

Bio-smart technologies for increasing shelf life and postharvest disease management in fruits for distant and export markets

Postharvest management is critical for ensuring fruit quality, especially when targeting distant and export markets where prolonged storage and transit pose major challenges. Fruits are highly perishable, and postharvest diseases such as anthracnose, stem-end rot, and sooty mould often cause significant economic losses. Conventional chemical treatments, though effective, raise concerns regarding food safety, residue levels, and environmental sustainability. Bio-smart technologies have emerged as promising alternatives by utilizing natural and eco-friendly interventions. These include secondary metabolite-based formulations, bio-control agents, organic-based fruit coatings, edible films, plant-based extracts, ethylene control mechanisms, and temperature and relative humidity alterations. These approaches for shelf life extension and maintaining fruit freshness not only prolong shelf life and reduce postharvest diseases but also ensure compliance with international quality standards. Adoption of these bio-smart interventions can play a pivotal role in reducing postharvest losses, enhancing fruit quality for consumer acceptability, and improving the export competitiveness of Indian fruits globally.

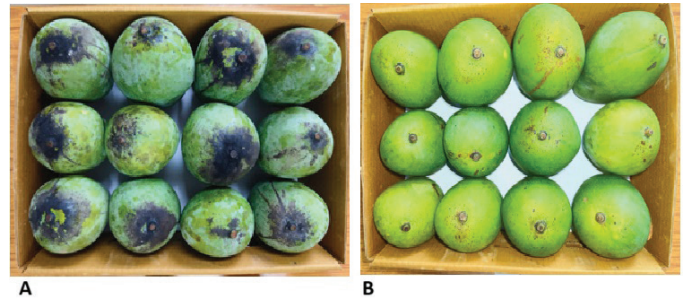
Keywords: Bio-control agents, Edible coatings, Ethylene scavengers, Postharvest disease management, Shelf life extension

MANGO (*Mangifera indica* L.) is one of the most economically important tropical fruits worldwide, highly valued for its distinctive flavour, nutritional attributes, and diversified consumer demand. India, the centre of origin and primary producer of mango, contributes the largest share to global production; however, its export volume remains disproportionately low, accounting for only about 0.52% of national output. As a climacteric fruit, mango is particularly vulnerable to postharvest deterioration due to its high respiration rate and rapid ethylene evolution, which accelerate ripening and shorten shelf life. Substantial postharvest losses are further aggravated by the prevalence of fungal diseases, especially during storage, transport, and marketing. The major postharvest pathogens affecting mango include anthracnose caused by *Colletotrichum gloeosporioides*, stem-end rot caused by *Lasiodiplodia theobromae*, and *Alternaria* fruit rot caused by *Alternaria alternata*. Among these, anthracnose is regarded as the most devastating, contributing to more than 40% economic losses in commercial supply chains. Its symptoms often remain latent during fruit development and become pronounced during ripening, severely compromising marketability and export potential. To address these challenges, the

institute has developed several breakthrough postharvest technologies aimed at enhancing shelf life, reducing decay incidence, and improving market quality of mango and banana. These interventions integrate improved handling practices, eco-friendly treatments, and optimized storage protocols, demonstrating significant potential for reducing postharvest losses and strengthening the value chain.

CISH Metwash

ICAR-CISH, Lucknow, developed a secondary metabolite-based organic formulation for increasing the shelf life of mango and banana. It is also effective in suppressing postharvest diseases during fruit storage. Using this formulation, ICAR-CISH has developed a protocol for extending the shelf life of mango as well as banana under reefer conditions, enabling their successful export to Singapore, London, United Kingdom, Russia, and Japan via sea route. Dipping fruits in a 1.0–1.5% solution of CISH Metwash for 7–10 minutes effectively controls postharvest diseases and regulates ethylene production during transit in both mango and banana. As a result, the shelf life of mango can be extended to 25–40 days. It was also validated in banana, where the shelf life can be extended up to 35–40 days when stored



