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Innovative Treatments for Polyester Nonwoven Fabrics to Resist Fruit Infestation by Agricultural Pests

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Abstract
Crop protection remains one of the major challenges faced by farmers in the agricultural sector. Agrotextiles such as sunscreens, bird nets, mulch mats, hail protection nets, harvesting nets, and windbreaks are widely used to mitigate such issues. Pre- and post-harvest diseases are the primary causes of fruit and vegetable crop losses. This study aimed to evaluate certain eco-friendly products for their potential to reduce these diseases.
In vitro tests were conducted to assess the antifungal activity of three organic acids—salicylic, sorbic, and benzoic acids—against Penicillium digitatum, Botrytis cinerea, and Colletotrichum gloeosporioides at concentrations of 0.0%, 2.5%, and 5.0%. At 5.0%, inhibition zones exceeded 11.0 mm, 10.0 mm, and 9.0 mm for salicylic, sorbic, and benzoic acids, respectively. Additionally, four salts—potassium bicarbonate, sodium benzoate, sodium bicarbonate, and potassium sorbate—were tested at the same concentrations. Sodium bicarbonate at 5.0% produced the largest inhibition zones (11.0, 9.0, and 8.0 mm for P. digitatum, B. cinerea, and C. gloeosporioides, respectively), while the other salts showed moderate effects.

Keywords
Agro-textiles, Agriculture, fruit flies, Nonwoven process, Pre-harvest bagging, organic acid.

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Introduction:
Textiles have been increasingly used to protect crops from pests by covering plants and trees with special fabrics that allow the passage of air and light necessary for photosynthesis while preventing insects from reaching the fruit. This approach yields pest-free produce, reduces pesticide use, and disrupts pest life cycles by removing their breeding hosts.
Citrus fruits are particularly susceptible to major postharvest diseases such as green mold (Penicillium digitatum), blue mold (P. italicum), and sour rot (Geotrichum citri-aurantii) (Zhang et al., 2005; Cheng et al., 2020; Bhatta, 2021; Shawky et al., 2023; Abd-El-Kareem et al., 2022). Similar fungal pathogens attack mangoes—commonly Colletotrichum gloeosporioides, causing anthracnose (Ploetz, 2003; Sangeetha & Rawal, 2008)—and apples and pears, where Botrytis cinerea and Penicillium expansum cause grey and blue molds, often entering through wounds (Snowdon, 1990; Wenneker & Thomma, 2020).
While chemical fungicides remain a common control method, their toxicity has negative environmental impacts, creating demand for safer alternatives (Abd-El-Kareem & Saied, 2015; Abd-El-Kareem et al., 2015, 2022). Most existing research has focused on postharvest treatments such as dipping or spraying with salts and organic acids (Nigro et al., 2006), but pre-harvest applications can also disrupt early infection stages (Ippolito & Nigro, 2000; Youssef et al., 2008, 2012).
Studies have shown that compounds like salicylic acid (SA) and abscisic acid can enhance disease resistance in fruits. SA application pre- or post-harvest reduced pear diseases (Jiankang et al., 2006) and boosted defense enzyme activity in peppers (Mahdavian et al., 2007). Citric acid

lowered browning and pH, while also reducing grey mold severity (Kanlayanarat, 2003; Abdel-Rahman, 2015). Other agents, including calcium chloride, methyl jasmonate, potassium sorbate, sodium benzoate, and various food preservatives, have also demonstrated pathogen growth inhibition in vitro (Abdel-latif et al., 2011; Kamara et al., 2016; El-Fawy et al., 2020).

Given the environmental and health risks of pesticides, physical barriers such as agro-textiles—nylon netting or fine-weave fabrics—offer a sustainable pest management solution. These materials allow light and air penetration but block insect access, helping maintain healthy crops without chemical inputs.

