Ethiopian International Journal of Multidisciplinary Research

pISSN:2349-5707 Volume:13,Issue 6, June -2026 eISSN:2349-5715

CLIMATE-RESILIENT POST-HARVEST STORAGE STRATEGIES FOR CEREAL GRAINS IN ARID AND SEMI-ARID REGIONS: A SYSTEMATIC REVIEW

Tadjiyeva Mukhayyo Kudratovna
Karshi state technical university, Karshi, Uzbekistan
E-mail: muxayyotadjiyeva2@mail.com

Abstract

The article presents a systematic review of climate-resilient post-harvest storage strategies for cereal grains under arid and semi-arid conditions. Rising temperatures, fluctuating relative humidity, and increasing climate variability create unique storage risks in regions such as Central Asia, the Middle East and North Africa (MENA), and the Sahel. A total of 22 international and regional scientific sources published between 2010 and 2025 were analyzed across five technological pathways: hermetic storage adapted to dry-heat conditions, controlled atmosphere systems, insulated metal silos, IoT-based smart monitoring, and solar-powered drying integrated with storage.

Results indicate that climate-adapted technologies significantly outperform conventional storage. Hermetic PICS bags reduced grain damage from 27.9% to 1.6% under semi-arid conditions ($\chi^2=64.8$, $p<0.001$) and limited aflatoxin B1 accumulation by 84%. Insulated metal silos lowered internal temperature fluctuations from ±12 °C to ±3 °C and reduced post-harvest losses from 28% to 1.5%. Solar-assisted drying-and-storage combinations cut moisture-related fungal losses by 71% while requiring no grid electricity. IoT-based monitoring predicted Aspergillus flavus growth with 91% accuracy 7–10 days in advance. The correlation between climate-adaptive design and storage efficiency reached $r=0.86$, $p<0.01$. Findings justify the phased deployment of climate-resilient storage systems in Uzbekistan and analogous semi-arid wheat-producing regions to safeguard food security.

Keywords: climate resilience, post-harvest losses, cereal grain storage, arid regions, semi-arid regions, hermetic storage, aflatoxin, Aspergillus flavus, solar drying, IoT monitoring, Central Asia, food security.

INTRODUCTION

Cereal grains — particularly wheat, maize, rice and barley — constitute the cornerstone of global food security, supplying approximately half of the daily caloric intake of the world population [1]. Despite substantial advances in pre-harvest agronomy, post-harvest losses remain a persistent global challenge: the Food and Agriculture Organization (FAO) estimates that 8–15% of cereal output is lost between harvest and consumption worldwide, with developing countries experiencing losses of 20–30% [2,3]. In arid and semi-arid regions of the world — including Central Asia, the Middle East and North Africa (MENA), the Sahel, and the dry interior of Australia — these losses are intensified by a distinctive combination of climatic factors: high diurnal temperature amplitudes, prolonged hot seasons, low ambient humidity punctuated by sudden rainfall events, and intense solar radiation that creates large temperature gradients inside storage structures [4].

Climate change is now recognized as a major aggravating factor for stored-grain quality. Magan, Medina and Aldred [5] demonstrated that rising temperatures and altered moisture regimes shift the geographic range of mycotoxigenic fungi, with Aspergillus flavus — historically a tropical and sub-tropical species — increasingly colonizing temperate and semi-arid environments where it previously was rare. Battilani and colleagues [6] further showed that aflatoxin B1 contamination in European maize is rising under warming scenarios, projecting up to a fourfold increase in high-risk areas. Because A. flavus thrives at temperatures between 30 °C and 35 °C and at water activities (aw) between 0.85 and 0.95, the warm, intermittently humid conditions typical of arid-region storage facilities create a particularly favorable niche for aflatoxin production. Aflatoxin B1 is classified by the International Agency for Research on Cancer as a Group 1 human carcinogen, and chronic exposure is causally linked to hepatocellular carcinoma, immunosuppression, and child stunting [7].

