

Effect of Calcium Chloride and Potassium Carbonate Treatments and Storage Conditions on Postharvest Quality of Pear (*Pyrus communis* L.)

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ABSTRACT

Pear is an important deciduous fruit crop in Afghanistan, produced in large quantities each year. However, its short shelf life and high postharvest losses during storage remain major challenges for producers and marketers. To address this issue, the present study was conducted in the laboratory and research farm of the Department of Horticulture, Faculty of Agriculture, Kabul University, Afghanistan, from 1 to 16 September 2025. The study aimed to evaluate the effects of CaCl_2 and K_2CO_3 on the postharvest quality of pear fruit under ZECC and ambient room storage conditions. The experiment was arranged in a factorial Split-split Plot CRD design with three factors: storage condition, chemical treatment, and storage duration, resulting in 40 treatment combinations with four replications. Storage conditions included room temperature (20–25 °C; 60–70% RH) and ZECC (10–15 °C; 85–95% RH). Treatments consisted of 2% and 3% CaCl_2 , 2% and 3% K_2CO_3 , and a control. Observations were recorded at initial, 5, 10, and 15 days. The results showed that physicochemical attributes (TSS, sugars, titratable acidity, pH, and weight loss) changed significantly during storage, whereas sensory attributes remained relatively stable. ZECC storage better preserved fruit quality by reducing respiration, and moisture loss. Among treatments, 2% CaCl_2 and 2% K_2CO_3 were the most effective in maintaining overall quality under both storage conditions. In conclusion, storing pear fruit under ZECC conditions combined with 2% CaCl_2 or 2% K_2CO_3 is recommended to extend shelf life and maintain quality. Further research on other fruit crops is suggested to validate these findings.

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INTRODUCTION

Pear (*Pyrus communis* L.) is an economically significant temperate fruit crop, which belongs to the family Rosaceae, subfamily Amygdaloideae, and tribe Maleae, where other commercially important crops like apples and quinces are also found. The genus *Pyrus* consists of more than 20–30 species along with over 5000 accessions that are spread across Europe, Asia, and North Africa (Li et al., 2022; Ruhsam, 2024). Out of all these species, P.

P. communis is the main European pear species, whereas *P. pyrifolia* and *P. ussuriensis* are the predominant Asian pear species. Phylogenetically, it has been suggested that there have been separate domestications of Asian and European pears from separate wild gene pools.

P. communis originated from a very wide geographical area that included Central and Eastern Europe as well as Western Asia, with the Caucasus being one of the major centers of its diversity and domestication (Ruhsam, 2024). It was suggested that the domesticated European pear was developed through hybridization of different wild subspecies, *P. communis* subsp. *pyraster* and subsp. *caucasica*, together with other species including *P. spinosa* and *P. salicifolia*. Hence, this resulted in high genetic diversity of current pear cultivars (Müller, 2024; Ruhsam, 2024). Moreover, there were also indications showing that the domestication of the pear species was polyphyletic (Li et al., 2022).

The pear fruit is highly valued because of the functional value. It is known to be rich in water, natural sugar (fructose, glucose, sucrose) and dietary fibers, such as pectin that aid in the process of digestion and glycemic regulation. In addition to this, the pear fruit offers many vitamins (e.g., vitamin C), minerals (potassium, calcium, magnesium) and other biologically active substances such as polyphenols, flavonoids and phenolic acids (chlorogenic acid, catechin, quercetin) (He et al., 2022; Li et al., 2016). These compounds have antioxidative, anti-inflammatory, and anticancer properties that could be used for the prevention of chronic diseases like cardiovascular disease and metabolic syndromes (Ferreira et al., 2024; Kolniak-Ostek et al., 2020). Other than that, the bioactive compounds present in pear fruit had cardioprotective, antidiabetic, and neuroprotective effects along with diuretic, antitussive, and laxative effects in folk medicine (Basit et al., 2024; Ji et al., 2025; Piluzza et al., 2023).

