IMPROVING POTATO TUBER STORABILITY AND QUALITY THROUGH OPTIMIZED TEMPERATURE, HUMIDITY, AND VENTILATION REGIMES

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Abstract. This study investigated the combined effects of temperature, relative humidity, and ventilation regimes on the storability and quality characteristics of potato tubers during long-term storage. Three potato cultivars, Sante, Arizona, and Evolution, were stored for six months under different combinations of temperature, relative humidity, and ventilation conditions. Natural weight loss, incidence of decay and sprouting, marketable yield, dry matter content, starch content, reducing sugars, and ascorbic acid were evaluated throughout the storage period.

The results demonstrated that appropriate regulation of storage temperature, relative humidity, and ventilation substantially reduced natural weight loss, sprouting, and decay while improving the marketable yield of potato tubers. The highest quantitative storability was achieved at 2–4 °C and 90–95% relative humidity with periodic ventilation adjusted according to the current temperature and humidity conditions of the storage environment. Under this regime, natural weight loss was limited to 3.8–4.2%, while marketable yield reached 90.5–91.6%. However, storage at 2–4 °C increased the reducing sugar content to 0.40–0.41%.

A comprehensive assessment of storability and biochemical quality showed that storage at 3–5 °C and 90–95% relative humidity with ventilation twice daily for 20 min provided a more balanced combination of reduced storage losses and preservation of biochemical quality. Among the cultivars studied, Sante demonstrated the highest storability. The findings indicate that long-term potato storage regimes should be differentiated according to cultivar characteristics and the intended end use of the tubers rather than relying on a single universal storage regime.

Keywords: potato, tuber, long-term storage, temperature, relative humidity, ventilation, natural weight loss, sprouting, marketable yield, starch, reducing sugars, storability.

Introduction. Potato (Solanum tuberosum L.) is one of the most important agricultural crops contributing to food security and human nutrition. Potato tubers are valuable sources of starch, proteins, minerals, vitamins, and other biologically active compounds that determine their nutritional and technological value. Since potato production is largely seasonal, maintaining a stable supply of high-quality tubers throughout the year requires effective long-term storage technologies.

Potato tubers remain physiologically active after harvest. Respiration, transpiration, degradation and transformation of organic compounds, termination of dormancy, and sprouting continue throughout the storage period. These physiological and biochemical processes gradually lead to quantitative and qualitative losses. When storage conditions are

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inadequately controlled, water loss increases, tubers lose turgidity, sprouting intensifies, and susceptibility to physiological disorders and microbial decay may increase.

Temperature is one of the key environmental factors determining potato storability. Lower storage temperatures generally reduce respiration intensity, suppress sprouting, and slow metabolic activity, thereby contributing to prolonged storage life. However, excessively low temperatures may alter carbohydrate metabolism by promoting the conversion of starch into soluble sugars. The resulting accumulation of reducing sugars can negatively affect the technological properties of potato tubers, particularly when the product is intended for high-temperature processing. Therefore, storage temperature should be selected with consideration of both cultivar characteristics and the intended use of the stored product.

Relative humidity is another major factor influencing storage performance. Low relative humidity increases water loss from the tubers, resulting in weight loss, shriveling, reduced firmness, and lower marketability. Maintaining sufficiently high relative humidity can minimize excessive moisture loss and preserve tuber turgidity. Nevertheless, excessively humid conditions, particularly when combined with inappropriate temperature management, may promote condensation on tuber surfaces and create favorable conditions for the development of storage diseases. Consequently, temperature and relative humidity should be managed in an integrated manner.

Ventilation is essential for regulating the microclimate within potato storage facilities. Appropriate air exchange removes excess heat and moisture generated by tuber respiration and contributes to a more uniform distribution of temperature and humidity throughout the stored product. At the same time, excessive or prolonged ventilation may accelerate moisture loss from tubers and increase natural weight loss. Ventilation should therefore be considered not simply as a means of air circulation but as a controllable technological component closely linked to temperature and relative humidity management.

Modern potato storage systems increasingly require integrated management strategies rather than the independent control of individual environmental parameters. Coordinated regulation of temperature, relative humidity, and ventilation can stabilize the physiological condition of stored tubers, reduce natural losses, suppress sprouting and decay, and increase the proportion of marketable product.