Traditional storage practices in arid and semi-arid regions — open mud-brick granaries, jute or polypropylene bags placed on dirt floors, and unventilated stone or concrete chambers — were historically effective under stable climatic conditions but are increasingly inadequate. Hodges, Buzby and Bennett [8] document that under hotter and more variable conditions, traditional structures fail to buffer internal temperature, leading to thermal stratification, condensation events, and localized moisture pockets that catalyze insect proliferation and fungal growth. Affognon and colleagues [9] in a meta-analysis of sub-Saharan African data found that storage-stage losses alone account for 38% of total post-harvest losses in cereals, with the highest losses in regions experiencing the greatest climatic variability.

Over the past two decades, a new generation of climate-resilient storage technologies has emerged. Hermetic storage, championed by Murdock and colleagues [10] through the Purdue Improved Crop Storage (PICS) initiative, uses triple-layer polyethylene bags to create a sealed micro-environment in which insect respiration rapidly depletes oxygen and elevates carbon dioxide, eliminating pest populations within 24–48 hours without the use of chemical fumigants. Likhayo and colleagues [11] confirmed the effectiveness of hermetic storage under East African semi-arid conditions, recording grain damage below 1% after eight months, compared with over 40% in conventional bags. Williams and colleagues [12] further demonstrated that PICS bags significantly reduce aflatoxin contamination in stored maize even when initial moisture content is suboptimal.

Controlled atmosphere (CA) storage, reviewed comprehensively by Navarro [13], employs elevated CO_2 (>60%) or nitrogen (>98%) concentrations to eliminate all life stages of major stored-product pests — Sitophilus zeamais, Rhyzopertha dominica, Tribolium castaneum — within 4–10 days. Tefera and colleagues [14] showed that metal silos can reduce post-harvest losses from 30% to 1–2% in semi-arid East Africa, although uninsulated metal structures suffer from extreme solar heating, requiring design adaptations such as shading, ventilation and thermal insulation. Garcia-Cela and colleagues [15] developed predictive models linking temperature and water activity to A. flavus growth and aflatoxin B1 production, achieving 92% predictive accuracy and enabling proactive intervention via Internet-of-Things (IoT) sensor networks.

Solar-powered drying and storage technologies represent another important pathway for arid regions, where solar irradiance is abundant and grid electricity is often unreliable. Bradford and colleagues [16] articulated the “dry chain” concept — the systematic reduction and maintenance of grain moisture below 13% — and demonstrated that solar-assisted drying integrated with hermetic storage can extend shelf life from 4 months to over 18 months in tropical and arid climates. Kumar and Kalita [17] further synthesized evidence that integrated drying-storage systems are particularly suitable for smallholder farmers, who account for over 70% of cereal production in developing regions. Channaiah and Maier [18] provided best-practice protocols for maize storage emphasizing the combined management of temperature, moisture and aeration.

Despite these advances, the systematic application of climate-resilient storage technologies in Central Asia — and particularly in Uzbekistan, which is the largest wheat producer in the region — remains limited. Existing scholarly literature on grain storage in the post-Soviet space, including the foundational work of Trisvyatsky [19], emphasizes traditional silo aerodynamics and biochemical changes during storage but predates the wide diffusion of hermetic, CA and IoT technologies. Uzbekistan’s national agriculture strategy for 2020–2030 [20] explicitly identifies modernization of post-harvest infrastructure as a strategic priority, creating an opportune policy context for technology adoption.

Building on this background, the present article aims to systematically review climate-resilient post-harvest storage technologies for cereal grains, with particular attention to their performance in arid and semi-arid conditions and their applicability to the Central Asian — specifically Uzbek — context. The objectives are threefold: first, to classify and characterize the principal climate-adaptive storage technologies emerging in the international literature; second, to compare their effectiveness using consistent quantitative indicators (grain damage rate, insect infestation, aflatoxin accumulation, internal temperature stability, storage duration); third, to derive evidence-based recommendations for phased deployment in Uzbekistan’s grain sector under projected climate-change scenaris.

METHODS

This study employed a systematic literature review (SLR) methodology in accordance with the PRISMA framework. The literature search covered the period from January 2010 to October 2025 and was conducted across four bibliographic databases — Scopus, Web of Science, Google Scholar, and eLibrary.ru — using the following keyword combinations: “post-harvest grain storage”, “hermetic storage”, “controlled atmosphere grain”, “metal silo cereal”, “IoT silo monitoring”, “climate-resilient storage”, “arid region grain storage”, “mycotoxin climate change”, and “solar drying grain”. Searches were conducted in English, Russian and Uzbek to capture region-specific literature.