The economic significance of pear can be attributed to its high value as an agricultural produce with a global market worth of USD 25 to 34 billion with an estimated annual growth rate of 5% (Shubham, 2024; Maida, 2024). It is a major contributor to the livelihoods of rural people, income diversification, and international trade (FAOSTAT, 2024). However, post-harvest losses still stand out as a big challenge that occurs in the harvesting, handling, storage, and marketing of the fruit due to physical injuries, physiological disorders, microorganisms' deterioration, and dehydration. Losses range from 18% at the time of harvest to increased levels during storage, especially in normal atmosphere because of increased respiration and ethylene production (Blanckenberg et al., 2022; Łysiak et al., 2021).

To solve these problems, more advanced storage techniques like the ZECC have been adopted extensively. The ZECC is an economic and environmentally friendly storage technique involving the use of evaporative cooling that reduces temperature by 4-100 °C and keeps high relative humidity of >90%. In this condition, there will be less respiratory activity, transpiration, and microbial action hence increasing shelf-life and ensuring quality fruits (Khalid et al., 2022; Rayaguru et al., 2010; Singh et al., 2022; Ghosh, 2022).

Apart from storing techniques, other postharvest treatments such as CaCl_2 have also been found effective in preserving fruit quality. Calcium improves the structural strength of

the cell wall due to cross-linking of calcium pectate, inhibits enzyme activity and softening of fruits (Khalaj et al., 2017; Pessoa et al., 2022; Wójcik et al., 2014; Eroğul et al., 2024).

Pear is an economically valuable fruit in Afghanistan; however, the postharvest handling of pear in Afghanistan is not very much developed. The climacteric behavior of pear causes respiration even after harvesting. This results in rapid softening and aging of pear fruits, especially when kept in ambient condition (Zhu et al., 2024). Pear is also susceptible to mechanical injury and pathogenic infections (Luna et al., 2024).

Therefore, the present study aims to evaluate the effects of different storage conditions (ZECC vs. ambient) and postharvest treatments (CaCl_2 and K_2CO_3) on the shelf life and quality of pear fruit. More specifically, the purpose of the study is to determine ideal storage conditions, to investigate the efficiency of chemical treatment procedures, and to examine changes in physicochemical and sensory characteristics during storage. It is expected that the results will aid in the formulation of affordable and feasible methods for reducing post-harvest losses in pear fruits.

Accordingly, the study addresses the following research questions:

- What is the most suitable storage condition (ZECC vs. ambient) for maintaining the physicochemical and sensory quality of pear during storage?
- How do different concentrations of CaCl_2 and K_2CO_3 affect the shelf life and quality of pear under ZECC and ambient storage conditions?
- What is the effect of storage duration on the physicochemical and sensory properties of pear fruit during postharvest storage?

METHODS AND MATERIALS

Research Area

The present research was conducted in the laboratory and research farm of the Faculty of Agriculture, Kabul University, Afghanistan, from 1 to 16 September 2025.

Research Materials

In the current experiment, pear fruits of *Pyrus communis* L., variety 'Santa Maria', were used. Pear fruits were collected from the local market of Kabul in order to have homogeneity in terms of their maturity, size, and quality characteristics. CaCl_2 and K_2CO_3 were used as postharvest treatments materials. All chemicals were collected from the local market of Kabul. Selection of these chemicals was made considering their availability, low cost, and previous effectiveness.

Research Design and Treatments

In the current experiment, the design followed for the same was Split-Split Plot CRD and consisted of three factors, namely the storage condition, chemical treatment, and the storage period. This resulted in 40 treatment combinations having four repetitions each. The first factor had two levels; room storage at 20-25 °C and 60-70 % relative humidity, and ZECC

storage at 10-15 °C and 85-95 % relative humidity. The sub-factor had five treatments: 2% CaCl₂, 3% CaCl₂, 2% K₂CO₃, 3% K₂CO₃, and the control. The sub-sub factor was the storage period for 15 days at four points of sampling every five days (Initial, 5, 10, and 15 days). Information about the experimental design is provided in Table 1 below.