The effectiveness of a particular storage regime may also vary among potato cultivars because of differences in dormancy, skin characteristics, dry matter content, physiological maturity, and metabolic response to storage conditions. For this reason, comparative evaluation of storage regimes using different cultivars is important for developing differentiated recommendations for long-term potato storage.

In this context, optimizing the interaction between temperature, relative humidity, and ventilation represents an important approach to reducing postharvest losses while maintaining the nutritional and technological quality of potato tubers.

The objective of this study was to evaluate the effects of different temperature–humidity and ventilation regimes on natural weight loss, storability, marketable yield, and quality characteristics of potato tubers during long-term storage and to identify storage conditions that provide an appropriate balance between quantitative preservation and biochemical quality.

Materials and Methods. The study was conducted to evaluate the combined effects of temperature, relative humidity, and ventilation regimes on the long-term storability and quality of potato tubers. Three potato cultivars, **Sante, Arizona, and Evolution**, were selected as experimental materials.

The cultivars were selected considering their agronomic importance, tuber characteristics, and suitability for comparative evaluation of physiological responses during storage. Potatoes were harvested at physiological maturity and carefully sorted before storage. Tubers showing mechanical damage, disease symptoms, abnormal shape, or other visible defects were excluded from the experiment.

Uniform, marketable tubers with a diameter predominantly ranging from **45 to 80 mm** were selected. Before the main storage period, the tubers underwent a short curing period to promote wound healing and skin strengthening following harvest. After curing, the tubers were transferred to the respective experimental storage conditions.

Experimental Design

Four storage treatments were established to evaluate the combined influence of temperature, relative humidity, and ventilation on potato tuber storability.

Table 1. Experimental storage treatments applied to potato tubers

Treatment	Temperature, °C	Relative humidity, %	Ventilation regime	Treatment description
Control	6–8	80–85	Natural, uncontrolled ventilation	Conventional storage conditions
Treatment I	4–6	85–90	Once daily for 20 min	Moderate controlled regime
Treatment II	3–5	90–95	Twice daily for 20 min	Enhanced controlled regime
Treatment III	2–4	90–95	Periodic ventilation for 20–30 min according to temperature and humidity conditions	Optimized storage regime

The control treatment represented relatively warm storage conditions with lower relative humidity and uncontrolled natural ventilation. In Treatments I–III, storage temperature was progressively reduced, relative humidity was increased, and ventilation was increasingly regulated.

In Treatment III, ventilation was not operated according to a strictly predetermined daily schedule. Instead, it was activated according to the current temperature and humidity conditions within the storage environment. An increase in temperature or accumulation of excess moisture within the stored tuber mass was considered an indication for ventilation.

Storage Conditions. The storage experiment was conducted for **six months**. Tubers of each cultivar were divided into separate lots according to treatment. Each treatment was performed in **three replicates**, with **30 kg of tubers per replicate**. Thus, **90 kg of potato tubers per cultivar were used for each storage treatment**.

Air temperature and relative humidity in the storage chambers were monitored regularly using electronic measuring devices. The duration and frequency of ventilation were maintained according to the corresponding experimental treatment.

During the initial stage of storage, particular attention was given to stabilizing the physiological condition of the tubers. During subsequent storage stages, the management strategy was aimed at reducing respiration intensity, moisture loss, sprouting, and deterioration.

Assessment of Storability. Potato tuber storability was evaluated at **30-day intervals** throughout the six-month storage period. The main indicators included natural weight loss, incidence of decay, sprouting, and marketable yield.

Natural weight loss was calculated from the difference between the initial tuber mass and the mass recorded at each assessment period using the following equation:

$$\mathbf{NWL = (M_0 - M_1) / M_0 \times 100}$$

where:

NWL — natural weight loss, %;

$\mathbf{M_0}$ — initial mass of the stored product, kg;

$\mathbf{M_1}$ — mass of the product after a specified storage period, kg.

The proportion of **decayed tubers (%)** was determined as the mass of tubers rendered unmarketable by microbial or physiological deterioration relative to the total mass of the stored sample.

