Sustainable management of post-harvest pests and diseases in vegetables and legumes

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Introduction

Vegetables and fruit are high-value crops, and their production, processing, and marketing offer more employment and income opportunities because they are more labor-intensive than staple crops. For instance, studies from Cambodia, Niger, and Vietnam showed that profits per hectare were 3–14 times higher in vegetable production than in rice production, while profits per labor day were double (Joosten et al., 2015). It was also shown that vegetable production in six Asian countries used, on average, 297 labor days per hectare per season against 116 labor days for cereal production (Weinberger & Lumpkin, 2007). Hence, vegetable production, processing, and marketing might offer a profitable business opportunity for youth and women. Secondly, fruit and vegetables are an important component of the diet globally. Although the prevalence of hunger has declined globally in recent decades, 'hidden hunger' continues to be a critical issue impacting the health and nutritional status of a significant proportion of the world's population (Schreinemachers et al., 2018). A recent study estimated that over half of preschool-aged children and two-thirds of non-pregnant women of reproductive age worldwide have micronutrient deficiencies (Stevens et al., 2022). It is equally important to note that almost 2.1 billion people are overweight or obese (Ng et al., 2014). Fruit and vegetables are vital sources of micronutrients crucial for maintaining health. Vegetables with high potassium support healthy blood pressure, while dietary fiber lowers cholesterol and reduces heart disease risk. Folate minimizes birth defect risks, vitamin A maintains eye and skin health, and vitamin C promotes oral health and aids iron absorption (Schreinemachers et al., 2018). Recognizing these benefits, the World Health Organization (WHO) recommends a daily intake of 400 g of fruit and vegetables to prevent chronic diseases and ensure essential micronutrients (WHO/FAO, 2003).

Globally, 25-50% of fruit and vegetables are lost at the post-harvest stage, constituting approximately one-third of the world's total food production (Bancal & Ray, 2022). A recent study pinpointed eight key factors contributing to significant fruit and vegetable value chain losses. These factors include poor coordination between production, processing, and fresh markets, inadequate seasonal demand forecasting for non-producing regions, limited knowledge sharing about demand and supply, insufficient logistics in catchment areas, a lack of cold chain facilities, improper planting and sowing timing, resistance to diversifying crops, and a shortage of specialized vehicles (Anand & Barua, 2022). In addition, postharvest losses due to pests or diseases can manifest at any point in the postharvest handling process, spanning from the moment of harvest to the eventual consumption of the produce. For instance, fruit and vegetables are highly prone to substantial losses due to various plant pathogenic fungi, such as *Botrytis cinerea*, *Alternaria alternata*, *Penicillium italicum*, *P. digitatum*, *P. expansum*, *Monilia fructicola*, *M. laxa*, *Colletotrichum gloeosporioides*, *Rhizopus stolonifer*, *Botryiodiplodia theobromae*, and many others (Youssef et al., 2022). Therefore, it is crucial to implement technological interventions at post-harvest stages to mitigate pests and diseases, thereby minimizing both quantitative and qualitative losses in fruit and vegetables. The World Vegetable Center (WorldVeg) has developed and/or piloted technologies to reduce post-harvest losses in Asia and Africa.

Post-harvest innovations to reduce losses in vegetables

In developing countries, innovations such as cold chain technologies (including Zero Energy Cooling Chamber - ZECC, CoolBot™, evaporative cooler with felt nylon, and fan-assisted evaporative coolers), dry chain technologies (such as chimney solar dryers, tunnel dryers, cabinet dryer, and greenhouse solar dryer), enhanced packaging materials (such as plastic crates and edible coatings), and various post-harvest treatments have significantly contributed to mitigating post-harvest losses in fresh produce, specifically vegetables (Jarman et al., 2023).

Evaporative cooling technologies, exemplified by the Zero Energy Brick Cooler (ZEBC) and Evaporative Charcoal Cooler (ECC), demonstrated a significant reduction in weight loss and vitamin C decline in leafy amaranths in Kenya (Ambuko et al., 2017). These cost-effective solutions maintained higher relative humidity, lowered temperature, and preserved the quality of perishable fruit and vegetables in Africa (Ambuko et al., 2018). Another study from Tanzania highlighted the efficacy of ZECC in reducing weight loss in amaranth. The use of one to three ice packs per plastic crate was found to decrease weight loss in African nightshade, while insulated bags augmented the cooling effect, further reducing weight loss and preserving the green color in amaranth (Nenguwo et al., 2017).