Table 1. *Experimental details*

Factors	Treatments	Details
Main factor (Storage Condition)	Room ZECC	Temperature 20–25 °C and relative humidity 60–70% Temperature 10–15 °C and Relative humidity 85–95%
Sub factor (Chemicals)	CaCl ₂ (2%) CaCl ₂ (3%) K ₂ CO ₃ (2%) K ₂ CO ₃ (3%) Control	2 Kg of pear fruit were immersed in each prepared solution for 20 minutes. For the control treatment, fruits were dipped in warm water instead of chemical solutions.
Sub-sub-Factor (Storage periods)	Four Time	At 5-day intervals.

For each treatment and replication, 2 kg of pear fruit were used. The fruits were immersed in the respective chemical solutions for 20 minutes. For the control treatment, fruits were dipped in warm water instead of chemical solutions. All pear fruits were carefully selected to ensure uniformity in weight, shape, color, and physiological maturity, and were free from visible disease symptoms and mechanical damage.

Measured Parameters

In this research, several quality attributes were evaluated to determine the effects of different postharvest treatments on the shelf life of pear fruits. The assessed parameters included TSS, reducing sugars, non-reducing sugars, total sugars, titratable acidity, firmness, and weight loss. In addition, sensory characteristics such as appearance, colour, aroma, taste, and overall acceptability were analyzed to assess the quality of the treated fruits during storage. The determination of these parameters was helpful in evaluating the effect of CaCl₂ and K₂CO₃ treatments on the post-harvest quality of pear fruits in both room and ZECC storage conditions. The determination methods of these parameters are explained in the subsequent sections.

The TSS content of the fruit was determined by extracting the pulp and measuring it with a digital hand refractometer, and the readings were recorded for subsequent analysis. For sugar determination, 25 mL of fruit pulp was diluted with 100 mL of distilled water. Phenolphthalein was used as an indicator, and the mixture was neutralized with 1 N sodium hydroxide (NaOH). Subsequently, 2 mL of 45% lead acetate solution was added, thoroughly mixed, and allowed to stand for 10 min. Thereafter, 2 mL of 22% potassium oxalate solution was added to remove excess lead. The volume was adjusted to 250 mL with distilled water, and the solution was filtered through Whatman No. 1 filter paper. An aliquot (10 mL) of the filtrate was then titrated against Fehling's reagent (5 mL Fehling A and 5 mL Fehling B) using methylene blue as the endpoint indicator. The resulting data were used for subsequent calculations and analysis (Ranganna, 1986).

$$\text{Reducing sugars(RS) (\%)} = \frac{\text{mg of invert sugar} \times \text{Dilution} \times 100}{\text{Titer} \times \text{Volume of sample} \times 100}$$

Since sucrose is generally considered the predominant non-reducing sugar in fruit pulp, the non-reducing sugar content was estimated from the difference between total sugars and reducing sugars.

$$\text{Non-Reducing Sugar (NRS)} = \text{Total Sugar (TS)} - \text{RS}$$

TS content was determined after hydrolysis (inversion) of sucrose in the clarified fruit extract. Briefly, 50 mL of the filtered reducing-sugar extract was transferred to a 250-mL conical flask, followed by the addition of 5 g citric acid and 50 mL distilled water. The mixture was gently boiled for 10 min to facilitate complete sucrose inversion and then allowed to cool. The hydrolyzed solution was transferred to a 250-mL volumetric flask and neutralized with 1 N NaOH using phenolphthalein as an indicator. The volume was subsequently adjusted to 250 mL with distilled water. A 10-mL aliquot was titrated against mixed Fehling's solution (5 mL Fehling A and 5 mL Fehling B), using methylene blue as the endpoint indicator. Total sugar content was calculated from the titration value and expressed as a percentage (Ranganna, 1986).

$$\text{TS (\%)} = \frac{\text{mg of invert sugar} \times \text{Dilution} \times 100}{\text{Titer} \times \text{Volume of sample}}$$

Titrateable acidity (TA) was determined by diluting a known quantity of fruit pulp with distilled water and titrating the resulting extract against standardized 0.1 N sodium hydroxide (NaOH), using phenolphthalein as the indicator. The titration was continued until a persistent faint pink endpoint was obtained. The TA was calculated based on malic acid equivalence and expressed as a percentage (Ranganna, 1986).