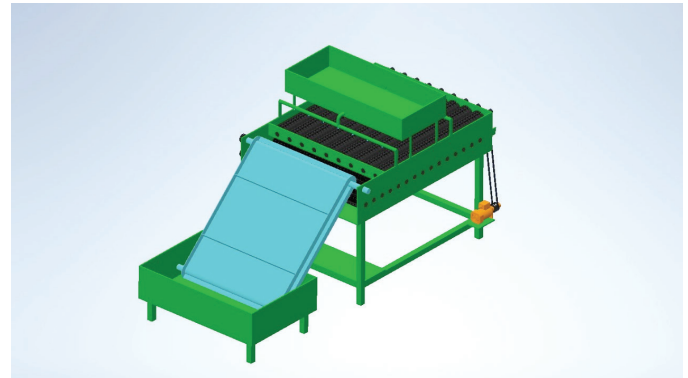
Pictorial view illustrating the surface view of the mango fruits: a. Sooty mould effected shabby and black spotted mangoes; b. Shiny and attractive CISH-Fruit wash treated fruits

in controlled atmosphere (CA) conditions inside reefer containers at 11–12°C for mango and 12–13°C for banana, with relative humidity maintained at 85–90%.

CISH Fruit Wash

CISH-Fruit Wash is an eco-smart formulation developed for the effective removal of sooty mould blotch, which has been a major concern for the reduction of market price of mango, particularly in commercial varieties such as *Chausa*, *Langra*, and *Amrapali*, which are highly affected during rains. The problem originates from a complex fungal disease involving more than 19 types of fungal spores that thrive on the honeydew secretions of sap-sucking insects, leading to the formation of a black, sticky layer—commonly known as sooty mould—on leaves, stems, and fruit peels. In the initial stages, the pulp remains unaffected; however, with disease progression, the infection spreads rapidly and, under severe conditions, penetrates the fruit surface, infecting the pulp and drastically reducing fruit quality and market value. This issue has emerged as a serious concern in mango-growing regions of Uttar Pradesh, particularly in the central and western belts. Application of CISH-Fruit Wash effectively removes up to 80–85% of surface blemishes and improves the fruit's shelf life by 5–7 days.

The integration of fruit washer machine with CISH-Fruit Wash enhances the washing efficiency and cost



(a) Mangoes before washing in machine, and (b) after machine washing with CISH-Fruit wash

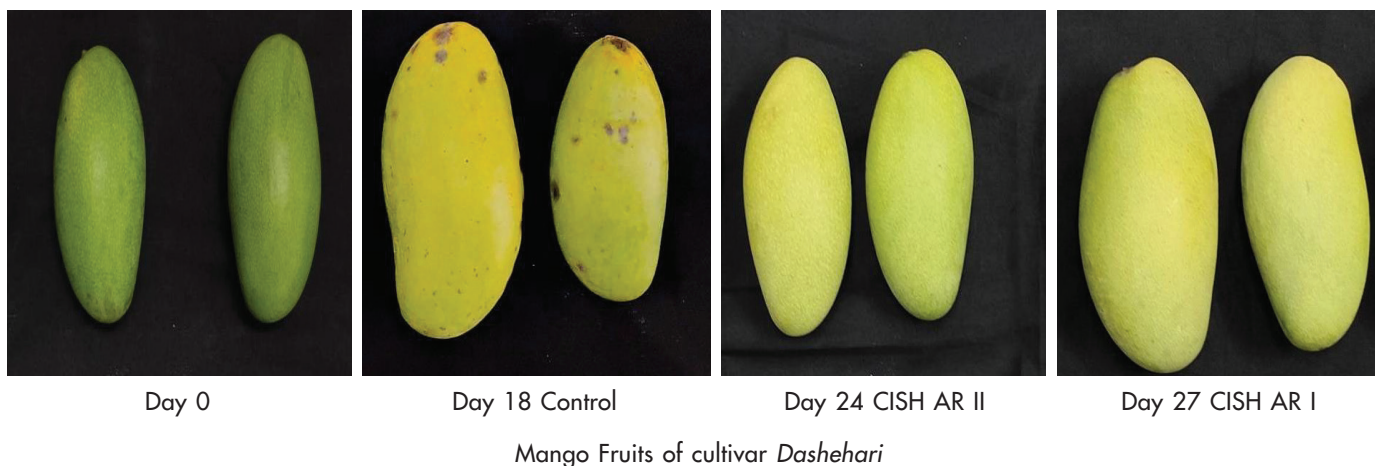
reduction significantly

Edible coatings on fruits

Conventional postharvest treatments, particularly synthetic chemicals, though effective, pose risks to human health and the environment due to indiscriminate use. Thus, safe and eco-friendly alternatives are required to maintain quality, reduce decay, and enhance storability.

