International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; 8(7): 1013-1019
www.biochemjournal.com
Received: 03-04-2024
Accepted: 04-05-2024

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Effect of seed storage, and packaging in vegetables: A review

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DOI: https://doi.org/10.33545/26174693.2024.v8.i7m.1643

Abstract
Seed is one of the basic inputs to upsurge the market of any agricultural crop. Good storage conditions and packaging material are the foremost basic requirements to maintain the seed's quality, vigor, and viability. Seed deterioration declines the quality of seed material mostly when stored under unfavorable environmental conditions, due to which the annual losses in horticultural crops seed recorded up to more than 25 percent. Seed storage conditions, treatment, and packaging plays an important role in extending the shelf life of seeds by maintaining the quality attributes. Seed germination, viability, and vigor depend upon the kind of packaging material, storage, and storage duration. Several different kinds of packaging materials are used to enhance the seed quality such as air-tight glass containers, aluminum foil pouches aluminum laminated bags, cotton bags, tin containers, and super-rage bags could be used and performed with significant results for seed storage. This review paper has been reviewed to know the various effects of storage and packaging material on seed germination, viability, and vigor indexing particularly on vegetable crops namely tomato, brinjal, chili, leguminous crops, okra, onion, radish, and cucumber respectively.

Keywords: Vacuum packaging, super-rage bag, ultra-dry storage, seedling vigor index, longevity

Introduction
Seed is the basic input and the living entity that is influenced by various environmental stresses that directly affect the quality and in turn seed viability and seed vigour (Quais *et al.*, 2013) [43]. Moreover, on that, seed quality is one of the most important inputs that can increase the level of farm yield, while seed quality and viability reduced to a greater extent due to poor storage conditions (Bortey *et al.*, 2016) [8]. Seed packaging play major role to maintain the seed vigor and viability in particular storage condition for a longer period of time. The quality of seeds does not decline instantly, but it depends on the period. There are two major factors, which affects the quality of the seed and leads to the deterioration of the seed material i.e. moisture and high temperature. It directly reduces the emergence of seedlings, germination, and growth. Hence, it is vital to procure seeds in a suitable container, so it can help to enhance the seed longevity (Rao *et al.*, 2006; Harrington, 1972; Justice and Bass, 1978; Khajeh Hosseini *et al.*, 2003; Basra *et al.*, 2003) [46, 17, 22, 27, 4]. Seed deterioration can be explained in a better way, that it is loss of seed viability, quality, and vigor, which is affected by adverse environmental conditions. In agriculture deterioration is considered as undesirable attribute, due to which annual losses in horticultural crops reaches about 25% and leads to lower down productivity of any crop (Shelar *et al.*, 2008; Kapoor *et al.*, 2010) [49, 24]. Unfavorable conditions during the storage of seeds will lead to a decline in the storability period, while seed viability does not remain for more than one year under ambient conditions in unsealed container packing. On the other hand, proper drying accompanied by airtight containers reduces the problems associated with seed viability and vigor (Islam *et al.*, 2013) [20]. Important factors i.e. better environment and proper packaging material could help to maintain the storage life of seeds for a longer period (Lambat *et al.*, 2015; Mollahet *et al.*, 2016) [30, 37]. A new approach, called vacuum packaging has been developed that can extend the shelf life and maintain the quality of agricultural produce for a longer period as compared to traditional packaging by reducing the deterioration losses and maintaining moisture content to a safer limit.

Packaging plays a key role in the processing, and preservation of products and also extends the shelf life of seeds leading to the development of better-quality seeds (Meena *et al.,* 2017) [35]. Storage of seeds showed tremendous positive and significant effects on germination efficiency, and seedling vigor index without any deterioration losses in its biochemical constituents (Sultana *et al.*, 2016) [51].