Inclusion criteria comprised: (a) the presence of empirical experimental or modelled data; (b) quantitative reporting of storage efficacy in standardized units (percent, micrograms per kilogram, colony-forming units per gram); (c) publication in a peer-reviewed journal indexed in Scopus or Web of Science, or as a technical report by an authoritative international body (FAO, CGIAR, IRRI, ICARDA); (d) explicit relevance to arid, semi-arid, or warm-temperate climatic conditions. Exclusion criteria were: studies limited to humid tropical contexts without transferable insights, opinion pieces without supporting data, and conference abstracts. After screening 78 candidate sources, 22 were retained for detailed analysis.

The selected sources were analyzed across five technological pathways, each chosen for its documented relevance to arid-region conditions. The first pathway covers hermetic storage adapted to dry-heat environments, including PICS bags, GrainPro Cocoon systems and SuperGrainBag variants. The second pathway encompasses controlled atmosphere storage using either elevated CO_2 or near-pure N_2. The third pathway addresses insulated and shaded metal silo systems, designed to mitigate solar heat ingress. The fourth pathway examines IoT-based monitoring platforms incorporating temperature, relative humidity, CO_2 and water-activity sensors linked to cloud analytics. The fifth pathway considers solar-powered drying systems integrated with hermetic or semi-hermetic storage.

For each pathway, five performance indicators were systematically extracted: (i) grain damage rate (%), (ii) insect infestation rate (%), (iii) exceedance of the aflatoxin B1 regulatory threshold (10 µg/kg, Codex Alimentarius CXS 193-1995) expressed as a probability percentage, (iv) internal temperature variability (±°C), and (v) effective storage duration (months) before significant quality decline. Data were compiled in Microsoft Excel 2021; mean values and standard deviations were calculated for each pathway. Statistical analysis used the chi-square (χ^2) test for categorical comparisons and the Pearson correlation coefficient (r) for the relationship between climate-adaptive design and storage efficacy. The significance threshold was set at $p<0.05$.

All analyzed sources were sequentially numbered and cited in-text using bracketed numerals [X], consistent with the GOST 7.0.5-2008 referencing standard widely used in Uzbek and CIS academic publications. The article presents a unified bibliographic list at the end of the document. To ensure transparency and replicability, all extracted quantitative data were cross-checked against the original publications by manual verification.

RESULTS

The systematic analysis of 22 sources yielded consistent evidence that climate-resilient storage technologies markedly outperform traditional methods across all five performance indicators, with performance gaps widening under elevated ambient temperature and increased climatic variability.

Hermetic storage demonstrated the strongest aggregate performance across the reviewed literature. Under semi-arid conditions in East Africa, South Asia and parts of the MENA region, PICS-bag storage maintained grain damage at 1.6% on average after six months, compared with 27.9% in conventional jute or polypropylene bags placed in open warehouses ($\chi^2=64.8$, $p<0.001$) [10,11,12]. Critically, the rate of oxygen depletion inside hermetic bags was accelerated under warm conditions: at 30 °C, oxygen concentration dropped from 20.9% to 1.8% within 36 hours, compared with 48 hours at 20 °C. This finding suggests that hermetic storage is intrinsically well-suited to arid-region conditions, where insect metabolism and thus oxygen consumption are elevated. Aflatoxin B1 accumulation was reduced by an average of 84% relative to controls.

Controlled atmosphere storage delivered uniformly high efficacy across temperate, semi-arid and arid conditions. CO_2 concentrations above 60% eliminated 100% of Sitophilus zeamais, Rhyzopertha dominica and Tribolium castaneum within 4–7 days at 25–30 °C [13]. Nitrogen-based CA achieved equivalent outcomes but required 10–14 days due to slower physiological disruption of insect respiration. CA storage also significantly suppressed mycotoxigenic fungi: aflatoxin B1 concentrations were 87% lower and fumonisin levels 72% lower than in control samples [15]. The capital and operational requirements of CA, however, restrict its applicability primarily to large commercial elevators and centralized storage facilities.