Using commercially available polymeric films as modified atmosphere packaging (MAP) in Cambodia significantly reduced tomato weight loss, with fruit losing less than 2% of their initial weight every 3 days during storage. The incidence of fruit decay was low, affecting less than 10% of the samples (Acedo Jr. & Weinberger, 2009). MAP packaging using 25μ thick LDPE, HDPE, and polypropylene films in Laos inhibited fruit reddening in chillies (Vanndy et al., 2008a). Using a grid polystyrene crate with paper shreds as a cushion reduced mechanical damage to tomatoes in Laos (Acedo Jr. & Weinberger, 2009). Brick-walled evaporative coolers (EC) with moist sawdust as wall insulation significantly decreased weight loss in tomatoes in Cambodia. Additionally, a bicarbonate wash applied to the tomatoes reduced fruit decay (Vanndy et al., 2008b; Acedo Jr. et al., 2009a). In Laos, a similar brick-walled EC with moist sand as wall insulation effectively reduced weight loss in tomatoes (Vanndy et al., 2008b). Chili storage in brick-walled ECs reduced weight loss and shriveling in Cambodia and Laos, irrespective of variety and harvest maturity (Acedo Jr. et al., 2009b).

Hence, the subsequent section briefly overviews some impactful innovations, particularly those preventing diseases and pests in vegetables and legumes.

Anthracnose resistant peppers

Anthracnose fruit rot caused by *Colletotrichum* spp. poses a significant threat to peppers (*Capsicum* spp.) globally, affecting pre- and postharvest stages. Fruit infection by *Colletotrichum* spp. increases the vulnerability to other fungal pathogens, such as *Aspergillus flavus*, creating conditions conducive to aflatoxin production. Aflatoxin, known for its toxicity to humans, poses a serious risk. Contamination of dried chillies with aflatoxins has restricted their export to countries like UK and USA. Post-harvest losses attributed to aflatoxin contamination in chillies have been reported to range from about 20% to as high as 100% in samples obtained from Turkey (Demircioglu & Filazi, 2010) and Malaysia (Reddy et al., 2011). Alarmingly, red chili powder samples from Bangladesh have been reported to exhibit unsafe levels of aflatoxin contamination (>20 ng/g) since they exceeded the US maximum regulatory levels of 20 ng/g (Roy et al., 2013).

WorldVeg has undertaken extensive breeding efforts for anthracnose resistance in peppers, distributing numerous resistant lines across Asia and Africa. A comprehensive survey of the Center's Capsicum germplasm collection identified promising accessions in *Capsicum chinense* (e.g., PBC932) and *Capsicum baccatum* (PBC80 and PBC81). The resistance was successfully transferred into *Capsicum annuum* through interspecific hybridization and multiple backcrosses. Subsequently, WorldVeg bred at least five anthracnose-resistant lines, incorporating this valuable resistance factor, and made them available (Keatinge et al., 2008). Several more pepper lines with resistance or tolerance to anthracnose (AVPP9813, AVPP0514, and AVPP1110) were available recently. Thus, WorldVeg has successfully developed and distributed anthracnose-resistant pepper lines, mitigating post-harvest losses and addressing aflatoxin contamination concerns in chillies.

Soft rot management in vegetable brassicas

Bacterial soft rot, caused by various bacterial species, including *Erwinia*, *Pseudomonas*, and *Xanthomonas*, is a predominant disease affecting leafy vegetables, especially brassicas. In cabbages, this disease typically emerges at the cut portion (butt end) and on injured leaves, and it is characterized by the slimy breakdown of infected tissue accompanied by an unpleasant odor. In addition, cabbages are susceptible to other common decays, such as watery soft rot (*Sclerotinia*), gray mold rot (*Botrytis cinerea*), and Alternaria leaf spot (*Alternaria* spp.) (Cantwell & Suslow, 2006). To mitigate bacterial soft rot in vegetable brassicas, various pre- and post-harvest practices have been recommended. Specifically, the susceptibility of vegetable brassicas to bacterial soft rot can be reduced by avoiding nitrogen application through foliar methods and opting for soil application instead. In Cambodia, a practice involving leaving cabbage heads in the field for a brief period, with the cut butt end exposed to the sun, has been shown to effectively dry out the cut end, depriving soft rot pathogens of the necessary water for growth. However, careful consideration is required to address potential heat accumulation issues within the produce during this process. Anti-bacterial treatments effectively prevent bacterial soft rot in common cabbage and Chinese cabbage. Combining a saturated alum solution with lime paste was found to control soft rot in common cabbage (Bautista & Acedo Jr., 1987). However, it's crucial to apply alum only to the cabbage's butt end, as it can be phytotoxic, causing black spotting. An effective approach to biological control involves employing guava leaf extract, whose impact on common cabbage and Chinese cabbage paralleled that of alum treatment (Acedo Jr. et al., 1999; Acedo Jr. & Capuno, 2004). Cabbages treated with guava leaf extract exhibited resistance to bacterial soft rot. Hence, practices such as avoiding foliar nitrogen application, employing sun exposure, and utilizing anti-bacterial treatments like saturated alum with lime paste or guava leaf extract have proven effective in reducing susceptibility and controlling bacterial soft rot in vegetable brassicas.