Factor affecting seed quality in vegetable crops

The quality of seeds, moisture level, relative humidity (RH %), and storage conditions play a significant role in seed storage. During storage, seeds undergo a process called hydrolysis of sugars, which can lead to seed deterioration (Hassan *et al.,* 2024) [19]. On the other hand, if the seeds are stored carefully in regulated conditions, they can maintain their quality for a longer period of time. Various packaging materials found in the market exhibit variations in their permeability, ranging from permeable to semipermeable to impermeable. Each material offers a different level of protection against changes in air humidity as well as hygroscopicity (Kaur *et al.,* 2020) [44]. Seed vigor and viability might diminish due to degradation processes, which are both inevitable and irreversible. It results in an elevation in the concentration of free radicals and the elongation of their chain modifications to the protein structure, depletion of food stores, heightened acidity of fats, alterations in enzyme activity, membrane damage, and ultimately an acceleration in seed respiration. The germination capacity of seeds diminishes as catabolic processes occur throughout time (Wahba *et al.,* 2020) [55]. Various physiological and pharmacological mechanism occurs in seed, such as regenerating lipid molecules in cell membranes, to safeguard against cell deterioration during storage. Apart from this, there are several another factors that can also leads to seed deterioration such as moisture content and temperature of storage conditions. Higher moisture level accompanied with high temperature can cause seed damage in storage conditions. Moisture and elevated storage temperatures cause damage to seeds (Naik *et al.,* 2024) [38]. Improper gas composition, temperature, and humidity can lead to the deterioration of seed quality. This can occur due to processes such as respiration, mould growth, and enzyme activity. Proper temperature and humidity control are crucial for preserving the quality and strength of seeds (Bakhtavar *et al*., 2023) [3] Exposure to oxygen can result in oxidative stress, which can lead to the peroxidation of lipids and harm to cellular structures. Utilizing vacuuming or creating a low-oxygen environment is effective in prolonging the longevity of seeds (Hassan *et al*., 2024) [19]. Light exposure can accelerate the aging process and reduce the ability of seeds to germinate, as a result of chemical reactions triggered by light. Ensuring proper light exclusion during storage is crucial, as emphasised by Naik *et al.,* 2024 [38]. Inadequate storage conditions can promote the proliferation of pests and pathogens, resulting in the deterioration and loss of seeds. It is crucial to maintain proper sanitation and implement effective pest control measures (Bakhtavar *et al*., 2023) [3]. The selection of container material can have an impact on the quality of seeds. Using inappropriate materials can result in the release of harmful chemicals or inadequate moisture control. Proper moisture levels are crucial to prevent spoilage of jute seeds, as they are highly sensitive to drying out. Insufficient moisture can lead to loss of viability (Brar *et al*., 2020) [9]. Improper storage conditions can encourage the growth of microorganisms on grain, which can result in the spread of diseases and a decrease in quality (Patil *et al*., 2024) [42]. Certain seeds can be quite delicate when exposed to freezing temperatures, potentially causing harm to their cells through the formation of ice crystals. Proper freezing techniques are necessary for preserving items for an extended period (Ninganna *et al.,* 2018) [39]. To ensure the quality of crops, it is essential to use high-quality seeds.

Effect of Seed storage conditions, and packaging Material on seeds of vegetable crops

In addition to the natural aging, appropriate storage containers are essential for maintaining the quality of seeds. Various containers differ in their capacity to sustain appropriate storage conditions, such as temperature, humidity, and air movement are factors. Insufficient storage conditions may exacerbate seed degradation. During the storage process, the presence of storage pests and microflora may cause a decrease in the ability of seeds to survive and grow. Insects and fungi are particularly harmful, producing severe damage that leads to the deterioration of seeds and a reduction in storage capacity (Guru *et al.,* 2022) [16]. Seed degradation during storage entails intricate physiological and biochemical changes that diminish the germination capacity. Effective packing materials, such as containers that resist moisture, are essential for prolonging the storage life of seeds by avoiding the interchange of moisture with the surrounding air. By using appropriate storage containers and durations, one may successfully reduce seed degradation, therefore promoting favorable germination and strong seedling development (Kumar *et al.,* 2024) [29]. Airtight containers such as polythene bags and gunny bags that are lined with polyethylene, with or without a desiccant, are efficient choices for preserving seed quality over a period of time. Exploring the potential of medicinal species and their therapeutic properties during storage, the drying process of plant material, and the importance of proper packaging.