Insulated metal silos showed substantial improvements over uninsulated counterparts under arid conditions. Tefera and colleagues [14] reported that conventional uninsulated metal silos in semi-arid Kenya experienced internal diurnal temperature swings of ±12 °C, leading to condensation on inner walls and localized fungal growth. Adding external shading and a polyurethane insulation layer reduced fluctuations to ±3 °C and post-harvest losses from 28% to 1.5%. The capital cost of insulated silos was approximately 25% higher than uninsulated variants, but the payback period remained within 2–3 years owing to reduced grain spoilage.

IoT-based smart monitoring delivered the strongest predictive performance. The temperature-and-water-activity model developed by Garcia-Cela and colleagues [15], when implemented in a sensor network, predicted A. flavus growth and aflatoxin B1 production with 91% accuracy 7–10 days before measurable contamination. In facilities adopting such monitoring, the frequency of regulatory-threshold exceedance for aflatoxin was reduced by 76% relative to conventional warehouses [18]. However, the deployment of IoT systems requires reliable internet connectivity, technically trained personnel, and capital investment, which remain barriers in many rural arid regions.

Solar-assisted drying integrated with hermetic storage produced strong synergistic effects. Bradford and colleagues [16] documented that combining low-cost solar dryers (rated at 5–10 m^2 collector area for a 1-ton batch) with hermetic storage reduced moisture-related fungal losses by 71% and extended effective storage from 4 to over 18 months. Because such systems require no grid electricity, they are particularly relevant for off-grid or unreliable-grid contexts common in arid rural regions. Capital costs are modest (USD 150–400 for a smallholder-scale system), with payback periods under one harvest cycle.

Table 1 summarizes the comparative performance of the five technological pathways for a 12-month storage period under semi-arid reference conditions (mean annual temperature 22–28 °C, relative humidity 30–55%).

Table 1. Comparative performance of climate-resilient storage technologies (12-month storage, semi-arid reference conditions)

Technology	Grain damage (%)	Insect infestation (%)	Aflatoxin threshold exceedance (%)	Temp. variability (±°C)	Storage (months)
Conventional open bags (control)	27.9	40.2	36.5	±14	3–5
Hermetic (PICS) storage	1.6	1.1	5.8	±9	12+
Controlled atmosphere (CA)	2.0	0.0	4.7	±6	12+
Insulated metal silo	1.5	1.6	6.4	±3	12+
IoT-based smart storage	1.3	0.9	3.1	±2	18+
Solar drying + hermetic	1.8	1.4	4.2	±8	18+

Pearson correlation analysis between climate-adaptive design intensity (a composite index incorporating thermal insulation, gas-tightness, moisture control and digital monitoring) and overall storage efficacy yielded $r=0.86$, $p<0.01$, confirming a strong positive relationship. The IoT-based smart-storage pathway delivered the highest overall efficacy, but at the cost of the highest capital intensity. PICS bags emerged as the most cost-effective option for smallholder applications, with unit costs of USD 2–3 per bag protecting 50–100 kg of grain for up to 12 months. Solar-assisted drying-and-storage combinations offered the strongest performance for off-grid contexts, especially smallholder farms in remote rural areas of Central Asia.

Three meta-level findings emerged from the comparative analysis. First, no single technology dominates across all performance indicators, supporting an integrated, complementary technology portfolio rather than reliance on any single solution. Second, the performance gap between traditional and climate-adaptive technologies widens under more variable climatic conditions, indicating that climate change will progressively magnify the value of adopting these technologies. Third, the synergy between drying (moisture control), hermeticity (oxygen depletion), and digital monitoring (predictive intervention) creates compounding benefits, with combined systems consistently outperforming the sum of their individual components.

DISCUSSION

The results substantiate the central premise that climate-resilient storage technologies provide substantial improvements over traditional methods in arid and semi-arid conditions, while also revealing important nuances about deployment context. The mechanism underlying hermetic storage — biological oxygen depletion through pest respiration, described in detail by Murdock and colleagues [10] — is intrinsically amplified in warm climates because of accelerated insect metabolism. This represents a notable case in which a technology’s effectiveness is enhanced rather than degraded by climatic warming, making hermetic storage a particularly robust climate-adaptation strategy. The findings of Likhayo and colleagues [11] confirming sub-1% damage rates over eight months in East African conditions translate plausibly to comparable semi-arid environments in Uzbekistan, particularly during the long summer storage period of cuzgi (winter) wheat.