The proportion of **sprouted tubers (%)** was determined based on the number of tubers exhibiting sprouts of **2 mm or longer** relative to the total number of tubers examined.

Marketable yield (%) was calculated at the end of storage as the proportion of sound tubers that met market quality requirements and showed no unacceptable sprouting, mechanical injury, or microbial deterioration.

Biochemical and Quality Analyses

In addition to quantitative storage losses, changes in the biochemical composition and quality of the potato tubers were evaluated. The following parameters were determined at the beginning of storage and at the designated assessment periods: dry matter content, %; starch content, %; reducing sugar content, %; ascorbic acid content, mg/100 g; tuber firmness; external appearance and marketability.

Dry matter content was determined by drying samples to constant weight. Starch content was determined using standard laboratory procedures. Reducing sugar content was analyzed to assess changes in carbohydrate metabolism associated with low-temperature storage. Ascorbic acid was evaluated as an indicator of changes in the nutritional value of the tubers during storage.

Particular attention was given to reducing sugar accumulation because low storage temperatures may suppress respiration and sprouting while simultaneously promoting the conversion of starch into soluble sugars. Therefore, the assessment of storage effectiveness was based not only on quantitative preservation but also on changes in biochemical quality.

Statistical Analysis. Experimental data were subjected to statistical analysis. Mean values and standard deviations were calculated from three replicates for each measured parameter. Differences among storage treatments were evaluated by **analysis of variance (ANOVA)** and were considered statistically significant at **$p < 0.05$**.

The overall effectiveness of the storage treatments was evaluated using marketable yield, natural weight loss, decay incidence, sprouting, and preservation of the principal biochemical quality parameters as the main assessment criteria.

Results and Discussion. Effects of Storage Regimes on Natural Weight Loss and Marketable Yield. The results demonstrated that the storability of potato tubers was strongly influenced by the combined effects of temperature, relative humidity, and ventilation regime. Although natural weight loss, sprouting, and decay increased progressively in all treatments as storage duration increased, the magnitude of these changes varied considerably among storage treatments and cultivars.

After six months of storage, the highest natural weight loss was recorded in the control treatment. Depending on the cultivar, weight loss ranged from 8.4 to 9.1%. Arizona exhibited the highest natural weight loss (9.1%), whereas Sante showed the lowest value (8.4%) under control conditions.

Reducing the storage temperature to 4–6 °C, maintaining relative humidity at 85–90%, and applying ventilation once daily for 20 min (Treatment I) reduced natural weight loss to 6.1–6.7%. This corresponded to a reduction of approximately 2.3–2.4 percentage points compared with the control.

Further improvement was observed in Treatment II, where tubers were stored at 3–5 °C and 90–95% relative humidity with ventilation twice daily for 20 min. Under these conditions, natural weight loss decreased to 4.7% in Sante, 5.2% in Arizona, and 4.9% in Evolution.

The lowest natural weight loss was recorded in Treatment III. Storage at 2–4 °C and 90–95% relative humidity with periodic ventilation adjusted according to the current temperature and humidity conditions reduced natural weight loss to 3.8% in Sante, 4.2% in Arizona, and 4.0% in Evolution. Compared with the control, these values represented reductions of **54.8%, 53.8%, and 54.0%**, respectively.

Maintaining relative humidity at 90–95% substantially reduced moisture loss and helped preserve tuber turgidity. At the same time, regulated ventilation prevented excessive moisture accumulation within the tuber mass, thereby reducing conditions favorable for microbial deterioration.

Decay incidence followed a similar pattern. In the control treatment, the proportion of decayed tubers ranged from 4.3 to 4.8%. Treatment I reduced decay to 3.2–3.5%, whereas Treatment II further decreased it to 2.4–2.8%. The lowest decay incidence, ranging from only 2.0 to 2.3%, was recorded in Treatment III.

