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RESEARCH ARTICLE

Effect of biological treatments on the technological quality preservation of sugar beet under long-term storage conditions

Dmytro Kyselov[1*], Bohdan Ropotilov[2], Mykhailo Chonka[1], Nataliia Smetaniuk[2], Oleg Zahorodnii[2], Svitlana Kalenska[3]

[1]Private Enterprise "Zakhidnyi Buh", 39 Yunosti Avenue, Sheptytskyi District, Lviv Region, Ukraine
[2]Private Enterprise "Scientific and Industrial Association "Agrobionovatics", Nemyriv, Ukraine
[3]National University of Life and Environmental Sciences of Ukraine, Ministry of Education and Science of Ukraine, Kyiv, Ukraine

***Corresponding author:** Dmytro Kyselov, Private Enterprise "Zakhidnyi Buh", 39 Yunosti Avenue, Sheptytskyi District, Lviv Region, Ukraine, Email: dmytro.kyselov@zahbug.com.ua

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Abstract

The study evaluated the effect of biological preparations on preserving the technological quality of sugar beet roots of the hybrid Augusto during long-term storage under commercial clamp conditions. The experiment was conducted from 31 October 2025 to 15 January 2026 and included 11 treatment variants with biological consortia, commercial bioproducts, liming, and an untreated control. The treatment factor significantly affected weight loss, sucrose content, digestion parameters, and root rot incidence ($p<0.05$). Biological treatments reduced total weight loss by 1.1%-2.7% compared with the control. The highest efficiency was recorded for Consortium 6, which ensured the lowest weight loss (1.20%), the lowest root rot incidence (0.60%), the highest sucrose content (18.35%), and the lowest accumulation of dextran and levan. The results confirm that biological post-harvest treatment is a promising tool for stabilizing sugar beet quality and reducing storage losses under industrial clamp storage conditions.

Keywords: Sugar beet, Long-term storage, Biological preparations, Root rots, Sucrose content, Post-harvest treatment, Clamp storage, Technological quality

Introduction

Long-term storage of sugar beet is one of the most critical stages in the technological chain of sugar production, since it is during the post-harvest storage period that the greatest losses of root mass, sucrose, and technological quality of raw material occur. Under current conditions of climatic instability, rising temperatures during the autumn-winter period, and prolonged processing logistics cycles, the issue of stabilizing beet quality during clamp storage is becoming especially relevant. Post-harvest losses may reach 10%-25% of the potential sugar yield, due to root respiration, the development of storage rots, and the accumulation of undesirable technological impurities. In view of this, the search for environmentally safe methods to reduce losses and stabilize technological parameters is an important direction of modern research in sugar beet production.

The physiological basis of storage losses is the intensity of root respiration, which is directly correlated with temperature and the degree of mechanical tissue damage. Stevanato, et al. 2019 noted that even minor damage to the root surface stimulates microflora activation and increases the rate of sucrose degradation. Further studies have shown that the accumulation of reducing substances and the increase in α-amino nitrogen content during storage directly affect sugar yield and syrup quality during processing (Hoffmann, et al. 2009).

A substantial role in the formation of losses is played by storage rots caused by the development of a complex of pathogens, among which species of the genera *Fusarium*, *Botrytis*, and *Penicillium predominate*. The intensity of rot development during storage is determined not only by the infectious background of the field, but also by the microclimatic conditions within the clamp (Paul, 2022).

In recent years, interest has grown in the use of biological preparations for pre-harvest or post-harvest treatment of roots. Biological agents based on *Bacillus* spp., *Pseudomonas* spp., and *Trichoderma* spp. are capable of inhibiting pathogen development, stimulating induced systemic resistance, and reducing the intensity of respiration in plant tissues (Wolfgang, et al. 2023).

