraternale, D.; Sestili, P. Pomegranate peel and peel extracts: Chemistry and food features. Food Chem. 2015, 174, 417–425.

[19] Seeram, N.P.; Adams, L.S.; Henning, S.M.; Niu, Y.; Zhang, Y.; Nair, M.G.; Heber, D. In vitro antiproliferative, apoptotic and antioxidant activities of punicalagin, ellagic acid and a total pomegranate tannin extract are enhanced in combination with other polyphenols as found in pomegranate juice. J. Nutr. Biochem. 2005, 16, 360–367.

[20] Orak, H.H.; Yagar, H.; Isbilir, S.S. Comparison of antioxidant activities of juice, peel, and seed of pomegranate (Punicagranatum L.) and inter-relationships with total phenolic, tannin, anthocyanin, and flavonoid contents. FoodSci. Biotechnol. 2012, 21, 373–387.

[21] Rongai, D.; Pulcini, P.; Pesce, B.; Milano, F. Antifungal activity of pomegranate peel extract against fusarium wilt of tomato. Eur.J.PlantPathol.2017, 147, 229–238.

[22] Rongai, D.; Sabatini, N.; Pulcini, P.; Di Marco, C.; Storchi, L.; Marrone, A. Effect of pomegranate peel extract on shelf life of strawberries: Computational chemistry approaches to assess antifungal mechanisms involved. J. Food Sci. Technol. 2018, 55, 2702–2711.

[23] Glazer, I.; Masaphy, S.; Marciano, P.; Bar-Ilan, I.; Holland, D.; Kerem, Z.; Amir, R. Partial identification of antifungal compounds from Punica granatum peel extracts. J. Agric. Food Chem. 2012, 60, 4841–4848.

[24] Andrade, M.A.; Lima, V.; Silva, A.S.; Vilarinho, F.; Castilho, M.C.; Khwaldia, K.; Ramos, F. Pomegran-

ate and grape by-products andtheiractivecompounds: Aretheyavaluablesourceforfoodapplications? TrendsFoodSci. Technol. 2019,86,68–84.

[25] Romeo, F.V.; Ballistreri, G.; Fabroni, S.; Pangallo, S.; Li Destri Nicosia, M.G.; Schena, L.; Rapisarda, P. Chemical characterization of different sumac and pomegranate extracts effective against Botrytis cinerea rots. Molecules 2015, 20, 11941–11958.

[26] Schwartz, E.; Tzulker, R.; Glazer, I.; Bar-Ya'akov, I.; Wiesman, Z.; Tripler, E.; Bar-Ilan, I.; Fromm, H.; Borochov-Neori, H.; Holland, D. Environmental conditions affect the color, taste, and antioxidant capacity of 11 pomegranate accessions' fruits. J. Agric. Food Chem. 2009, 57, 9197–9209.

[27] McCarrell, E.M.; Gould, S.W.; Fielder, M.D.; Kelly, A.F.; El Sankary, W.; Naughton, D.P. Antimicrobial activities of pomegranate rind extracts: Enhancement by addition of metal salts and vitamin C. BMC Complement. Altern. Med. 2008, 8, 64.

[28] Nuamsetti, T.; Dechayuenyong, P.; Tantipaibulvut, S. Antibacterial activity of pomegranate fruit peels and arils. Sci. Asia 2012, 38, 319–322.

[29] Al-Zoreky, N. Antimicrobial activity of pomegranate (Punica granatum L.) fruit peels. Int. J. Food Microbiol. 2009, 134, 244–248.

[30] Tayel, A.; El-Baz, A.; Salem, M.; El-Hadary, M. Potential applications of pomegranate peel extract for the control of citrus green mould. J. Plant Dis. Prot. 2009, 116, 252–256.

[31] Rongai, D.; Milano, F.; Sciò, E. Inhibitory effect of plant extracts on conidial germination of the phytopathogenic fungus Fusarium oxysporum. Am. J. Plant Sci. 2012, 3, 1693–1698.

[32] Rongai, D.; Pulcini, P.; Di Lernia, G.; Nota, P.; Preka, P.; Milano, F. Punicalagin content and antifungal activity of different pomegranate (Punica ganatum L.) genotypes. Horticulturae 2019, 5, 52.

[33] Oraki, H.H.; Demirci, A.S¸.; Gümüs¸, T. Antibacterial and antifungal activity of pomegranate (Punica granatum L. cv.) peel. Electron. J. Environ. Agric. Food Chem. 2011, 10, 1958–1969.

[34] Pangallo, S.; Li Destri Nicosia, M.G.; Agosteo, G.E.; Abdelfattah, A.; Romeo, F.V.; Cacciola, S.O.; Rapisarda, P.; Schena, L. Evaluation of a Pomegranate Peel Extract (PGE) as Alternative Mean to Control Olive Anthracnose. Phytopathology 2017, 107, 1462–1467.

[35] Li Destri Nicosia, M.G.; Pangallo, S.; Raphael, G.; Romeo, F.V.; Strano, M.C.; Rapisarda, P.; Droby, S.; Schena, L. Control of postharvest fungal rots on citrus fruit and sweet cherries using a pomegranate peel extract. Postharvest Biol. Technol. 2016, 114, 54–61.

[36] Sudharsan, S.; Shapiro, O.; Ziv, C.; Barda, O.; Zakin, V.; Sionov, E. Synergistic Inhibition of Mycotoxigenic Fungi and Mycotoxin Production by Combination of Pomegranate Peel Extract and Azole Fungicide. Front. Microbiol. 2019, 10, 1919.

[37] Singh, B.; Singh, J.P.; Kaur, A.; Singh, N. Antimicrobial potential of pomegranate peel: A review. Int. J. Food Sci. Technol. 2019, 54, 959–965.

[38] Manapure, N.; Naik, R.; Satbhai, R.; Mohite, S. Evaluation of Antioxidant Activity of Solvent Extracted Pomegranate Peel and its Effect against Plant Pathogenic Bacteria and Fungi. J. Pure Appl. Microbiol. 2015, 9, 1081–1089.

[39] Pirzadeh, M.; Caporaso, N.; Rauf, A.; Shariati, M.A.; Yessimbekov, Z.; Khan, M.U.; Imran, M.; Mubarak, M.S. Pomegranate as a sourceofbioactiveconstituents: Areviewontheircharacterization,propertiesandapplications.Crit. Rev. FoodSci. Nutr.2020,1–18.

[40] Rongai, D.; Pucci, N. Esperienze preliminari sul contenimento di alcuni batteri fitopatogeni attraverso l'utilizzo dell'estratto di Punica granatum. AttiGiornate Fitopatol. 2016, 2, 311–314.

[41] Hassan, N.A.; El-Feky, G.S.; Elegami, H.M. Antibacterial Activity of Thirty Two Pomegranate (Punicagranatum L.) Accessions Growing in Egypt Fruit Peels. World Appl. Sci. J. 2013, 21, 960–967.

[42] Belgacem, I.; Schena, L.; Teixidó, N.; Romeo, F.; Ballistreri, G.; Abadias, M. Effectiveness of a pomegranate peel extract (PGE) in reducing Listeria monocytogenes in vitro and on fresh-cut pear, apple and melon. Eur. Food Res. Technol. 2020, 246, 1765–1772.