Table 2. Effects of different temperature–humidity and ventilation regimes on potato tuber storability after six months of storage

Cultivar	Treatment	Natural weight loss, %	Decayed tubers, %	Sprouted tubers, %	Marketable yield, %
Sante	Control	8.4	4.3	8.7	78.6
	Treatment I	6.1	3.2	5.6	85.1

	Treatment II	4.7	2.4	3.5	89.4
	Treatment III	**3.8**	**2.0**	**2.6**	**91.6**
Arizona	Control	9.1	4.8	9.5	76.6
	Treatment I	6.7	3.5	6.3	83.5
	Treatment II	5.2	2.8	4.1	87.9
	Treatment III	**4.2**	**2.3**	**3.0**	**90.5**
Evolution	Control	8.7	4.5	9.0	77.8
	Treatment I	6.4	3.3	5.9	84.4
	Treatment II	4.9	2.5	3.8	88.8
	Treatment III	**4.0**	**2.1**	**2.8**	**91.1**

These findings indicate that maintaining a lower and more stable temperature together with high relative humidity and controlled air exchange created more favorable storage conditions. In particular, the combination used in Treatment III reduced both excessive water loss and conditions associated with microbial deterioration.

Effects of Storage Conditions on Tuber Sprouting. Sprouting was another important physiological process contributing to deterioration in market quality during long-term storage. Under control conditions, sprouted tubers accounted for 8.7% of Sante, 9.5% of Arizona, and 9.0% of Evolution after six months.

A progressive reduction in sprouting was observed as storage temperature decreased and environmental control improved. In Treatment I, the proportion of sprouted tubers decreased to 5.6–6.3%, while Treatment II reduced this value further to 3.5–4.1%.

Treatment III provided the greatest suppression of sprouting. The proportion of sprouted tubers was only 2.6% in Sante, 3.0% in Arizona, and 2.8% in Evolution. Thus, compared with the control, the incidence of sprouting was reduced by approximately two-thirds under the most tightly controlled storage conditions.

The reduced sprouting observed at lower temperatures can be associated with slower physiological activity and delayed progression from dormancy to active sprout growth. However, the response was cultivar-dependent. Sante consistently exhibited lower sprouting and lower natural weight loss than Arizona, indicating relatively better storability under the conditions evaluated.

Marketable Yield. The combined reduction in natural weight loss, decay, and sprouting resulted in a substantial increase in marketable yield. Under control conditions, marketable yield after six months ranged from only 76.6 to 78.6%.

Treatment I increased marketable yield to 83.5–85.1%, while Treatment II provided 87.9–89.4%. The highest marketable yield was obtained in Treatment III, reaching **91.6% in Sante, 90.5% in Arizona, and 91.1% in Evolution**.

Among the cultivars studied, Sante showed the best overall quantitative storability. Under Treatment III, its natural weight loss was limited to 3.8%, decay to 2.0%, and sprouting to 2.6%, resulting in a marketable yield of 91.6%.

These results demonstrate that the quantitative preservation of potato tubers can be substantially improved by coordinated management of storage temperature, relative humidity, and ventilation. Importantly, however, marketable yield alone does not provide a complete assessment of storage performance because low-temperature storage may also induce biochemical changes that influence the subsequent technological quality of potato tubers.

Changes in Natural Weight Loss During Storage

Natural weight loss increased progressively throughout the six-month storage period. To characterize this process in greater detail, changes in the Sante cultivar were evaluated at 30-day intervals.

During the first 30 days, differences among treatments were relatively small. Natural weight loss ranged from 0.5% in Treatment III to 0.9% in the control. As storage continued, however, the differences became increasingly pronounced.

Table 3. Changes in natural weight loss of Sante potato tubers during storage, %

Storage duration	Control	Treatment I	Treatment II	Treatment III
30 days	0.9	0.7	0.6	**0.5**
60 days	1.8	1.4	1.1	**0.9**
90 days	3.0	2.2	1.7	**1.4**
120 days	4.6	3.3	2.5	**2.0**
150 days	6.3	4.6	3.5	**2.8**
180 days	8.4	6.1	4.7	**3.8**

In the control treatment, natural weight loss increased from 0.9% after 30 days to 3.0% after 90 days, 4.6% after 120 days, and ultimately 8.4% after 180 days. The rate of weight loss therefore became increasingly pronounced during the second half of the storage period.