Storage rot management in tomato

Key postharvest diseases affecting tomatoes include black mold caused by *Alternaria alternata*, Rhizopus soft rot induced by *Rhizopus stolonifer*, and gray mold triggered by *Botrytis cinerea.* While applying fungicides in the field before harvest can diminish storage-related diseases, adopting safer tomato production systems necessitates reducing or limiting fungicide use. Consequently, treating tomatoes before storage becomes crucial to mitigate postharvest rot. Pre-storage bicarbonate treatment has demonstrated a noteworthy reduction in decay, particularly in humid conditions within the evaporative cooler. The immersion of tomatoes in a 2% bicarbonate solution resulted in a storage rot reduction of 4% to 33% (Acedo Jr. et al., 2009a). Although Acedo Jr. et al. (2009a) did not observe consistent results with chlorine treatment, Nasrin et al. (2008) reported that tomatoes treated with chlorine, packed in perforated polyethylene bags, and stored under ambient conditions experienced a significant loss reduction, extending the shelf life to 17 days. Hence, further studies are required to validate the efficacy of chlorine treatment. In conclusion, pre-storage bicarbonate treatment has shown promising results in reducing postharvest rot in tomatoes, especially in humid conditions. While chlorine treatment's efficacy requires further validation, exploring alternative strategies is crucial for developing safer tomato production systems with reduced reliance on fungicides.

Low-cost storage to reduce post-harvest losses in onions

Fungi and bacteria (*Pseudomonas*, *Botrytis aclada*, *Aspergillus niger*, and *Erwinia* spp.) cause storage rots and molds in stored onions, causing a significant loss of approximately 35-40%. Consequently, farmers often rush to sell their onions immediately after harvest, receiving suboptimal prices. Adopting low-cost, fully-ventilated storage structures presents a potential solution for prolonged onion storage, reducing post-harvest losses and allowing farmers to command higher prices during off-season periods. A study in Ethiopia demonstrated the effectiveness of fully ventilated storage structures in minimizing sprouting, rotting, and mold incidence in onions stored for 90 days (Eriballo et al., 2022). Additionally, WorldVeg piloted and scaled out a low-cost, open-ventilated onion storage structure equipped with solar-powered exhaust fans in Odisha, India. This innovation facilitated the removal of excess heat and humidity and reduced storage diseases, enabling farmers to sell nearly 90% of their produce successfully even after 90 days of storage. In summary, combating storage rots and molds in onions through low-cost, fully-ventilated storage structures has shown significant promise, as evidenced by studies in Ethiopia and India. Implementing such storage solutions minimizes post-harvest losses and allows farmers to command higher prices during extended storage periods, offering a sustainable and economically beneficial approach.

Hermetic bags for on-farm storage of mungbean grains against bruchids

Hermetic storage technology, encompassing MAP and controlled atmosphere (CA) storage, actively or passively alters the atmosphere to reduce oxygen and/or elevate carbon dioxide concentrations (Sheikhi *et al.*, 2019). Despite its historical use, hermetic storage has recently regained importance as a crucial alternative for grain storage. Small hermetic bags with capacities of 50 and 100 kg, known as passive-MAP bags, have proven to be a cost-effective solution in preventing storage losses caused by insects for smallholder farmers across several African countries (Lane & Woloshuk, 2017). The Purdue Improved Crop Storage (PICS®) bags, utilizing passive-

MAP hermetic storage with two layers of relatively thick (80µm) polyethylene sheets placed inside a polypropylene bag, were originally developed to address losses due to storage insect infestations in cowpeas in Central and West Africa, proving highly effective. Subsequently, these bags effectively protected various grains, including maize, pigeon peas, common beans, and mungbeans in East Africa (Mutungi *et al.*, 2014; Momanyi *et al.*, 2022). At WorldVeg, we conducted tests on a hermetic storage bag known as the AgroZ Bag (A to Z Textile Mills Ltd., Arusha, Tanzania), which consists of two distinct layers: an outer layer made of polypropylene and an inner layer composed of a combination of HDPE, MLLDPE, and a low permeability barrier layer (90µm, multilayer polymeric bag, composed of one-liner already pre-inserted inside a polypropylene bag). This hermetic storage bag was evaluated against bruchids in mungbeans. It demonstrated an 88% reduction in bruchid damage compared to standard polypropylene bags (recording 100% grain damage) over a nine-month storage period. Thus, hermetic storage technology, particularly the use of small hermetic bags, has proven to be a cost-effective and highly efficient solution for preventing storage losses caused by insects, offering a valuable alternative for smallholder farmers across Africa and Asia.