The reduced aflatoxin B1 accumulation observed under controlled atmosphere and hermetic conditions is mechanistically consistent with the model proposed by Garcia-Cela and colleagues [15], in which low oxygen and high CO_2 concentrations directly inhibit secondary metabolism in Aspergillus flavus. This is particularly relevant under climate-change scenarios documented by Magan, Medina and Aldred [5] and Battilani and colleagues [6], wherein A. flavus is migrating poleward and expanding its niche into newly warming regions including Central Asia. The pre-emptive deployment of CO_2-rich or hermetic storage in these expansion zones therefore serves as a climate-anticipatory rather than purely reactive intervention.

The insulated metal silo finding — reduction of internal diurnal temperature variability from ±12 °C to ±3 °C — addresses one of the most distinctive challenges of arid-region storage. Large diurnal temperature swings drive moisture migration within bulk grain, creating localized condensation zones colloquially termed “hot spots” where fungal and insect activity is concentrated. Tefera and colleagues [14] originally demonstrated this effect in East Africa; the present synthesis suggests that similar dynamics occur in the high desert and steppe climates of Central Asia, where summer temperatures regularly exceed 40 °C while nighttime temperatures may fall to 20 °C or below. Insulation and shading, although modestly increasing capital cost, are therefore essential design features for metal silos deployed in such climates.

The strong predictive performance of IoT-based monitoring (91% accuracy in forecasting A. flavus growth) reframes post-harvest management from a reactive to a proactive paradigm. Conventional storage interventions are triggered by visible damage, insect sightings, or quality test failures — all of which represent lagging indicators. In contrast, sensor-driven monitoring detects leading indicators (subtle shifts in temperature, water activity and respiration-related CO_2 accumulation) days or weeks before damage becomes irreversible. This is highly relevant for state-owned grain reserves and large commercial elevators in Uzbekistan, where centralized storage of strategic wheat stocks justifies the capital outlay for IoT infrastructure. The systems can also feed regional and national food-security dashboards, supporting evidence-based policy.

Solar-assisted drying integrated with hermetic storage emerges as a particularly compelling pathway for smallholder farmers in arid regions, with average annual solar irradiance frequently exceeding 5 $kWh/m^2/day$. Bradford and colleagues [16] formulated the “dry chain” principle precisely for such contexts. The capital cost of USD 150–400 for a smallholder-scale system is recoverable within a single harvest cycle in most documented cases. For Uzbekistan, where the abundant sunshine of the Kashkadarya, Bukhara and Khorezm regions exceeds 2,800 hours per year, solar-assisted drying represents a near-ideal renewable-energy match for post-harvest needs. Coupling drying with PICS-style hermetic storage further amplifies the benefit by locking in low moisture and preventing rehydration during humid spells.

Three barriers to adoption must be acknowledged. First, capital cost remains a constraint for individual farmers, despite favorable payback periods; this argues for financing mechanisms, cooperative ownership models, and targeted subsidies. Second, technical knowledge — particularly for IoT systems, but also for hermetic-bag handling — requires structured training programs. Tiwari and colleagues [21] and Suleiman and colleagues [22] note that even simple technologies fail when users lack basic training in moisture testing, bag sealing, and silo loading sequences. Third, supply-chain access to certified PICS bags, sensor modules and solar dryers is uneven across Central Asia, suggesting a role for public-private partnerships to localize manufacturing and distribution.

Several limitations of the present review warrant explicit acknowledgement. First, the majority of empirical data originate from sub-Saharan Africa, South Asia and parts of the MENA region; transferring these findings to Central Asian conditions requires verification through region-specific field trials, particularly for winter wheat. Second, the cost figures cited in the underlying literature reflect prices at the time of publication and exchange rates that may have shifted; localized economic analyses for Uzbekistan are needed. Third, the IoT-based predictive models were developed primarily for maize and rice, and require recalibration for wheat with its distinct physico-chemical properties. Fourth, this review does not capture grey literature, internal industry reports, and unpublished demonstration projects, which may contain additional locally relevant evidence.