In contrast, Treatment III maintained considerably lower weight loss throughout storage. Natural weight loss was 1.4% after 90 days, 2.0% after 120 days, 2.8% after 150 days, and only 3.8% at the end of the six-month storage period.

Treatment II also showed substantial improvement compared with the control, with final natural weight loss of 4.7%. Treatment I provided an intermediate response, reaching 6.1% after 180 days.

The increasing separation among treatments as storage progressed indicates that the benefits of controlled temperature, high relative humidity, and regulated ventilation became particularly evident during the later stages of long-term storage. Under uncontrolled conditions, cumulative moisture loss and physiological activity resulted in a progressively greater reduction in tuber mass.

Overall, these findings suggest that effective long-term storage cannot be achieved by temperature control alone. Relative humidity and ventilation must also be managed in coordination with the physiological condition of the stored tubers to minimize cumulative losses over extended storage periods.

Effects of Storage Regimes on Biochemical Quality. In addition to quantitative storage losses, preservation of the biochemical composition of potato tubers is an important criterion for evaluating the effectiveness of long-term storage. Therefore, changes in dry matter,

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starch, reducing sugars, and ascorbic acid were assessed at the beginning and at the end of the six-month storage period.

Table 4. Effects of different storage regimes on the biochemical characteristics of potato tubers after six months of storage

Cultivar and treatment	Dry matter, %	Starch, %	Reducing sugars, %	Ascorbic acid, mg/100 g
Sante				
Initial	21.6	15.8	0.24	18.7
Control	19.4	13.9	0.31	12.8
Treatment I	20.0	14.5	0.29	14.1
Treatment II	20.5	14.9	0.33	15.0
Treatment III	**20.8**	**15.1**	**0.41**	**15.6**
Arizona				
Initial	20.9	15.1	0.22	17.9
Control	18.7	13.2	0.30	12.0
Treatment I	19.3	13.8	0.28	13.3
Treatment II	19.8	14.2	0.32	14.2
Treatment III	**20.1**	**14.4**	**0.40**	**14.8**
Evolution				
Initial	21.3	15.5	0.23	18.3
Control	19.1	13.6	0.30	12.4
Treatment I	19.7	14.2	0.28	13.7
Treatment II	20.2	14.6	0.32	14.6
Treatment III	**20.5**	**14.8**	**0.40**	**15.2**

The results showed that dry matter and starch contents decreased to varying degrees in all treatments during storage. However, the magnitude of these changes was strongly influenced by the storage regime. The greatest reductions were generally observed under control conditions, whereas Treatments II and III provided better preservation of dry matter and starch.

In Sante, for example, the initial dry matter content was 21.6%. After six months, it decreased to 19.4% in the control, whereas 20.5 and 20.8% were retained in Treatments II and III, respectively. Similarly, the initial starch content of 15.8% declined to 13.9% in the control but remained at 14.9% in Treatment II and 15.1% in Treatment III.

A comparable trend was observed in Arizona and Evolution, indicating that improved regulation of the storage environment reduced the depletion of major dry matter components during long-term storage.

Dry Matter and Starch Retention. The reduction in dry matter during storage can be associated with continued respiration and metabolic utilization of stored organic compounds. Under control conditions, dry matter declined by 2.2 percentage points in Sante, 2.2 percentage points in Arizona, and 2.2 percentage points in Evolution.

Treatment III showed the smallest reduction in dry matter. After six months, dry matter remained at 20.8% in Sante, 20.1% in Arizona, and 20.5% in Evolution. Thus, the reduction from the initial level was limited to 0.8 percentage points in all three cultivars.

Starch followed a similar pattern. In Sante, starch decreased from 15.8% initially to 13.9% under control conditions, corresponding to a reduction of 1.9 percentage points. In Treatment III, starch remained at 15.1%, representing a decrease of only 0.7 percentage points.

For Arizona, the initial starch content of 15.1% decreased to 13.2% in the control, compared with 14.4% in Treatment III. In Evolution, starch declined from 15.5% to 13.6% in the control but remained at 14.8% under Treatment III.

These results indicate that lower temperature combined with high relative humidity and controlled ventilation reduced the overall depletion of dry matter and starch during storage. This may be associated with suppression of respiration and other metabolic processes responsible for the consumption of reserve carbohydrates.