Despite the considerable number of studies on the use of biological preparations under field conditions, the question of their influence on the preservation of the technological quality of sugar beet during long-term storage remains insufficiently studied. Most works are focused on the control of individual pathogens or on yield assessment, whereas a comprehensive evaluation of the effect of biological preparations on weight loss, sucrose content, juice purity parameters, and rot development during storage is presented only fragmentarily (Lamichhane, et al. 2022). In addition, under climate change conditions, characterized by increased autumn temperatures, the relevance of biological technologies for clamp stabilization is increasing (Jaggard, et al. 2012).

Thus, the scientific problem lies in the need for a comprehensive assessment of the effect of biological preparations on the preservation of the technological quality of sugar beet during long-term storage, taking into account physiological, microbiological, and technological aspects.

The aim of the study is to determine the effect of biological preparations on the dynamics of changes in the technological parameters of sugar beet (sucrose content, dry matter, reducing substances, α-amino nitrogen, development of storage rots, and weight loss) during long-term storage and to determine their effectiveness as a tool for stabilizing raw material quality.

Materials and Methods

The study on the effectiveness of biological preparations in preserving the technological quality of sugar beet was conducted under the conditions of the production unit of "Zakhidnyi Buh" (Lviv region, 50°17' N, 24°14' E) during the period from 31 October 2025 to 15 January 2026.

The object of the study was sugar beet roots (*Beta vulgaris* L.), hybrid Augusto (Strube), grown in the farm's commercial fields according to the technology typical for the region. Harvesting was carried out at the stage of technological maturity. Before storage, the roots were sorted, and mechanically damaged, partially rotted, and physiologically weakened specimens were removed in order to standardize the initial phytosanitary condition of the treatments.

The experiment was arranged as a one-factor trial with 11 treatments, which included the application of different biological preparations and their combinations, as well as a physico-chemical protection treatment (liming) and an untreated control (Tab. 1).

Table 1. Experimental scheme for assessing the effect of biological preparations on the preservation of sugar beet hybrid Augusto during storage.

No.	Treatment	Species composition	Manufacturer	Storage period
1	Consortium 1	Bc5, Bc5.1, Bs7, Tr256	LBH	31.10.2025-15.01.2026
2	Consortium 2	Bm5a, Bc5.1, Bs7, Tr256	LBH	31.10.2025-15.01.2026
3	Consortium 3	Bm5a, Bc5, Bs7, Tr256	LBH	31.10.2025-15.01.2026
4	Consortium 4	Bm5a, Bc5, Bc5.1, Bs7, Tr256	LBH	31.10.2025-15.01.2026
5	Consortium 5	Bm5a, Bc5, Bc5.1, Bs7	LBH	31.10.2025-15.01.2026
6	Consortium 6	Bc5, Bc5.1, Bs7	LBH	31.10.2025-15.01.2026
7	Ecostern *Trichoderma*	*Trichoderma viride*	BTU	31.10.2025-15.01.2026
8	Sclerocyd	*Paraphaeosphaeria minitans, Trichoderma harzianum, Bacillus licheniformis, Bacillus subtilis*	BTU	31.10.2025-15.01.2026
9	Ecostern classic	*Trichoderma viride, Trichoderma harzianum, Bacillus subtilis, Bacillus licheniformis*	BTU	31.10.2025-15.01.2026
10	Liming with slaked lime	—	—	31.10.2025-15.01.2026
11	Control (untreated)	—	—	31.10.2025-15.01.2026

Note: Bm5a: *Bacillus megaterium*; Bc5, Bc5.1: *Bacillus cereus*; Bc7: *Bacillus subtilis*; Tr256: *Trichoderma* sp.; LBH: LifeBioChem, Ukraine; BTU: Biotech company

The roots were treated at a dose of 25 mL of preparation per 200 kg of roots. Liming was carried out by treating the mesh bags in which the roots were placed with slaked lime at a rate of 30 g per 200 kg of produce. The experimental period for all treatments lasted from 31.10.2025 to 15.01.2026.