$$\text{Titrateable Acidity(\%)} = \frac{\text{Titer} \times \text{Normality of alkali} \times \text{Volume made up} \times \text{Equivalent weight of acid} \times 100}{\text{Volume of sample} \times \text{Volume of aliquot} \times 1000}$$

Fruit firmness was measured using a digital fruit penetrometer, and the results were expressed as kg cm⁻². The pH of the fruit pulp was determined using a calibrated digital pH meter, and the measurements were recorded for subsequent analysis. Individual fruit weights were measured accurately using a digital balance and expressed in grams (g). These parameters were recorded for further statistical analysis.

$$\text{Weight Losses} = \frac{\text{Initial total fruit weight (g)} - \text{Final total fruit weight (g)}}{\text{Initial total fruit weight (g)}} \times 100$$

Sensory quality was evaluated by eight semi-trained panellists based on five attributes: appearance, colour, aroma, taste, and overall acceptability. All samples were assessed using a nine-point Hedonic scale ranging from 1 (dislike extremely) to 9 (like extremely), with 5 representing neither like nor dislike. Sensory evaluations were conducted at four storage intervals: 0, 5, 10, and 15 days, and the scores obtained from the panellists were recorded for statistical analysis.

Data Collection and Analyses

The data on all parameters were collected in four sampling phases: Initial, 5, 10, and 15 days. The above experiment was carried out based on the Split-Split Plot experimental design with CRD design. The data that were collected were analyzed using factorial analysis of variance (ANOVA) by STAR software package. Treatment effect was considered to be significant when $P \leq 0.05$ and very significant when $P \leq 0.01$. Means comparison was done by using LSD test. When presenting the results, means with the same small letter(s) in columns are not significantly different, while means with the same capital letter(s) in rows are not significantly different.

FINDINGS

In this section, the findings of the study are systematically presented and interpreted based on the parameters evaluated. The results are organized into clear and well-structured tables to facilitate accurate interpretation and comparison among treatments. Each table is accompanied by a detailed description and discussion of the observed trends, significant differences, and treatment effects, thereby providing a comprehensive understanding of the experimental outcomes.

Fruit Firmness

The results of the study indicate that storage conditions, different chemical treatments, and storage duration had a highly significant effect ($P \leq 0.01$) on the firmness of pear fruit Table 2. Since the interaction among all three factors (storage condition, chemical treatment, and storage time) was statistically significant, only the interaction effect is described in the results, as it simultaneously represents the combined influence of all three factors. Storage time caused significant changes in fruit firmness at all treatments under both storage conditions, with the highest firmness recorded at the initial stage, while the lowest firmness was observed after 15 days of storage.

Table 2. Impact of Chemical Treatments on Pear Fruit Firmness during Storage under Different Condition

Storage Condition	Treatments	Storage Period			
		Initial	5 Days	10 Days	15 Days
Room	CaCl ₂ (2%)	2.43 ^{aA}	1.43 ^{bB}	1.23 ^{bB}	0.80 ^{abC}
	CaCl ₂ (3%)	2.48 ^{aA}	1.06 ^{cB}	0.45 ^{dC}	0.63 ^{bcC}
	K ₂ CO ₃ (2%)	2.55 ^{aA}	1.44 ^{bB}	0.93 ^{cC}	0.90 ^{aC}
	K ₂ CO ₃ (3%)	2.50 ^{aA}	2.55 ^{aA}	1.44 ^{aB}	0.48 ^{cC}
	Control	2.55 ^{aA}	1.55 ^{bB}	1.14 ^{bC}	0.53 ^{cC}
ZECC	CaCl ₂ (2%)	2.58 ^{aA}	1.33 ^{bB}	0.95 ^{bC}	1.08 ^{bC}
	CaCl ₂ (3%)	2.53 ^{aA}	1.46 ^{bB}	1.35 ^{aBC}	1.15 ^{bC}
	K ₂ CO ₃ (2%)	2.45 ^{aA}	1.44 ^{bB}	0.94 ^{bC}	0.83 ^{cC}
	K ₂ CO ₃ (3%)	2.55 ^{aA}	1.48 ^{bC}	0.45 ^{cD}	1.88 ^{aB}
	Control	2.53 ^{aA}	1.85 ^{aB}	1.08 ^{bC}	0.73 ^{cD}
Factors	F-Test	LSD (0.01)		CV	
Storage Condition (Main)	**	-		10.08	
Treatments (Sub)	**	-		6.76	