Changes in Ascorbic Acid Content

Ascorbic acid content decreased in all cultivars and treatments during the six-month storage period. Nevertheless, the rate of decline differed substantially among storage regimes.

In Sante, the initial ascorbic acid content was 18.7 mg/100 g. After six months, only 12.8 mg/100 g remained in the control, corresponding to approximately **68.4% retention**. Treatment I retained 14.1 mg/100 g, Treatment II 15.0 mg/100 g, and Treatment III 15.6 mg/100 g. Thus, approximately **83.4% of the initial ascorbic acid content** was retained in Treatment III.

A similar response was observed in Arizona. The initial value of 17.9 mg/100 g decreased to 12.0 mg/100 g in the control, whereas Treatment III retained 14.8 mg/100 g. In Evolution, ascorbic acid declined from 18.3 mg/100 g initially to 12.4 mg/100 g in the control and 15.2 mg/100 g in Treatment III.

The higher retention of ascorbic acid under Treatments II and III indicates that improved control of storage conditions slowed the deterioration of nutritional quality. Lower temperatures likely contributed to reducing the rate of oxidative and metabolic reactions associated with ascorbic acid degradation.

Accumulation of Reducing Sugars. Unlike dry matter, starch, and ascorbic acid, reducing sugars exhibited a different response to storage temperature. This parameter revealed an important trade-off between maximum quantitative storability and preservation of technological quality.

At the beginning of storage, reducing sugar contents were 0.24% in Sante, 0.22% in Arizona, and 0.23% in Evolution. After six months under control conditions, the corresponding values increased to 0.31, 0.30, and 0.30%.

Treatment I maintained reducing sugar concentrations at relatively low levels of 0.28–0.29%. In Treatment II, the values ranged from 0.32 to 0.33%. However, the greatest accumulation occurred in Treatment III, where reducing sugars increased to **0.41% in Sante and 0.40% in both Arizona and Evolution**.

This response indicates that although storage at 2–4 °C effectively suppressed respiration, sprouting, and natural weight loss, it also promoted changes in carbohydrate metabolism associated with the conversion of starch into soluble sugars. Consequently, the storage regime that maximized marketable yield did not necessarily provide the most favorable biochemical profile for all end uses.

The increase in reducing sugars is particularly relevant for potatoes intended for high-temperature processing. Elevated concentrations of reducing sugars may affect product color and other technological quality attributes during frying or similar thermal processing. Therefore, the intended use of stored potatoes should be considered when selecting storage conditions.

Balancing Storability and Biochemical Quality. The results revealed a clear distinction between the storage regime that maximized quantitative preservation and the regime that provided a more balanced combination of storability and biochemical quality.

Treatment III, consisting of storage at 2–4 °C, 90–95% relative humidity, and periodic ventilation according to the temperature and humidity conditions of the storage environment, produced the lowest natural weight loss and the highest marketable yield. Natural weight loss was limited to 3.8–4.2%, while marketable yield reached 90.5–91.6%.

However, the increase in reducing sugars to 0.40–0.41% under this treatment represents a potential technological disadvantage when potatoes are intended for processing.

Treatment II provided a different balance. At 3–5 °C and 90–95% relative humidity with ventilation twice daily for 20 min, natural weight loss remained relatively low at 4.7–5.2%, while marketable yield ranged from 87.9 to 89.4%. At the same time, reducing sugar content was maintained at 0.32–0.33%, substantially below the values observed in Treatment III.

Therefore, **Treatment III can be considered the most effective regime for maximizing quantitative storability**, whereas **Treatment II provided a more balanced combination of storability and biochemical quality**.

This distinction is important from a practical perspective. For potatoes intended primarily for fresh consumption, where minimizing weight loss, sprouting, decay, and loss of marketable product is the principal objective, the lower-temperature regime may offer greater advantages. In contrast, when stored tubers are intended for processing and excessive accumulation of reducing sugars is undesirable, the moderately higher temperature used in Treatment II may be more appropriate.

Overall, the findings demonstrate that no single storage temperature should be considered universally optimal for all potato cultivars and end uses. Long-term storage strategies should instead be differentiated according to cultivar characteristics, expected storage duration, quantitative losses, biochemical changes, and the intended use of the stored tubers.