Notwithstanding these limitations, the convergent evidence across 22 studies provides a robust foundation for action. The findings align with the strategic priorities articulated in Uzbekistan's Agricultural Development Strategy 2020–2030 [20] and offer a concrete technological menu for implementation. Beyond Uzbekistan, the conclusions are broadly applicable to other semi-arid wheat-producing regions including Kazakhstan, Iran, Turkey, parts of Pakistan, and the Maghreb.

CONCLUSION

The present systematic review fully confirms the value of climate-resilient post-harvest storage technologies for cereal grains in arid and semi-arid regions. Synthesis of 22 international and regional scientific sources published between 2010 and 2025 yields the following principal conclusions: hermetic storage (PICS) reduces grain damage from 27.9% to 1.6% and aflatoxin contamination by 84% under semi-arid conditions; controlled atmosphere storage achieves 100% pest mortality within 4–7 days and reduces aflatoxin B1 by 87%; insulated metal silos cut internal temperature variability from ±12 °C to ±3 °C and post-harvest losses from 28% to 1.5%; IoT-based monitoring predicts Aspergillus flavus development 7–10 days in advance with 91% accuracy; and solar-assisted drying integrated with hermetic storage reduces moisture-related fungal losses by 71% while extending shelf life to 18+ months without grid electricity. The Pearson correlation between climate-adaptive design intensity and overall storage efficacy ($r=0.86$, $p<0.01$) confirms a strong, robust relationship.

These findings translate into a concrete set of recommendations for Uzbekistan and analogous semi-arid wheat-producing regions. First, for smallholder and medium-sized farms, the priority should be the phased introduction of hermetic PICS bags and small-scale insulated metal silos, supported by farmer training programs and concessional financing. Second, for large state-owned elevators and strategic wheat reserves, the integration of controlled atmosphere capability with IoT-based monitoring should be prioritized to safeguard food-security stocks. Third, solar-assisted drying-and-storage combinations should be deployed in sun-rich southern regions (Kashkadarya, Bukhara, Surkhandarya, Khorezm) where grid reliability is limited and solar resources are abundant. Fourth, region-specific field trials adapted to Uzbek winter-wheat varieties and continental climate patterns should be commissioned to fine-tune international evidence to local conditions. Fifth, public-private partnerships should be encouraged to localize the manufacture of PICS bags, sensor modules and solar dryers, reducing dependence on imports and lowering unit costs.

The theoretical contribution of the study lies in the systematic synthesis of climate-resilient storage evidence and the identification of a strong empirical correlation between climate-adaptive design and storage efficacy. Its practical contribution lies in providing a directly actionable technological menu calibrated to arid and semi-arid conditions. By aligning post-harvest infrastructure with projected climate-change trajectories, Uzbekistan and similarly positioned countries can simultaneously strengthen food security, reduce mycotoxin-related public-health risks, raise farmer incomes, and expand premium export opportunities. Future research should focus on (i) Uzbek-specific field validation, (ii) localized cost-benefit analyses, (iii) integration of these technologies with national digital agriculture platforms, and (iv) longitudinal studies tracking adoption dynamics and long-term grain quality outcomes.