Storage Time (Sub Sub)	**	-	7.38
Main x Sub	**	-	
Main x Sub Sub	**	-	
Sub x Sub Sub	**	-	
Main x Sub x Sub Sub	**	0.2	

Note: When the interaction among all three factors is significant, the LSD is calculated only for the three-way interaction, and the results are interpreted accordingly, as it simultaneously represents the combined effects of all factors. **The CV** is calculated only for the main factors and not for their interactions. *: $P \leq 0.05$. **: $P \leq 0.01$. **CV**: refers to the coefficient of variation. **x**: denotes interaction. **Lowercase** superscript letters indicate the grouping of treatments within columns, whereas uppercase letters represent grouping across rows. **LSD**: Least Significant Difference. **ZECC**: Zero Energy Cool Chamber.

Furthermore, the results revealed that the lowest changes in fruit firmness during storage were observed in the 3% K_2CO_3 treatment under ZECC conditions, whereas the greatest changes were recorded in the control treatment under ambient room conditions. Based on the LSD test at the 0.01 level of significance, means within the same column sharing similar lowercase letters are not significantly different from each other, while means within the same row sharing similar uppercase letters also do not differ significantly.

Fruit TSS

The TSS were significantly affected during storage. The results indicated that storage conditions, different concentrations of calcium chloride and potassium carbonate, and storage duration had a highly significant effect ($P \leq 0.01$) on TSS. Moreover, a significant interaction was observed among these three factors in Table 3. During the storage period, significant changes in TSS were observed under both storage conditions, with a general increasing trend in fruit TSS. The lowest TSS values were recorded at the initial stage, while the highest values were observed at the final stage of storage.

Table 3. Effect of Chemical Treatments on Pear Fruit TSS during Storage under Different Conditions

Storage Condition	Treatments	Storage Period			
		Initial	5 Days	10 Days	15 Days
Room	CaCl ₂ (2%)	12.53 ^{aD}	14.45 ^{aC}	18.93 ^{bB}	20.68 ^{cA}
	CaCl ₂ (3%)	12.58 ^{aC}	15.23 ^{aB}	22.43 ^{aA}	21.93 ^{bA}
	K ₂ CO ₃ (2%)	12.65 ^{aD}	14.75 ^{aC}	19.85 ^{bB}	21.68 ^{bA}
	K ₂ CO ₃ (3%)	12.60 ^{aD}	14.93 ^{aC}	22.55 ^{aB}	24.18 ^{aA}
	Control	12.65 ^{aD}	14.35 ^{aC}	23.05 ^{aB}	20.00 ^{cA}
ZECC	CaCl ₂ (2%)	12.68 ^{aD}	14.75 ^{cC}	17.20 ^{aB}	18.25 ^{bA}
	CaCl ₂ (3%)	12.63 ^{aC}	15.98 ^{abB}	17.00 ^{aA}	17.25 ^{cA}
	K ₂ CO ₃ (2%)	12.55 ^{aC}	15.35 ^{bcB}	16.43 ^{aA}	15.25 ^{dB}
	K ₂ CO ₃ (3%)	12.65 ^{aC}	16.08 ^{abB}	16.35 ^{aB}	18.25 ^{bA}
	Control	12.63 ^{aD}	16.35 ^{aB}	15.05 ^{bC}	19.25 ^{aA}
Factors	F-Test	LSD (0.01)		CV	
Storage Condition (Main)	**	-		4.21	
Treatments (Sub)	**	-		2.77	
Storage Time (Sub Sub)	**	-		3.13	

Main x Sub	**	-	
Main x Sub Sub	**	-	
Sub x Sub Sub	**	-	-
Main x Sub x Sub Sub	**	0.94	

Note: Changes in treatments were calculated by subtracting the initial (0-day) values from those recorded at 15 days of storage. Additionally, the difference between the two storage environments was determined by comparing the mean changes under ambient room conditions with those under ZECC conditions.