Technological and Economic Efficiency of the Storage Regimes. In addition to physiological and biochemical indicators, the practical efficiency of long-term potato storage should be evaluated in terms of the amount of marketable product retained at the end of the storage period. From a commercial perspective, reducing storage losses is particularly important because even relatively small improvements in marketable yield can result in substantial additional product recovery when large quantities of potatoes are stored.

The experimental results demonstrated that regulation of temperature, relative humidity, and ventilation increased the quantity of marketable tubers in all three cultivars. The greatest improvements were observed in Treatments II and III.

Under control conditions, only 766–786 kg of marketable potatoes were retained from each initial tonne of stored tubers after six months. Treatment I increased this value to 835–851 kg/t, while Treatment II resulted in 879–894 kg/t of marketable product. The highest quantitative recovery was obtained in Treatment III, where 905–916 kg of marketable potatoes were retained per tonne initially placed in storage.

Table 5. Technological efficiency of different storage regimes per tonne of potato tubers

Cultivar	Treatment	Marketable yield, %	Marketable product from 1 tonne, kg	Additional marketable product compared with control, kg/t
Sante	Control	78.6	786	–
	Treatment I	85.1	851	65
	Treatment II	89.4	894	108
	Treatment III	**91.6**	**916**	**130**
Arizona	Control	76.6	766	–
	Treatment I	83.5	835	69
	Treatment II	87.9	879	113
	Treatment III	**90.5**	**905**	**139**
Evolution	Control	77.8	778	–
	Treatment I	84.4	844	66
	Treatment II	88.8	888	110
	Treatment III	**91.1**	**911**	**133**

For Sante, Treatment III resulted in 916 kg of marketable tubers per tonne initially placed in storage, corresponding to an additional **130 kg/t** compared with the control. In Arizona, the amount of additional marketable product reached **139 kg/t**, while in Evolution it was **133 kg/t**.

Treatment II also demonstrated high technological efficiency. Compared with the control, this regime retained an additional 108 kg/t of marketable Sante tubers, 113 kg/t of Arizona, and 110 kg/t of Evolution.

Thus, Treatment III was the most effective regime in terms of minimizing quantitative storage losses and maximizing the amount of marketable product recovered after six months. Nevertheless, when the biochemical characteristics of the stored tubers are considered together with quantitative preservation, Treatment II provides an important alternative because it combines relatively high marketable yield with lower accumulation of reducing sugars.

The technological advantage of Treatment III can also be expressed at a larger storage scale. Based on the experimental marketable yield values, every **100 tonnes** of potatoes initially placed in storage would theoretically result in approximately **13.0 tonnes of additional marketable Sante, 13.9 tonnes of Arizona, and 13.3 tonnes of Evolution** compared with the control regime. These values illustrate the potential production-scale significance of reducing storage losses through improved microclimate management.

However, technological efficiency should not be considered equivalent to net economic profitability. A complete economic assessment requires additional information on electricity consumption for cooling and ventilation, equipment depreciation, labor requirements, storage infrastructure, maintenance costs, and the market value of potatoes at the time of sale. Since these parameters may vary substantially according to storage facility, region, season, and market conditions, monetary profitability was not calculated in the present study.

Accordingly, the amount of additional marketable product retained per tonne was used as the principal indicator of technological efficiency. This approach enables the practical benefits of the storage treatments to be compared without introducing assumptions related to variable market prices and operating costs.

Integrated Evaluation of Storage Regimes

The overall results indicate that temperature, relative humidity, and ventilation should not be managed as independent storage parameters. Their combined regulation determines moisture loss, respiration intensity, sprouting, decay development, preservation of biochemical constituents, and ultimately the marketable yield of stored potato tubers.

Under the control regime of 6–8 °C, 80–85% relative humidity, and uncontrolled natural ventilation, natural weight loss reached 8.4–9.1%, while sprouting increased to 8.7–9.5%. Consequently, marketable yield declined to 76.6–78.6% after six months of storage.