The technology was successfully validated in following trial shipment of banana and mango cultivars via sea route in reefer container:

Fruit	Destination	Quantity (tonnes)	Travel time (Days)
Banana	St. Petersburg	24	32
Banana	Spain	24	30
Banana	Moscow	24	32
Banana	Rotterdam	18	22
Mango <i>Banaganapalli</i>	London	7	53
Mango <i>Kesar</i>	Japan	7	40
Mango <i>Dashehari</i>	Singapore	6	25
Mango <i>Dudhia malda</i>	Dubai	14	10



Edible coatings have emerged as an effective strategy to prolong fruit shelf life by serving as thin, biodegradable barriers on the fruit surface. Composed of polysaccharides, proteins, or lipids, these coatings regulate the exchange of oxygen, carbon dioxide, and water vapour between the fruit and its surrounding atmosphere. By modifying the internal microenvironment, they reduce respiration, delay ripening, inhibit senescence, and maintain firmness. Additionally, edible coatings can carry bioactive molecules such as antioxidants, antimicrobials, nutraceuticals, and anti-browning agents (all with GRAS status), further protecting fruits from oxidative stress and microbial spoilage. The success of edible coatings depends on formulation and method of application, such as dipping, spraying, or brushing.

Climacteric fruits like mango and guava particularly benefit from coatings because they exhibit rapid ethylene production and respiratory activity during ripening. ICAR-CISH, Lucknow, is working on evaluation of hydrogel-based coatings enriched with natural antioxidants and seed extracts. These smart hydrogels provide uniform coverage, enhance antioxidant protection, and are easy to handle. In guava cvs. '*dhawal*' and '*lalima*,' hydrogel coatings extended shelf life to 8 days under ambient conditions compared to 6 days in controls. Similarly, mango cvs. '*dashehari*,' '*langra*,' '*chausa*,' '*amrapali*,' and '*mallika*,' when coated with hydrogels, packed in modified atmosphere packaging (MAP), and cold-stored at $13 \pm 1^\circ\text{C}$ with 85–90% RH, retained good quality for 30 days compared to 28 days in untreated fruits.

Ethylene scavengers CISH AR I and CISH AR II

Postharvest physiological and biochemical activities of fruit greatly affect fruit quality, storability, and transportability. Rapid ripening and senescence during handling, retailing, and storage greatly impact the external and internal quality of fruits and lead to huge postharvest losses. Dealing with postharvest loss reduction may well be the agricultural challenge of the present century. Changes in postharvest metabolic processes (anabolic and catabolic) are pivotal for enhancing shelf life and storability of fruits. The pace of catabolic changes plays a pivotal role in the postharvest shelf life of fruits. Ethylene, a gaseous plant hormone, is considered responsible for rapid catabolic changes and senescence in fruits. The production of

ethylene in climacteric fruits is an autocatalytic process. CISH AR II scavenges ethylene produced during ripening and enhances the shelf life of fruits.

The gaseous plant hormone ethylene is biologically active at very low concentrations of around 0.01 to 1.0 parts per million (ppm). Depending on the species, response sensitivity may be lower or higher. Ethylene is produced by a fairly simple two-step biosynthesis route. Despite this pathway's simplicity, regulation of ethylene biosynthesis is a complex process. Ethylene production is intimately linked with the homeostasis of its general precursor S-adenosyl-L-methionine (SAM), which is controlled by its synthesizing enzymes (SAM synthetase), as well as the metabolic flux through the adjacent Yang cycle. Ethylene biosynthesis continues from SAM by two dedicated enzymes: 1-aminocyclopropane-1-carboxylic (ACC) synthase (ACS) and ACC oxidase (ACO). For regulation of ethylene production, control of ACS or ACO is crucial. CISH AR II delays fruit ripening through removal, absorption, or scavenging of initially produced ethylene.