Theoretical Frame Work:

1.1 Agriculture textiles (agro-textiles):

The term “agro textiles” refers to woven, nonwoven, and knitted textiles as shown in figure (1), as well as mesh or foil, that are used for crop or animal cultivation, harvesting, and storage, livestock protection, shading, weed and insect control, and extending the growing season (Basu, 2011). Agro textiles can be separated based on product classification, application area, and production method. Agriculture applications (crop farming), horticulture, floristry, forestry, agro-textiles for cattle breeding, and aquaculture comprise the application field. Agro textiles are made using a variety of production techniques, each of which offers unique structures and capabilities needed for the intended usage (Palamutcu and Devrent, 2017). Both natural and synthetic fibers can be utilized in the creation of agricultural textiles. With the exception of trace amounts of polyester and polyamide fibers, polyolefin fibers are the most widely used synthetic fibers. The fibers that best reflect natural fibers are hemp, flax, sisal, jute, wool, and coir. Because of their high strength, durability, and other advantageous qualities, man-made fibers are frequently employed in the production of agro textiles. However, agro textiles made of natural fibers not only fulfill a specific function but also break down and function as natural fertilizers after a few years

Fig.1. Different types of agro textiles are used in agriculture

1.1.1 Structures for Agro-Textiles

Various textile structures—including knitted, nonwoven, and woven—are employed in agricultural applications depending on their intended functions and performance requirements (Mansfield, 2005). Key properties of these textiles include flexibility, porosity, and permeability to both water and air (Hsieh, 2016).

1.1.1.1 Woven Agro-Textiles

Woven agro-textiles are produced using specialized projectile weaving machines (Basu, 2011). They are applied in diverse agricultural sectors such as crop cultivation, horticulture, aquaculture, forestry, and animal husbandry, serving to protect silages and other products from environmental damage as well as from bird and insect attacks (Buyukbayraktar & Bedeloglu, 2020).

1.1.1.2 Nonwoven Agro-Textiles:

Nonwoven agro-textiles- manufactured from natural or synthetic fibers- are increasingly popular due to their excellent mechanical and functional properties, environmental compatibility, recyclability, and biodegradability. Commonly used fibers include jute (natural) and polypropylene (synthetic). The use of biodegradable fibers can also improve soil fertility and health (Agrawal, 2013).

Polypropylene-based nonwoven agro-textiles protect crops and seeds from frost and cold and can be laid directly over crops or used in tunnel structures to promote seedling growth and vegetable production. These coverings can lead to higher yields and earlier harvests by accelerating seed germination and plant growth; however, differences in nonwoven material types have shown little impact on overall germination rates or total growth duration (Fisher, 2013).

Spun-bonded nonwoven fabrics offer an effective alternative to plastic films, providing protection from adverse weather, pests, and insects while allowing adequate ventilation and preventing crop rotting or freezing (Sharma, Ali, & Khatr, 2018).

1.1.1.3 Knitted Agro-Textiles

Knitted agro-textiles are widely used for agricultural screens, packaging materials, anti-bird nets, and fishing nets (Nair & Pandian, 2014). Compared with traditional materials such as burned clay pots, knitted and other specialized agro-textile forms- such as thermal-bonded, stitch-bonded, hydroentangled, and wet-laid nonwovens- offer greater versatility and adaptability for multiple applications (Scarlat, Rusu, & Pricop, 2017).

1.1.2 Fibers for Agro-Textiles:

Textile fibers are essential in the production of agro-textiles, with the choice of fiber—synthetic, natural, or regenerated—being determined by the specific agricultural application (Ajmeri & Ajmeri, 2016; Subramanian, Poongodi, & Sindhuja, 2008).

1.1.2.1 Natural Fibers:

Natural fibers are valued for their biodegradability, renewability, low cost, high mechanical strength, low elongation, elasticity, and density, making them economically important for developing countries (Miraftab, 2016). Examples include jute, coir, sisal, and hemp, all of which possess high moisture retention, reducing evaporation and maintaining soil hydration. These fibers are often incorporated into agro-textiles as natural fertilizers (Tosic et al., 2019b).

To improve their performance, natural fibers can undergo chemical treatments such as alkali treatment, silane treatment, acetylation, benzoylation, acrylation, maleated coupling agents, isocyanates, and permanganate applications. These treatments enhance fiber strength, reduce water absorption, and improve resistance to degradation (Ali et al., 2018; Li, Tabil, & Panigrahi, 2007).

1.1.2.2 Synthetic Fibers

Synthetic fibers are preferred for many agricultural applications due to their high strength, durability, and favorable mechanical properties (Sharma, Ali, & Khatr, 2018). Common examples include nylon, polyester, polyethylene, and polypropylene, which are known for their high mechanical strength, modulus, elongation, elasticity, and low moisture absorption (Annapoorani & Saranya, 2019).