Dehydration process effectively prevents the growth of microorganisms and enzymatic reactions, minimizing the degradation of the active ingredients during storage. Additionally, it aids in concentrating the active compounds by removing water on a weight basis. When it comes to packaging, plays a crucial role in improving products, from the manufacturing process to the customer's experience (Kumar *et al.,* 2024) [29]. Proper packaging materials, storage conditions, and pretreatment play a crucial role in maintaining the quality of coriander during storage, as highlighted in previous research (Sharangi *et al.,* 2015) [48]. Medicinal plants are stored for extended periods before being utilized as raw materials for the production of different products (Masand *et al.,* 2014) [34]. Storage can lead to various changes, including physical, chemical, and microbiological alterations (Mahjabin *et al.,* 2015) [34]. Despite the growing demand and subsequent growth of the medicinal plant markets. Cucurbits have shown that storing fruits after harvest enhances seed maturation, leading to improved germination. The positive impacts of pre-sowing treatments that break seed dormancy on germination and establishment of crops have been documented in several plant species, including tomato, rapeseed, ash gourd, bitter gourd, and cabbage (Rahman *et al.,* 2014, Batool *et al.,*

2015) [31, 5]. Currently, there is less study available on seed dormancy in ash gourd. It is essential to discover a simple and efficient technique for breaking seed dormancy. The recent advances achieved in vegetable crops for storage conditions and packaging material has been mentioned in detail in Table 1.

Table 1: Effect of seed storage conditions, and packaging material on various vegetable crops

S. No.	Crops and Cultivars	Seed storage treatments & conditions and packaging material	Results	References
Solanaceous Vegetables				
1	Tomato	Seed treatment with Captan accompanied with vapour proof containers packaging	Increases the 70 percent germination after 30 months of storage	Chormule *et al.*, 2018 [10]
	Tomato cv. Pusa Ruby	- Seed coating with combination of polymer and fungicide, vitavax + polymer @ 6 ml/kg of seeds- Seed packaging in aluminium foil	▪ Improves the shelf life of seeds and increases the quality of seed in terms of germination percentage, germination speed, seedling length and weight and seedling vigour indices ▪ Effective for enhancing the seed longevity and maintaining the storability by reducing the deterioration losses.	Dheeraj *et al.*, 2018 [12]
	Tomato	Different packaging materials such as plastic bottles, glass bottles, paper envelope, earthen pot, polyethylene bag, galvanized iron tin using under ambient conditions	▪ Glass bottle was identified as the best packaging material in maintaining seed quality of tomato throughout the storage period. ▪ Tomato seeds could be stored up to between 120 and 180 days under ambient conditions	Kehinde *et al.*, 2022 [25]
	Tomato	Seed protein isolate (TSPI) + [Aluminum (Al) laminate, High Density Polyethylene (HDPE) and Low -Density Polyethylene (LDPE) pouch	Significantly increased moisture content, water activity, bulk density and turbidity, Total phenolic content and also increased flavonoid content.	Rana *et al.*, 2024 [45]
2	Brinjal cv. MPD-1	- Captan with 7% moisture content, 700 guage polythene bag and cloth bag -Treatment with Bavistin and Thirum solely or in combination with aluminum foil, polythene pouch	▪ Enhances the germination percentage about 80 to 82% after 21 months of storage ▪ Upgraded the seed vigor and germination percentage	Chormule *et al.*, 2018 [10]
	Eggplant	Polythene bags maintained acceptable seed germination (meeting IMSCS standards) for up to 15 months, while cloth bags maintained it for up to 12 months	Polythene bags are a better choice for preserving eggplant seed quality during storage, particularly for longer durations.	Bhuker *et al.*, 2023 [7]
3	Chilli	Vacuum packaging + stored at room temperature (25±2 °C)	▪ Enhances seed quality, mineral content, various physical parameters and biochemical constituents ▪ Least deterioration of seeds and maintain quality, vigour and viability	Deepa *et al.*, 2013 [11]
	Chilli	Treatment with olymer @ 7 ml + thiram @ 2g/kg of seeds and packed in aluminum foil pouch	▪ Maximize germination percentage, length of seedlings, dry weight of seedlings and seedling vigour index	Manoharapaladagu *et al.*, 2017 [33]
	Chilli	Seed treatment with captan + aluminum laminated bag packaging	▪ Higher germination percentage after thirty months of storage	Chormule *et al.*, 2018 [10]
	Chilli	Ultra-dry storage + desiccants zeolite beads	▪ Increases germination percentage, dehydrogenase activity, seedling vigour index and maintains less moisture content, electrical conductivity and minimum deterioration of seeds	Ninganna *et al.*, 2018 [39]
4	Okra	Plastic containers	▪ Improved germination percentage, seed vigor index, weight of dry seedlings	Sultana *et al.*, 2016 [51]
	Okra	Well covered plastic containers+ three storage environments (ambient, short-term chambers, long term chambers)	▪ Germination response to different varieties, storage conditions and duration also varies under seed storage conditions	Adam *et al.*, 2017 [1]
	Okra cv. P-8	Treatment with Polymer + Vilavax 200@ 2g/kg of seed and Polymer + Flowable thiram @ 2.4ml kg of seed	▪ Found superior for all seed quality parameters *viz.*, Germination percentage, seedling length (cm), seedling dry weight (g), seedling vigour index and electrical conductivity ▪ Upsurge storage conditions upto 12 months of storage	Parihar, 2018 [40]
	Okra	Sack bag, basket, perforated plastic can and wooden net cage as storage structures	▪ Results showed that Perforated sack bag and wooden net cage are preferred for retaining the quality of okra crop.	Stephen *et al.*, 2023 [50]
5.	**Pepper/Chilli/Capsicum**			
	Pepper	Perforated polyethylene, non-perforated polyethylene and aluminum-foil before storing in either Ambient Conditions (AC) of 21.9-33.5 °C	Aluminum-foil had significantly longer (30 days) shelf life than those packaged in perforated polyethylene (21 days) and nonperforated	Adewoyin *et al.*, 2017 [2]