At the end of the storage period, a comprehensive assessment of quantitative and qualitative characteristics of the roots was carried out, including total weight loss (%), incidence of root rots (% of infected roots), sucrose content (%), dry matter content (%), and the proportion of technological impurities (%). Weight loss was calculated as the relative reduction in the mass of each batch compared with the initial values recorded at the beginning of storage. Sucrose content was determined by the polarimetric method in accordance with International Commission for Uniform Methods of Sugar Analysis (ICUMSA) standards, ensuring high accuracy in the assessment of raw material technological quality. Dry matter content was determined by drying samples to constant weight. The incidence of root rots was assessed by selective phytopathological analysis followed by recalculation of the number of infected roots as a percentage of the total number of evaluated specimens.

The experiment was established in three replications. Data were processed using Analysis Of Variance (ANOVA). The significance of differences between treatments was determined by Duncan's test at $p<0.05$.

Results and Discussion

The storage results of sugar beet roots of the hybrid Augusto during the period from 31.10.2025 to 15.01.2026 demonstrated a significant effect of the biological treatment factor on weight preservation, technological characteristics, and the phytopathological condition of the produce (Tab. 2). According to the analysis of variance, the factor "treatment variant" was statistically significant ($p<0.05$) for total weight loss, sucrose content, water and alcoholic digestion, as well as the incidence of root infection by rot-causing pathogens. At the same time, the microclimatic storage conditions within the experiment remained uniform, as confirmed by the low between-replication variation in the control treatment and the absence of systematic deviations in humidity and temperature dynamics.

Table 2. Effect of treatment variants on weight loss, root rots, and technological parameters of sugar beet during storage.

Treatment	Weight loss, %	Root rots, %	Sucrose, %	Water digestion, %	Alcoholic digestion, %	Dextran, %	Levan, %	Juice pH
Consortium 1	2.05 ± 0.22 bc	1.40 ± 0.12 bc	18.05 ± 0.07 bc	18.70 ± 0.10 b	18.20 ± 0.11 b	1.10 ± 0.10 b	0.80 ± 0.08 b	6.84 ± 0.10 ab
Consortium 2	2.25 ± 0.25 bc	1.55 ± 0.13 b	18.00 ± 0.08 c	18.50 ± 0.12 b	17.90 ± 0.13 c	1.20 ± 0.12 b	0.95 ± 0.09 b	5.95 ± 0.12 c
Consortium 3	2.10 ± 0.24 bc	1.20 ± 0.11 c	18.15 ± 0.07 b	18.35 ± 0.10 bc	17.95 ± 0.11 c	1.05 ± 0.10 b	0.75 ± 0.08 b	6.12 ± 0.10 bc
Consortium 4	1.85 ± 0.20 c	1.10 ± 0.10 c	18.20 ± 0.07 b	18.30 ± 0.10 bc	18.10 ± 0.10 b	0.90 ± 0.09 c	0.55 ± 0.06 c	6.72 ± 0.09 ab
Consortium 5	2.45 ± 0.28 b	1.65 ± 0.14 b	17.95 ± 0.08 c	18.20 ± 0.12 c	17.80 ± 0.13 c	1.30 ± 0.12 b	0.95 ± 0.10 b	6.67 ± 0.10 ab
Consortium 6	1.20 ± 0.15 d	0.60 ± 0.08 d	18.35 ± 0.06 a	19.25 ± 0.11 a	18.90 ± 0.10 a	0.70 ± 0.07 d	0.45 ± 0.05 c	6.79 ± 0.08 a
Ecostern *Trichoderma*	1.95 ± 0.22 c	1.05 ± 0.11 c	18.25 ± 0.07 ab	18.55 ± 0.11 b	18.35 ± 0.12 ab	0.95 ± 0.10 c	0.50 ± 0.06 c	6.68 ± 0.10 ab
Sclerocyd	2.10 ± 0.26 bc	1.30 ± 0.12 bc	18.10 ± 0.08 bc	18.10 ± 0.13 c	18.00 ± 0.12 bc	1.00 ± 0.12 bc	0.60 ± 0.07 c	6.63 ± 0.11 ab
Ecostern Classic	2.30 ± 0.27 b	1.45 ± 0.13 bc	18.05 ± 0.08 bc	18.35 ± 0.12 bc	18.40 ± 0.11 ab	1.10 ± 0.10 b	0.65 ± 0.07 c	6.42 ± 0.11 bc
Liming	2.80 ± 0.30 a	2.05 ± 0.15 a	17.90 ± 0.09 c	18.20 ± 0.12 c	17.85 ± 0.14 c	1.60 ± 0.15 a	1.10 ± 0.12 a	6.78 ± 0.12 ab
Control	3.10 ± 0.33 a	2.30 ± 0.16 a	17.80 ± 0.10 c	18.10 ± 0.13 c	17.75 ± 0.14 c	1.70 ± 0.16 a	1.20 ± 0.13 a	6.76 ± 0.12 ab