1.1.2.3 Regenerated Man-Made (Bio-Based) Fibers

Regenerated man-made (bio-based) fibers are suitable for producing knitted, woven, and nonwoven fabrics (Senthilkumar, 2017). Advances in biopolymer technology have expanded their use in applications ranging from composites and medical products to agriculture and packaging (Vinod, Sanjay, Siengchin, & Parameswaranpillai, 2020).

1.2 Fruits

Fruits are an essential component of the human diet and represent a significant source of income for producers. However, their postharvest quality is often affected by environmental factors, including insect pests and pathogenic infections, which can cause physiological disorders and various diseases. Pre-harvest fruit bagging has been shown to reduce disease incidence, lower pesticide residues, and improve fruit quality through both chemical and physical means. This technique is commercially applied worldwide to a variety of fruits, including mango, banana, guava, grape, apple, and litchi (Kumar, Singh, Jat, Ahamad, & Kumar, 2021).

With increasing awareness of environmental protection, consumer health, and safety, recent efforts have emphasized improving fruit yield, quality, and appearance while reducing pest and disease incidence through minimal chemical use (Dorugade et al., 2023). Pre-harvest fruit bagging is one such technique, applied to individual fruit bunches or berries to enhance their physical appearance and chemical quality. This method also provides protection against biotic and abiotic stresses, helping to prevent external damage such as cracking, sunburn, and rusting (Amarante, Banks,

& Max, 2002; Xu, Chen, & Xie, 2010; Joshi, Singh, Saxena, Mishra, & Kumar, 2016).

1.2.1 Pests of fruit trees (Johnson & Lyon, 2018)

To minimize crop damage and promote sustainable agricultural practices, integrated pest management (IPM) strategies—combining biological, cultural, and chemical control methods—have become increasingly popular. By staying informed about emerging pest trends and adopting innovative control approaches, farmers can more effectively protect their crops while preserving both quality and yield.

1.2.1.1 Fruit flies (Khan et al., 2021)

Globally, fruit flies (Diptera: Tephritidae) pose a serious threat to fruit production. However, studies indicate that these pests are not fully adapted to all potential host plants (Sharma et al., 2014)Fruit flies infest fruits and vegetables, causing direct damage, promoting fruit rot, and triggering strict quarantine measures to prevent the introduction of new species. The indiscriminate use of pesticides by farmers to control fruit flies in orchards and vegetable fields has led to problems such as insecticide resistance, soil contamination, and risks to human health. Therefore, alternative control strategies, including physical barriers and biological control through natural predators, are essential. One such physical method is fruit bagging—a mechanical approach used to enhance fruit quality, reduce pesticide residues, and minimize fruit fly infestation.

1.2.2 Pre-Harvest Fruit Bagging

Pre-harvest fruit bagging is a widely adopted horticultural practice in which developing fruits are enclosed in protective bags to safeguard them from biotic threats, such as insect pests, birds, and fungal pathogens, as well as abiotic stresses like sunburn, wind damage, and mechanical injuries. This technique serves as an effective physical barrier, significantly reducing the incidence of pest infestation and disease without relying heavily on chemical pesticides, thus promoting safer and more sustainable fruit production (Sharma et al., 2014; Jadhav & Saxena, 2025).

In addition to protection, bagging alters the fruit's microenvironment by regulating light exposure, temperature, and humidity, which can improve peel coloration, reduce blemishes, and enhance the overall appearance of the fruit (Zhang et al., 2022; Wu et al., 2013). Controlled studies have shown that bagged fruits generally exhibit better marketable quality, lower post-harvest decay, and longer shelf life compared to unbagged fruits (Sharma et al., 2014; Asrey et al., 2020). Furthermore, by limiting pesticide sprays close to harvest, bagging can significantly reduce chemical residues on fruits, aligning with consumer demand for safer produce (PMC, 2021).

2. Materials and Methods

Chemicals and fabrics

Nonwoven polyester fabrics with thicknes of 0.2 mm and weight 26.6g/m2 were purchased from Egyptian Company CTMC Unengraved Fabric Limited in Suez, sodium bicarbonate, potassium bicarbonate, sodium benzoate and potassium sorbate were grade chemicals of laboratory also organic acids (salicylic, sorbic and benzoic acids) purchased from Merck.