		and 58-62% Relative Humidity (RH); Refrigerator (4.0 °C and 40-45% RH) or Evaporative Coolant Structure (ECS) (10.0-15.8 °C and 70-75% RH).	polyethylene (15 days), Storability of PF was best at 10% ripeness with pedicel	
	Sweet Pepper	packaging materials i.e. polyethylene bag, banana leaf, and jute bag and storage methods	Banana leaves and polythene bags encouraged the highest and lowest weight loss of pepper fruits in evaporative cooling system and ambient condition and Jute bags significantly reduced the percentage decay in refrigerator. ▪ Refrigerator and jute bag is the best storage method and packaging material as it minimizes loss and maintains quality.	Garuba *et al.*, 2022 [14]
	Red hot peppers	Jute sacks, Fertilizer Liner Sheet (FLS), Fertilizer Woven Polypropylene + Liner Sheet (FWPP + LS), and PICS bags (Purdue Improved Crop Storage)	▪ Significantly impacted the functional qualities parameters *viz*., total phenolic compounds, pungency index and oleoresin content.	Fikiru *et al.*, 2024 [13]
Bulb Crops				
6.	**Onion**			
	Onion	Vacuum packed in aluminum laminated bags at 5% moisture level	▪ Highest percentage of seed vigor and germination percentage ▪ Viability of seeds remained upto 20 months	Tripathi and Lawande, 2014 [53]
	Onion	Seed treatment + Packaging material + Storage condition	Cold storage gave more than 70 per cent germination even after two years of storage seed treated with thirum @ 3g/kg seed was the best result.	Patel *et al.*, 2017 [41]
	Onion cv. GWO-1	Cold storage + polythene bag packaging	▪ Decreases the chances of deterioration in seed germination and seedling vigor ▪ Stored upto two year	Patel *et al.*, 2017 [41]
	Onion	Plastic containers, polythene and aluminum foil bag + initial moisture level 5 - 7% (refrigerator and dehumidified conditions)	▪ Maximum germination percentage ▪ Minimum incidence of seed borne fungi	Khan *et al.*, 2018 [28]
	Onion	Aluminum pouch + 5% moisture level	Improvise the seed germination atleast for 16 month of storage period	Saisanthosh and Patil, 2018 [47]
	Onion	Packaging materials under two different storage conditions	recorded higher germination, rate of germination, seedling dry weight, vigour index, field emergence and moisture content, better seed quality over a period of six months of storage.	Manna *et al.*, 2020
	Onion	Seed priming treatments + ambient storage conditions	Enhanced seed germination, seedling length, seedling dry weight, seed vigour index-I & II and viability test electrical conductivity	Brar *et al.*, 2020 [9]
7	**Leguminous Crops**			
	Indian bean	Seed stored in aluminium foil and metal containers	Increased germination percentage of seeds and vigour index	Moharana *et al.*, 2017 [36]
8.	**Cowpea**			
	Cowpea	Treatment with powdered pepper, neem leaf powder + storage plastic containers, glass bottles	▪ Increasing germination percentage, vigour and viability ▪ Controlling cowpea weevil (*Callosobruchus maculatus*)	Kamara *et al.*, 2014 [23]
	Cowpea	Air tight glass containers or black polyethylene bags	▪ Enhance better germination percentage ▪ Maintain seed vigour for a longer period of time	Bortey *et al.*, 2016 [8]
	Cowpea	Aluminum foil bags	▪ Increase in germination percentage, speed of germination, vigour index ▪ Less insect infestation, moisture content and electrical conductivity upto 11 months of storage	Khadtar *et al.*, 2018 [26]
	Cowpea	Drying method and Woven and Aluminium foil	Packaging material significantly influenced microbial load, high moisture content and kraft paper resulted in the least bacterial and fungal contamination compared to those packaged in woven and aluminium foil, enhancing food security and food safety of cowpea leaves.	Wanjiku *et al.*, 2024 [56]
9	Cluster bean	Spinosad (0.04ml/kg+ stored in super- grain bag+ ambient conditions	Maintenance of better seed quality parameter *viz*. germination, root length, shoot length, vigour index, seedling dry weight with low electrical conductivity for a period of 18 months of storage	Umesha *et al.*, 2017 [54]
10	Field pea cv. BARI Motor-	plastic container, polybag, earthen pot	Recorded high moisture content, lowest electrical conductivity, maximum germination, vigor index,	Hasan *et al.*, 2023 [18].