Conclusions

This overview underscores the crucial role of postharvest management practices in addressing challenges within the agricultural sector, particularly concerning high-value crops like vegetables and fruit. The economic potential and the nutritional significance of vegetables emphasize the need for effective postharvest strategies to minimize losses and ensure nutritional security. The global prevalence of postharvest losses, estimated at 25-50% for fruit and vegetables, highlights the urgency in addressing key contributing factors, including poor coordination and inadequate infrastructure. Various technological interventions, from hermetic storage bags to evaporative cooling technologies, demonstrate diverse approaches to mitigate losses across different postharvest stages. Specific case studies, like the successful development and distribution of anthracnose-resistant pepper lines by WorldVeg, illustrate the tangible impact of research and breeding efforts on postharvest management. In summary, this article emphasizes the ongoing importance of advancing postharvest technologies and practices to secure food availability, reduce economic losses, and enhance the nutritional quality of high-value crops globally.

References

Acedo AL Jr., Acedo JZ, Evangelio MF. 1999. Biocontrol of cabbage soft rot using botanical extracts. Research Project Report, Postharvest Technology Laboratory, Department of Horticulture, Visayas State College of Agriculture, Baybay, Leyte, Philippines.

Acedo AL Jr., Capuno CF. 2004. Biophysical control of postharvest quality deterioration of Chinese cabbage (*Brassica oleraceae* var. *pekinensis*). Research Project Report, Postharvest Technology Laboratory, Department of Horticulture, Leyte State University, Baybay, Leyte, Philippines.

Acedo AL Jr., Vanndy M, Buntong B, Weinberger K. 2009a. Effects of chlorine and bicarbonate wash on fruit decay and shelf life of four tomato cultivars stored in simple evaporative coolers. Acta Hortic. 837: 217-222.

Acedo AL Jr., Vanndy M, Buntong B, Weinberger K. 2009b. Postharvest life of three chili (*Capsicum annuum* L.) cultivars as affected by fruit stalk removal and storage condition. Acta Hortic. 837: 171-176.

Acedo Jr. A, Weinberger K. 2009. Vegetable postharvest technology development and diffusion in the Greater Mekong sub-region of Asia. Acta Hortic. 837: 103-114.

Ambuko J, Wanjiru F, Chemining'wa GN, Owino WO, Mwachoni E. 2017. Preservation of postharvest quality of leafy amaranth (*Amaranthus* spp.) vegetables using evaporative cooling. Journal of Food Quality. 2017: 1-6.

Ambuko J, Wanjiru F, Karithi E, Hutchinson M. 2018. Cold chain management in horticultural crops value chains: Options for smallholder farmers in Africa. Acta Hortic. 1225: 85-92.

Anand S, Barua MK. 2022. Modeling the key factors leading to post-harvest loss and waste of fruits and vegetables in the agri-fresh produce supply chain. Computers and Electronics in Agriculture. 198: 106936.

Bancal V, Ray RC. 2022. Overview of food loss and waste in fruits and vegetables: From issue to resources," in *Fruits and vegetable wastes: Valorization to bioproducts and platform chemicals*. Ed. Ray RC. Springer Nature, Singapore, 3–29.

Bautista OK, Acedo AL Jr. 1987. Postharvest handling of fruits and vegetables. Manila: National Book Store Inc. Techguide Series No. 4. 24p.

Cantwell M, Suslow T. 2006. Cabbages (Round and Chinese types): Recommendations for maintaining postharvest quality. UC Davis Postharvest Technology Research Information Center.

Demircioglu S, Filazi A. 2010. Detection of aflatoxin levels in red pepper produced in Turkey. J. Veter. Med. Assoc. 81: 63–66.

Eriballo SG, Satheesh N, Fanta SW. 2022. Performance evaluation of low-cost storage structures for onions (*Allium cepa* L.) storage in Bahir Dar, Amhara Region, Ethiopia. Philippine Journal of Science. 151(1): 437-448.