Fungal isolate

The Plant Pathology Department (NRC) in Egypt provided one virulent isolate of the fungi that cause anthracnose disease in mango fruits (Colletotrichum gloeosporioides), the green mold disease-causing Penicillium digitatum, and the gray mold-causing Botrytis cinerea.

Preparation of Alkali and Acids with Different Concentration:

Potassium and sodium bicarbonate, potassium sorbate and sodium benzoate with different concentrations (0.0, 2. 5, 5%) by dissolving the known weight of salt in the determined volume water to obtain the debit concentrations. Also the known weight of organic acids (sorbic, benzoic and salicylic acids) were dissolved in known volume of water to obtain the demand concentration of organic acids

Preparation of spore suspension

The standard inoculum was prepared by cultivating isolates of Penicillium digitatum, Colletotrichum gloeosporioides, and Botrytis cinereaon PDA plates for 10 days at 20 ± 2°C. The culture's surface was brushed with 10 mL of sterile distilled water per plate to create spore suspension. After that, muslin was used to filter the spore suspensions. The concentration of spore suspension was reduced to about 106 spore/mL using a hemocytometer slide.

Treatment of fabric disks with different chemicals

Nonwoven fabric disks measuring 10 × 10 cm with a thickness of 0.2 mm were immersed in the designated chemical solutions for 30 minutes and then air-dried at room temperature for 0, 1, 6, and 12 hours.

Testing of different organic acids on inhibition zone of pathogenic fungi

Salicylic, sorbic, and benzoic acids three organic acids were examined at concentrations of 0.0, 2.5, and 5.0%. Sterilization-treated fabric disks were utilized as test substance carriers. As previously stated, inoculation plates and treated fabric disks were used.

Testing of different salts on inhibition zone of pathogenic fungi

Four salts potassium bicarbonate, sodium benzoate, sodium bicarbonate and potassium sorbate at three different concentrations 0.0, 2.5, and 5.0% were examined. Sterilization-treated fabric disks were utilized as test substance carriers. As previously stated, inoculation plates and treated fabric disks were used.

3. Results:

3.1 Effect of different organic acids on inhibition zone of pathogenic fungi

The growth inhibition zone of Penicillium digitatum, Botrytis cinerea, and Colletotrichum gloeosporioides was tested against three organic acids salicylic, sorbic, and benzoic acids at concentrations of 0.0, 2.5, and 5.0%. Table 1 and Fig2 showed that the inhibition zones for Penicillium digitatum, Botrytis cinerea, and Colletotrichum gloeosporioides were more than 11.0, 10.0, and 9.0 mm for salicylic, sorbic, and benzoic acids at 5.0%, respectively.

Table 1: Effect of different organic acids on inhibition zone of pathogenic fungi

Organic acids	Conc.%	Inhibition zone (mm)		
		Penicillium Digitatum	Botrytis cinerea	Colletotrichum Gloeosporioides
Benzoic	2.5	6.1b	5.0c	4.0b
	5.0	12.0a	10.0a	8.0a
Salicylic	2.5	4.5b	4.0c	4.0b
	5.0	13.0a	11.0a	10.0a
Sorbic	2.5	5.4b	3.9c	3.9b
	5.0	11.0a	10.0a	9.0a
Control (sterilized water)	0.0	0.0c	0.0d	0.0 c

- Mean values in the same column followed by the same letter are not significantly different at $p < 0.05$

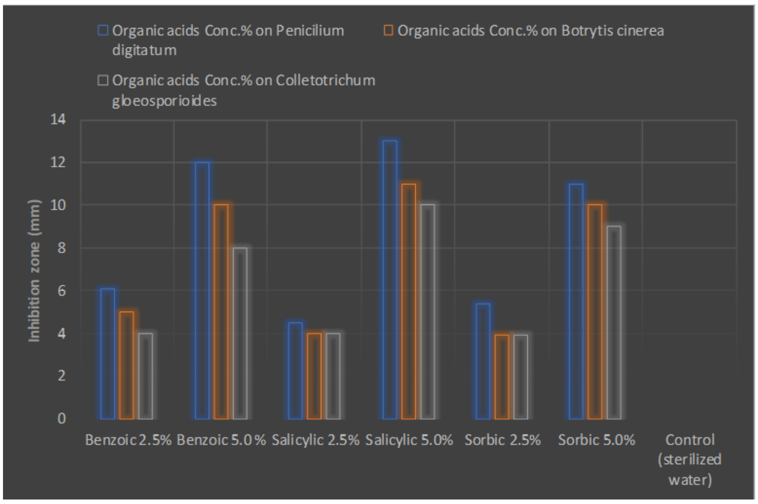

Fig. 2: Effect of different organic acids on inhibition zone of pathogenic fungi.