Note: Letters a, b, c, and d within one column indicate statistically homogeneous groups according to multiple comparison of means (Duncan's test) after Analysis of Variance (ANOVA).

The highest weight losses were recorded in the control treatment, 3.10 ± 0.33%, which did not differ statistically from the "Liming" treatment (2.80 ± 0.30%, group a). Among the biologically active combinations, increased weight losses were also observed in Consortium 5 (2.45 ± 0.28%, group b) and Consortium 2 (2.25 ± 0.25%, group bc). Moderate losses were noted in Consortiums 1 (2.05 ± 0.22%), 3 (2.10 ± 0.24%), and 4 (1.85 ± 0.20%), as well as in Ecostern *Trichoderma* (1.95 ± 0.22%) and Sclerocyd (2.10 ± 0.26%), which formed statistically homogeneous groups b-c. The lowest level of weight loss was ensured by Consortium 6, 1.20 ± 0.15% (group d), which differed significantly from all other treatments. These results are consistent with the findings of Stevanato et al. (2019), who pointed out the determining role of biological agents in stabilizing clamp microflora and reducing the intensity of secondary rots during storage.

A similar trend was established for root rot incidence. In the control, this parameter amounted to 2.30 ± 0.16%, while in the "Liming" treatment it was 2.05 ± 0.15% (group a). Consortiums 2 (1.55 ± 0.13%) and 5 (1.65 ± 0.14%) formed group b, whereas Consortium 1 (1.40 ± 0.12%) and Ecostern classic (1.45 ± 0.13%) belonged to the intermediate group bc. Lower infection was observed in Consortium 3 (1.20 ± 0.11%), Consortium 4 (1.10 ± 0.10%), and Ecostern *Trichoderma* (1.05 ± 0.11%), which corresponded to group c. The minimum level of root rots was recorded in Consortium 6, 0.60 ± 0.08% (group d).

For sucrose content, the lowest values were obtained in the control (17.80 ± 0.10%) and in the "Liming" treatment (17.90 ± 0.09%), which together with Consortiums 2 and 5 formed group c. Consortium 1 (18.05 ± 0.07%), Sclerocyd (18.10 ± 0.08%), and Ecostern classic (18.05 ± 0.08%) belonged to group bc. Higher values were recorded in Consortium 3 (18.15 ± 0.07%) and Consortium 4 (18.20 ± 0.07%), group b. Ecostern *Trichoderma* ensured 18.25 ± 0.07% (group ab). The maximum sucrose content was found in Consortium 6, 18.35 ±

0.06% (group a). The maintenance of a higher sucrose level in the Consortium 6 treatment was accompanied by more favorable digestion values and reduced accumulation of reducing sugars, which may indicate a slowdown in the processes of cell structure destruction and microbial enzymatic activity.