A study was conducted for three consecutive years (2022–2024) at Post Harvest Physiology Lab, ICAR-CISH, Rehmankhera, Lucknow, on mango fruits of cultivar *Dashehari* treated with anti-ripeners II (25, 37.5, and 50 mg per kg fruits). The prepared sachet of AR II was placed in each box containing 5.0 kg fruits in 5-ply CFB packaging boxes, which were stored at $12 \pm 1^\circ\text{C}$ with relative humidity 85%. Simultaneously, a set of control fruits was maintained without any treatment. Fruits were withdrawn at 3-day intervals to determine treatment effects on shelf life and enzymatic/biochemical parameters. CISH AR II offers the potential to enhance the shelf life of mango cultivar *Dashehari* up to 24 days. This provides sufficient time for farmers and traders. CISH AR II sachets can be used during postharvest handling, packaging, storage, and transport of fruits. This allows absorption of ethylene initially produced during ripening. Farmers can use CISH AR II by placing a sachet in the packaging box. Treated fruits may be transported safely to distant domestic markets as well as foreign destinations. By extending shelf life, farmers can wait to obtain appropriate prices for their produce, reducing market glut. Consequently, farmers can achieve better prices, and cultivation and trade become more profitable.

CONCLUSION

Bio-smart technologies provide a sustainable and effective approach to mitigating fruit perishability, postharvest diseases, and challenges related to market competitiveness. By integrating biological control agents, natural edible coatings, and eco-friendly wash formulations such as CISH-metwash, CISH-fruit wash, AR II, and edible coatings, these technologies reduce dependence on synthetic chemicals while maintaining food safety and quality. Within export-oriented supply chains, the use of edible coatings, active packaging systems incorporating ethylene scavengers, and packaging infused with microbial

antagonists has demonstrated significant potential to extend fruit shelf life during long-distance transport. Moreover, bio-smart solutions align with international regulations related to maximum residue limits (MRLs), food safety, and environmental sustainability, ultimately enhancing consumer confidence in global markets.

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भारतीय कृषि अनुसंधान परिषद (ICAR) के 98वें स्थापना दिवस के उपलक्ष्य में, परिषद की लोकप्रिय पत्रिकाओं के विशेषांकों हेतु लेख आमंत्रित

1. खेती पत्रिका के “आजीविका उद्यमिता” विशेषांक हेतु लेख आमंत्रित

इस विशेषांक के लिए आजीविका एवं उद्यमिता विषयक सफलता-गाथाएँ आमंत्रित हैं। प्रस्तुत लेख मौलिक, अप्रकाशित तथा किसी नवाचार, तकनीकी हस्तांतरण, व्यावहारिक समाधान या अभिनव कृषि प्रयोग की सफलता पर आधारित होना चाहिए। लेख सरल, प्रवाहपूर्ण भाषा में तथा आवश्यकता अनुसार सचित्र तैयार किया जाए।

2. फल फूल पत्रिका के “जैव विविधता” विशेषांक हेतु लेख आमंत्रित

इस विशेषांक के लिए जैव विविधता, संरक्षण, कृषि-परिस्थितिकी तथा संबंधित नवाचारों पर आधारित सफलता-गाथाएँ आमंत्रित हैं। प्रस्तुत लेख मौलिक, अप्रकाशित तथा किसी नवाचार, तकनीकी हस्तांतरण, संरक्षण प्रयास या अभिनव कृषि प्रयोग की सफलता पर आधारित होना चाहिए। लेख सरल, प्रवाहपूर्ण एवं सचित्र तैयार किया जाए।

खेती एवं फल फूल पोर्टल: epatrika.icar.org.in

लेखकों से अनुरोध है कि वे प्रस्तुति दिशानिर्देशों का सख्ती से पालन करें और लेख को संबंधित अंग्रेजी/हिंदी पत्रिकाओं के मचनइधचजतपां पोर्टल पर ही जमा करें।

लेख जमा करते समय कृपया यह स्पष्ट रूप से उल्लेख करें कि यह प्रस्तुति विशेषांक के लिए है।

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