3.2 Effect of different salts on inhibition zone of pathogenic fungi:

Colletotrichum gloeo sp orioides and Botrytis cinerea were examined for their impact on the inhibition zone of Penicillium digitatum. Four salts i.e. Sodium benzoate, Potassium sorbate, Sodium bicarbonate and Potassium bicarbonate at three concentrations, 0.0, 2.5 and 5.0 %, were investigated. All tested salts considerably recorded the inhibitory zone of all rested fungus, according to the results in Table (2) and Fig 3. With sodium bicarbonate at 5.0%, the inhibitory zone increased the most, measuring 11.0, 9.0, and 8.0 mm for Penicillium digitatum, Botrytis cinerea, and Colletotrichum gloeosporioides, respectively. The effects of other salts were mild.

Table 2: Effect of salts inhibition zone of pathogenic fungi

Salts	Conc. %	Inhibition zone (mm)		
		Penicillium digitatum	Botrytis cinerea	Colletotrichum Gloeosporioides
Sodium benzoate	2.5	6.1c	6.1c	4.1c
	5.0	6.0c	6.0c	5.0b
Potassium sorbate	2.5	4.5d	4.0d	2.0e
	5.0	7.0b	8.0a	4.0c
Sodium bicarbonate	2.5	5.0d	6.0c	5.0b
	5.0	11.0a	19.0a	8.0a
Potassium bicarbonate	2.5	2.4e	4.0d	3.0d
	5.0	10.0a	7.0b	8.0a
Control (sterilized water)	0.0	0.0f	0.0 e	0.0f

- Mean values in the same column followed by the same letter are not significantly different at $p < 0.05$

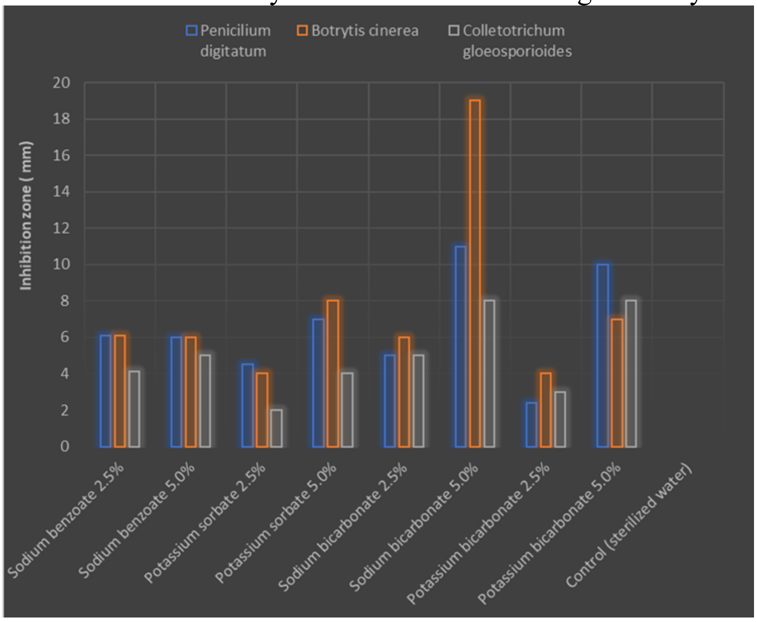

Fig. 3: Effect of salts inhibition zone of pathogenic fungi.

Conclusions:

- This study demonstrated the potential of polyester nonwoven fabrics, treated with selected eco-friendly agents, as an effective strategy for reducing fungal infection in fruit crops. The produced fabrics allowed the passage of air, water, and light while serving as a physical barrier against insect pests. Treatments with salicylic acid, benzoic acid, and sodium bicarbonate enhanced the antifungal performance of the fabrics, with benzoic acid and sodium bicarbonate showing the most pronounced inhibitory effects against Penicillium digitatum, Botrytis cinerea, and Colletotrichum gloeosporioides. The findings highlight that integrating treated agro-textiles into crop management can reduce dependence on chemical pesticides, promote healthier produce, and support sustainable agricultural practices.

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