The indicators of water and alcoholic digestion also varied depending on treatment. The lowest values of water digestion were characteristic of the control (18.10 ± 0.13%) and the "Liming" treatment (18.20 ± 0.12%), whereas the highest level was observed in Consortium 6, 19.25 ± 0.11%. For alcoholic digestion, Consortium 6 (18.90 ± 0.10%) significantly exceeded all other treatments, while the control (17.75 ± 0.14%) and Consortium 5 (17.80 ± 0.13%) had the minimum values. Analysis of dextran and levan content showed the greatest accumulation in the control (1.70 ± 0.16% and 1.20 ± 0.13%) and in the "Liming" treatment (1.60 ± 0.15% and 1.10 ± 0.12%), corresponding to group a. Among the biological treatments, elevated dextran values were observed in Consortium 5 (1.30 ± 0.12%) and Consortium 2 (1.20 ± 0.12%). Lower concentrations were found in Consortium 4 (0.90 ± 0.09%), Ecostern *Trichoderma* (0.95 ± 0.10%), and Sclerocyd (1.00 ± 0.12%). The lowest levels of dextran (0.70 ± 0.07%) and levan (0.45 ± 0.05%) were recorded in Consortium 6. The reduction in the synthesis of high-molecular-weight polysaccharides is of fundamental importance for sugar extraction processes, since dextran worsens juice filtration properties and increases processing losses (Olsen et al, 2023). Thus, biological treatment contributed not only to reducing weight loss but also to preserving the processing suitability of roots.

Phytopathological analysis confirmed that the most common pathogens were *Fusarium* spp. and *Rhizopus* spp., which corresponds to the structure of the storage rot pathocomplex in temperate climate regions. In the Consortium 6 treatment, the frequency of *Fusarium* spp. detection was 0.8 ± 0.2%, which was significantly lower than in the control (2.9 ± 0.4%). These findings are consistent with the results of Grunwald, et al. 2025, who reported that biological antagonists are capable of forming a competitive microbial environment in the storage zone and limiting pathogen development even under long exposure periods.

Overall, the results of the study confirm that the effectiveness of biological preparations in the post-harvest treatment system is determined by their ability to simultaneously influence the microbiological balance, reduce the intensity of respiratory losses, and stabilize the technological parameters of raw material. The advantage of Consortium 6 consisted in the combination of minimal weight loss, preservation of high sucrose content, and the lowest level of phytopathological infection. Thus, the obtained results confirm the expediency of integrating biological preparations into the long-term storage system of sugar beet as an element of increasing resource efficiency and stabilizing product quality under commercial clamp storage conditions.

Conclusion

The results of the study confirmed that the application of biological preparations at the time of placing sugar beet roots of the hybrid Augusto into long-term storage significantly affected weight preservation, technological parameters, and the phytopathological condition of the roots. Under homogeneous microclimatic storage conditions, a statistically significant effect of the treatment factor ($p<0.05$) was established for the level of weight loss, sucrose content, digestion parameters, and the incidence of storage rots. The biological preparations reduced total weight losses by 1.1%-2.7% compared with the control, which is of considerable production and economic importance under large-scale clamp storage.

The highest efficiency was demonstrated by the treatment Consortium 6, which was characterized by minimal weight loss (1.20 ± 0.15%), the lowest incidence of root infection (0.60 ± 0.08%), and stable preservation of sucrose content throughout the entire storage period. Compared with the control, this treatment showed a smaller decrease in sugar content and a lower level of accumulation of undesirable polysaccharides, which directly affects the technological suitability of the raw material for processing. The obtained data indicate the ability of biological compositions to form a more stable microbiological background within the clamp and to limit the development of the major causative agents of root rots.

In general, it was established that biological post-harvest treatment is an effective tool for reducing losses and stabilizing the technological quality of sugar beet during storage for up to 75 days. The practical value of the results lies in the possibility of integrating the most effective combination of biological preparations into the commercial clamp storage system in order to increase resource efficiency and minimize the risks of raw material quality degradation.

Further research should be directed toward evaluating the effect of biological preparations during longer storage periods (90-150 days), studying their interaction with different sugar beet hybrids, and modeling the economic efficiency of their application under industrial clamp storage conditions of different types.

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