Among the treatments, the highest increase in TSS was recorded in the 3% K₂CO₃ treatment under ambient room conditions, where TSS increased from 12.60 °Brix to 24.18 °Brix. In contrast, the lowest change was observed in the 2% K₂CO₃ treatment under ZECC conditions, where TSS increased from 12.55 °Brix to 15.25 °Brix. Furthermore, the results demonstrated that the changes in TSS under ZECC conditions were comparatively lower than those under ambient conditions, with an average reduction of approximately 45%.

Fruit Reducing Sugar

The results of the study revealed that storage conditions, different concentrations of calcium chloride and potassium carbonate, and storage duration had a highly significant effect ($P \leq 0.01$) on the reducing sugar content of pear fruit Table 4. Furthermore, a significant interaction was observed among these three factors.

Table 4. Effect of Chemical Treatments on Pear Fruit Reducing Sugar Content

Storage Condition	Treatments	Storage Period			
		Initial	5 Days	10 Days	15 Days
Room	CaCl ₂ (2%)	6.21 ^{aD}	8.48 ^{aC}	12.72 ^{bB}	14.72 ^{cA}
	CaCl ₂ (3%)	6.24 ^{aC}	8.94 ^{aB}	15.08 ^{aA}	15.61 ^{bA}
	K ₂ CO ₃ (2%)	6.28 ^{aD}	8.66 ^{aC}	13.35 ^{bB}	15.43 ^{bA}
	K ₂ CO ₃ (3%)	6.25 ^{aD}	8.77 ^{aC}	15.16 ^{aB}	17.21 ^{aA}
	Control	6.28 ^{aD}	8.43 ^{aC}	15.50 ^{aA}	14.24 ^{cB}
ZECC	CaCl ₂ (2%)	6.29 ^{aD}	8.66 ^{bC}	10.40 ^{aB}	12.34 ^{bA}
	CaCl ₂ (3%)	6.26 ^{aD}	9.39 ^{aC}	10.29 ^{aB}	11.66 ^{cA}
	K ₂ CO ₃ (2%)	6.23 ^{aC}	9.02 ^{abB}	9.94 ^{aA}	10.31 ^{dA}
	K ₂ CO ₃ (3%)	6.28 ^{aD}	9.45 ^{aC}	9.89 ^{aB}	12.33 ^{bA}
	Control	6.26 ^{aC}	9.60 ^{aB}	9.10 ^{bB}	13.02 ^{aA}
Factors	F-Test	LSD (0.01)		CV	
Storage Condition (Main)	**	-		4.57	
Treatments (Sub)	**	-		3.05	
Storage Time (Sub Sub)	**	-		3.45	
Main x Sub	**	-			
Main x Sub Sub	**	-			
Sub x Sub Sub	**	-		-	
Main x Sub x Sub Sub	**	0.94			

During the storage period, noticeable changes in reducing sugar content were observed across all treatments under both storage conditions. In general, reducing sugars increased

progressively with storage time. Regarding the effect of chemical treatments, the highest increase in reducing sugars was recorded in the 3% K_2CO_3 treatment under ambient room conditions, where the values increased from 6.25% to 17.21%. In contrast, the lowest increase was observed in the 2% K_2CO_3 treatment under ZECC conditions, where reducing sugars increased from 6.23% to 10.31%. With respect to storage conditions, the results indicated that changes in reducing sugar content under ZECC conditions were approximately 38% lower compared to ambient room conditions.

Fruit Non-Reducing Sugar

The non-reducing sugar content of pear fruit was also significantly influenced during the 15 days' storage period. The results indicated that storage conditions, different concentrations of $CaCl_2$ and K_2CO_3 , and 15 days storage duration, had a highly significant effect ($P \leq 0.01$) on the non-reducing sugar content of the fruit. Furthermore, a significant interaction was observed among these three factors Table 5.