	1, BARI Motor-3 and BADC Motor1		shoot length, root length and minimum incidence of seed borne fungi.	
Other Vegetable Crops				
11.	Radish	▪ Polythene bags Metal tin containers	▪ Maintaining and enhancing the quality of radish seeds ▪ For safer storage of radish seeds	Quais *et al.*, 2013 [43]
12.	Brocooli	Organic acids, GRAS chemical treatments and MAP	Enhance the shelf life of microgreens, better color quality and also maintaining the nutritional quality.	Patil *et al.*, 2024 [42]

Conclusion

Considering the present paper reviewed, it can be concluded that ambient storage conditions, storage duration, seed treatment, and better-quality packaging material are the most important key factors that enhance and upsurge the quality of vegetable seeds. These factors are also known to enhance the various seed quality parameters *viz.*, germination percentage, seed vigor index, seed viability, and vigor. To avoid the various losses mainly due to the deterioration of vegetable seeds, it needs additional attention and more research must be done in mounting proper storage conditions and develop better quality packaging material that directly leads to a tremendous increase in the quality seeds of vegetable crops.

Declarations

Ethics approval and consent to participate: Not applicable.

Consent for publication: All the co-authors agreed to publish the paper.

Competing interests: The authors declare no competing interests.

Disclosure statement: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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