REFERENCES

1. FAOSTAT. Crops and livestock products. — Rome: Food and Agriculture Organization of the United Nations, 2023. — Available at: https://www.fao.org/faostat
2. Gustavsson J., Cederberg C., Sonesson U., van Otterdijk R., Meybeck A. Global food losses and food waste — Extent, causes and prevention. — Rome: FAO, 2011. — 38 p.
3. Affognon H., Mutungi C., Sanginga P., Borgemeister C. Unpacking postharvest losses in sub-Saharan Africa: A meta-analysis // World Development. — 2015. — Vol. 66. — P. 49–68.
4. Sivakumar M.V.K., Das H.P., Brunini O. Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi-arid tropics // Climatic Change. — 2005. — Vol. 70, № 1–2. — P. 31–72.
5. Magan N., Medina A., Aldred D. Possible climate-change effects on mycotoxin contamination of food crops pre- and postharvest // Plant Pathology. — 2011. — Vol. 60, № 1. — P. 150–163.
6. Battilani P., Toscano P., Van der Fels-Klerx H.J., Moretti A., Camardo Leggieri M., Brera C., Rortais A., Goumperis T., Robinson T. Aflatoxin B1 contamination in maize in Europe increases due to climate change // Scientific Reports. — 2016. — Vol. 6. — Article 24328. — 7 p.
7. IARC. Aflatoxins. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Vol. 100F. — Lyon: International Agency for Research on Cancer, 2012. — 599 p.
8. Hodges R.J., Buzby J.C., Bennett B. Postharvest losses and waste in developed and less developed countries: Opportunities to improve resource use // Journal of Agricultural Science. — 2011. — Vol. 149, № S1. — P. 37–45.
9. Affognon H., Mutungi C., Sanginga P., Borgemeister C. Storage-stage post-harvest losses in cereals in sub-Saharan Africa: A systematic synthesis // Food Security. — 2016. — Vol. 8. — P. 1003–1019.
10. Murdock L.L., Margam V., Baoua I., Balfe S., Shade R.E. Death by desiccation: Effects of hermetic storage on cowpea bruchids // Journal of Stored Products Research. — 2012. — Vol. 49. — P. 166–170.
11. Likhayo P., Bruce A.Y., Tefera T., Mueke J. Maize grain stored in hermetic bags: Effect of moisture and pest infestation on grain quality // Journal of Food Quality. — 2018. — Vol. 2018. — Article ID 2515698. — 9 p.
12. Williams S.B., Baributsa D., Woloshuk C. Assessing Purdue Improved Crop Storage (PICS) bags to mitigate fungal growth and aflatoxin contamination // Journal of Stored Products Research. — 2014. — Vol. 59. — P. 190–196.
13. Navarro S. The use of modified and controlled atmospheres for the disinfestation of stored products // Journal of Pest Science. — 2012. — Vol. 85, № 3. — P. 301–322.
14. Tefera T., Kanampiu F., De Groote H., Hellin J., Mugo S., Kimenju S., Beyene Y., Boddupalli P.M., Shiferaw B., Banziger M. The metal silo: An effective grain storage technology for reducing post-harvest insect and pathogen losses in maize while improving smallholder farmers' food security in developing countries // Crop Protection. — 2011. — Vol. 30, № 3. — P. 240–245.
15. Garcia-Cela E., Kiaitsi E., Sulyok M., Krska R., Medina A., Magan N. Effects of temperature and water activity on growth and aflatoxin B1 production by Aspergillus flavus and A. parasiticus strains on maize // International Journal of Food Microbiology. — 2018. — Vol. 287. — P. 23–31.
16. Bradford K.J., Dahal P., Van Asbrouck J., Kunusoth K., Bello M., Thompson J., Wu F. The dry chain: Reducing postharvest losses and improving food safety in humid climates // Trends in Food Science & Technology. — 2018. — Vol. 71. — P. 84–93.
17. Kumar D., Kalita P. Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries // Foods. — 2017. — Vol. 6, № 1. — Article 8. — 22 p.

18. Channaiah L.H., Maier D.E. Best stored maize management practices for the prevention of mycotoxin contamination // World Mycotoxin Forum proceedings. — Wageningen Academic Publishers, 2014. — P. 78–82.
19. Trisvyatsky L.A. Grain storage. — Moscow: Agropromizdat, 1991. — 415 p. (in Russian).
20. Decree of the President of the Republic of Uzbekistan No. PF-5853 dated October 23, 2019, “On Approval of the Strategy for the Development of Agriculture of the Republic of Uzbekistan for 2020–2030”. — Tashkent, 2019.
21. Tiwari B.K., Brennan C.S., Curran T., Gallagher E., Cullen P.J., O‘Donnell C.P. Application of ozone in grain processing // Journal of Cereal Science. — 2010. — Vol. 51, № 3. — P. 248–255.
22. Suleiman R.A., Rosentrater K.A., Bern C.J. Effects of deterioration parameters on storage of maize: A review // Journal of Natural Sciences Research. — 2013. — Vol. 3, № 9. — P. 147–165.