Table 5. Effect of Chemical Treatments on Pear Fruit Non-Reducing Sugar Content

Storage Condition	Treatments	Storage Period			
		Initial	5 Days	10 Days	15 Days
Room	$CaCl_2$ (2%)	3.81 ^a	3.08 ^{bc}	2.42 ^c	1.82 ^{cd}
	$CaCl_2$ (3%)	3.82 ^a	3.24 ^a	2.86 ^a	1.93 ^b
	K_2CO_3 (2%)	3.85 ^a	3.14 ^{abc}	2.54 ^b	1.91 ^{bc}
	K_2CO_3 (3%)	3.83 ^a	3.18 ^{ab}	2.88 ^a	2.13 ^a
	Control	3.85 ^a	3.06 ^c	2.94 ^a	1.76 ^d
ZECC	$CaCl_2$ (2%)	3.85 ^a	3.14 ^c	3.35 ^a	2.26 ^a
	$CaCl_2$ (3%)	3.84 ^a	3.40 ^{ab}	3.32 ^{ab}	2.14 ^b
	K_2CO_3 (2%)	3.82 ^a	3.27 ^{bc}	3.20 ^b	1.89 ^c
	K_2CO_3 (3%)	3.85 ^a	3.42 ^a	3.19 ^b	2.26 ^a
	Control	3.75 ^a	3.48 ^a	2.93 ^c	2.11 ^{ab}
Factors	F-Test	LSD (0.01)		CV	
Storage Condition (Main)	**	-		2.92	
Treatments (Sub)	**	-		2.13	
Storage Time (Sub Sub)	**	-		2.09	
Main x Sub	**	-		-	
Main x Sub Sub	**	-		-	
Sub x Sub Sub	**	-		-	
Main x Sub x Sub Sub	**	0.08		-	

The findings revealed that, under ZECC conditions, the reduction in non-reducing sugar content was approximately 26% lower compared to ambient room conditions. Regarding treatment effects, the highest reduction was observed in the control treatment under room conditions, where the non-reducing sugar content decreased from 3.85% to 1.76%. In contrast, the lowest reduction was recorded in the combined treatment of $CaCl_2$ (2%) and K_2CO_3 (3%) under ZECC conditions, where the values decreased from 3.85% to 2.26%. Throughout the 15-day storage period, a gradual decline in non-reducing sugar content was observed over time. The highest values were recorded at the initial stage in both storage conditions, while the lowest values were observed at the end of the storage period.

Fruit Total Sugar

It has been found from the current study that the storage conditions, varying levels of CaCl_2 and K_2CO_3 and storage period have highly significant impact ($P \leq 0.01$) on the total sugar content of pear fruit. Furthermore, there is a significant interaction between these three factors Table 6.

Table 6. Effect of Chemical Treatments on Pear Fruit Total Sugar Content

Storage Condition	Treatments	Storage Period			
		Initial	5 Days	10 Days	15 Days
Room	CaCl_2 (2%)	10.02 ^{aD}	11.56 ^{aC}	15.14 ^{bB}	16.54 ^{cA}
	CaCl_2 (3%)	10.06 ^{aC}	12.18 ^{aB}	17.94 ^{aA}	17.54 ^{bA}
	K_2CO_3 (2%)	10.12 ^{aD}	11.80 ^{aC}	15.88 ^{bB}	17.34 ^{bA}
	K_2CO_3 (3%)	10.08 ^{aD}	11.94 ^{aC}	18.04 ^{aB}	19.34 ^{aA}
	Control	10.12 ^{aD}	11.48 ^{aC}	18.44 ^{aA}	16.00 ^{cB}
ZECC	CaCl_2 (2%)	10.14 ^{aD}	11.80 ^{cC}	13.76 ^{aB}	14.60 ^{bA}
	CaCl_2 (3%)	10.10 ^{aC}	12.78 ^{abB}	13.60 ^{aA}	13.80 ^{cA}
	K_2CO_3 (2%)	10.04 ^{aC}	12.28 ^{bcB}	13.14 ^{aA}	12.20 ^{dB}
	K_2CO_3 (3%)	10.12 ^{aC}	12.86 ^{abB}	13.08 ^{aB}	14.60 ^{bA}
	Control	10.10 ^{aD}	13.08 ^{aB}	12.04 ^{bC}	15.40 ^{aA}
Factors	F-Test	LSD (0.01)		CV	
Storage Condition (Main)	**	-		4.21	
Treatments (Sub)	**	-		2.77	
Storage Time (Sub Sub)	**	-		3.13	
Main x Sub	**	-			
Main x Sub Sub	**	-			
Sub x Sub Sub	**	-		-	
Main x Sub x Sub Sub	**	0.75			