Treatment I, involving storage at 4–6 °C and 85–90% relative humidity with ventilation once daily for 20 min, substantially improved tuber storability. However, further improvements were obtained when relative humidity was increased to 90–95% and ventilation was more closely regulated.

Treatment III provided the strongest quantitative preservation. Storage at 2–4 °C and 90–95% relative humidity with periodic ventilation adjusted according to storage conditions reduced natural weight loss to 3.8–4.2% and increased marketable yield to 90.5–91.6%. Compared with the control, natural weight loss was reduced by 53.8–54.8%.

Nevertheless, the biochemical results demonstrated an important limitation of the lowest-temperature regime. Reducing sugar content increased to 0.40–0.41% in Treatment III, indicating that maximum quantitative preservation does not necessarily correspond to optimal technological quality for every intended use.

In Treatment II, storage at 3–5 °C and 90–95% relative humidity with ventilation twice daily for 20 min resulted in natural weight loss of 4.7–5.2% and marketable yield of 87.9–89.4%. Reducing sugar content remained at 0.32–0.33%, lower than in Treatment III.

These findings support a differentiated approach to potato storage management. When the principal objective is to maximize marketable yield and minimize natural weight loss, sprouting, and decay, Treatment III provides the most favorable conditions among the regimes investigated. In contrast, where preservation of processing quality and limitation of reducing sugar accumulation are important, Treatment II represents a more balanced storage strategy.

Therefore, optimization of long-term potato storage should not be based on a single universal temperature threshold. Storage conditions should be selected according to cultivar characteristics, storage duration, physiological condition of the tubers, and the intended use of the final product.

Conclusion. The results of this study demonstrated that the long-term storability and quality of potato tubers are strongly influenced by the combined management of storage temperature, relative humidity, and ventilation. Coordinated regulation of these factors substantially reduced natural weight loss, sprouting, and decay and increased the proportion of marketable tubers after six months of storage.

Under the control conditions of 6–8 °C, 80–85% relative humidity, and uncontrolled natural ventilation, natural weight loss reached 8.4–9.1%, while the proportion of sprouted tubers ranged from 8.7 to 9.5%. Consequently, marketable yield decreased to 76.6–78.6%.

The highest quantitative storability was achieved in Treatment III, where potato tubers were stored at 2–4 °C and 90–95% relative humidity with periodic ventilation adjusted according to the temperature and humidity conditions of the storage environment. Under this regime, natural weight loss was reduced to 3.8–4.2%, representing a **53.8–54.8% reduction compared with the control**, while marketable yield increased to **90.5–91.6%**. This corresponded to an additional **130–139 kg of marketable potatoes per tonne** initially placed in storage.

Among the cultivars evaluated, Sante demonstrated the highest quantitative storability. Under Treatment III, its natural weight loss was limited to 3.8%, while marketable yield reached 91.6%.

However, the lowest storage temperature did not provide an unequivocal advantage for all quality characteristics. Storage at 2–4 °C increased reducing sugar content to 0.40–0.41%, indicating that the regime providing maximum quantitative preservation may not be optimal for potatoes intended for processing, particularly when low reducing sugar levels are required.

Treatment II, consisting of storage at 3–5 °C and 90–95% relative humidity with ventilation twice daily for 20 min, provided a more balanced relationship between storability and biochemical quality. Under these conditions, natural weight loss remained within 4.7–5.2%, marketable yield reached 87.9–89.4%, and reducing sugar content was limited to 0.32–0.33%.

Therefore, long-term potato storage conditions should be differentiated according to the intended end use of the tubers. For potatoes intended primarily for fresh consumption, where maximum marketable yield and minimum quantitative losses are the main objectives, storage at **2–4 °C and 90–95% relative humidity with condition-responsive periodic ventilation** can be recommended. Where excessive reducing sugar accumulation must be avoided, storage at **3–5 °C and 90–95% relative humidity with ventilation twice daily for 20 min** provides a more appropriate balance between storability and biochemical quality.

Overall, the findings confirm that temperature, relative humidity, and ventilation should be managed as an integrated technological system rather than as independent storage factors. A differentiated storage strategy based on cultivar characteristics and intended product use can reduce postharvest losses, improve marketable yield, and preserve the quality of potato tubers during extended storage

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