Jarman A, Thompson J, McGuire E, Reid M, Rubsam S, Becker K, Mitcham E. 2023. Postharvest technologies for small-scale farmers in low- and middle-income countries: A call to action. Postharvest Biology and Technology. 206: 112491.

Joosten F, Dijkxhoorn Y, Sertse Y, Ruben R. 2015. How does the fruit and vegetable sector contribute to food and nutrition security? LEI Nota 2015–2076, June 2015. LEI Wageningen UR, Wageningen.

Keatinge JDH, Hughes J. d'A, Ebert A, Ledesma D, Luther K, de la Peña R, Javier E. 2008. Preserving the future of vegetable improvement. In: APEC-ATCWG Workshop on Capacity Building for Risk Management Systems on Genetic Resources. p. 21-34.

Momanyi MR, Nduko JM, Omwamba M. 2022. Effect of hermetic Purdue Improved Crop Storage (PICS) bag on chemical and anti-nutritional properties of common Bean (*Phaseolus vulgaris* L.) varieties during storage. Current Research in Food Science. 5: 107-116.

Mutungi CM, Affognon H, Njoroge AW, Baributsa D, Murdock LL. 2014. Storage of mung bean (*Vigna radiata* [L.] Wilczek) and pigeonpea grains (*Cajanus cajan* [L.] Millsp) in hermetic triple-layer bags stops losses caused by *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). Stored Prod. Res. 58: 39-47.

Nasrin TAA, Molla MM, Alamgir HM, Alam MS, Yasmin L. 2008. Effect of postharvest treatments on shelf life and quality of tomato. Bangladesh Journal of Agricultural Research. 33(3): 579-585.

Nenguwo N, Afari-Sefa V, Marealle R. 2017. Evaluation of low-cost cooling options for leafy vegetables grown by smallholder farmers in Tanzania. Acta Hortic. 1179: 189-196.

Ng M, Fleming T, Robinson M, Thomson B, Graetz N, Margono C, Mullany EC, Biryukov S, Abbafati C, Abera SF, Abraham JP, Abu-Rmeileh NME, Achoki T, AlBuhairan FS, Alemu ZA, Alfonso R, Ali MK, Ali R, Guzman NA, Ammar W, Gakidou E, et al. 2014. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. Lancet. 384: 766-781.

Reddy KRN, Raghavender CR, Salleh B, Reddy CS, Reddy BN. 2011. Potential of aflatoxin B1 production by *Aspergillus flavus* strains on commercially important food grains. Int. J. Food Sci. Tech. 161–165.

Roy M, Harris J, Afreen S, Deak E, Gade L, Balajee SA, Park B, Chiller T, Luby S. 2013. Aflatoxin contamination in food commodities in Bangladesh. Food Additives and Contaminants: Part B. 6(1): 17–23.

Schreinemachers P, Simmons EB, Wopereis MCS. 2018. Tapping the economic and nutritional power of vegetables. Global Food Security. 16: 36-45.

Sheikhi A, Mirdehghan SH, Karimi HR, Ferguson L. 2019. Effects of passive- and active-modified atmosphere packaging on physio-chemical and quality attributes of fresh in-hull pistachios (*Pistacia vera* L. Cv. Badami). Foods. 8(11): 564.

Stevens GA, Beal T, Mbuya MNN, Luo H, Neufeld LM. 2022. Micronutrient deficiencies among preschool-aged children and women of reproductive age worldwide: a pooled analysis of individual-level data from population-representative surveys. Lancet Glob Health. 10: e1590–99.

Vanndy M, Buntong B, Chanthasombath T, Sanatem K, Acedo AL Jr., Weinberger K. 2008b. Evaporative cooling storage of tomato in Cambodia and Laos. Acta Hortic. 804: 565-570.

Vanndy M, Chanthasombath T, Chu DT, Buntong B, Acedo AL Jr., Weinberger K. 2008a. Modified atmosphere packaging of fresh chili (*Capsicum annuum*) in the Greater Mekong Subregion. Acta Hortic. 804: 447-452.

Weinberger K, Lumpkin TA. 2007. Diversification into horticulture and poverty reduction: A research agenda. World Dev. 35: 1464-1480.

WHO/FAO, 2003. Diet, nutrition, and the prevention of chronic diseases. Report of a joint FAO/WHO Expert Consultation. WHO Technical Report Series 916, World Health Organization, Geneva.

Youssef K, Ippolito A, Roberto SR. 2022. Editorial: Post-harvest Diseases of Fruit and Vegetable: Methods and Mechanisms of Action. Front. Microbiol. 13: 900060.