The data further indicated that total sugar content increased significantly in both storage condition throughout the storage period. The lowest total sugar levels were recorded at the initial stage, whereas the highest values were observed after 15 days of storage. Regarding the effect of chemical treatments, the greatest increase in total sugar content was observed in the K_2CO_3 (3%) treatment under ambient room conditions, where values increased from 10.08% to 19.34%. In contrast, the lowest increase was recorded in the K_2CO_3 (2%) treatment under ZECC conditions, where total sugars increased from 10.04% to 12.20%. Similarly, in the CaCl_2 (3%) treatment, total sugar content increased from 10.10% to 13.80%. In terms of storage condition, the highest increase in total sugar content was observed under room conditions, while the lowest increase was recorded under ZECC conditions. Notably, the increase in total sugar content under ZECC conditions was approximately 45% lower compared to room conditions.

Fruit pH

The results of the present study indicated that fruit pH was significantly influenced ($P \leq 0.01$) by storage duration, storage conditions, and different concentrations of CaCl_2 and K_2CO_3 . Furthermore, a significant interaction among these factors was observed Table 7.

Table 7. Effect of Chemical Treatments on Pear Fruit pH during Storage under Different Conditions

Storage Condition	Treatments	Storage Period			
		Initial	5 Days	10 Days	15 Days
Room	CaCl ₂ (2%)	5.18 ^{aD}	5.44 ^{aC}	5.60 ^{aB}	5.76 ^{aA}
	CaCl ₂ (3%)	4.83 ^{bD}	5.07 ^{bC}	5.22 ^{bB}	5.38 ^{bA}
	K ₂ CO ₃ (2%)	4.55 ^{cD}	4.78 ^{cC}	4.92 ^{cB}	5.07 ^{cA}
	K ₂ CO ₃ (3%)	5.20 ^{aD}	5.46 ^{aC}	5.62 ^{aB}	5.79 ^{aA}
	Control	4.93 ^{bD}	5.17 ^{bC}	5.33 ^{bB}	5.49 ^{bA}
ZECC	CaCl ₂ (2%)	4.55 ^{cD}	4.78 ^{cC}	4.92 ^{cB}	5.07 ^{cA}
	CaCl ₂ (3%)	4.75 ^{bD}	4.99 ^{bC}	5.14 ^{bB}	5.29 ^{bA}
	K ₂ CO ₃ (2%)	4.75 ^{bD}	4.99 ^{bC}	5.14 ^{bB}	5.29 ^{bA}
	K ₂ CO ₃ (3%)	4.60 ^{bcD}	4.83 ^{bcC}	4.97 ^{bcB}	5.12 ^{bcA}
	Control	4.95 ^{aD}	5.20 ^{aC}	5.36 ^{aB}	5.52 ^{aA}
Factors	F-Test	LSD (0.01)		CV	
Storage Condition (Main)	**	-		6.75	
Treatments (Sub)	**	-		3.92	
Storage Time (Sub Sub)	**	-		0.12	
Main x Sub	**	-			
Main x Sub Sub	**	-			
Sub x Sub Sub	**	-		-	
Main x Sub x Sub Sub	**	0.2			

The findings revealed that fruit pH increased progressively during the 15-day storage period in both environments. The lowest pH values were recorded at the initial stage, whereas the highest values were observed at the end of the 15-day storage period. Regarding the effect of chemical treatments, the greatest increase in pH was observed in the K₂CO₃ (3%) treatment under ambient room conditions, where pH increased from 5.20 to 5.79. In contrast, the lowest increase in pH was recorded under the same treatment (K₂CO₃, 3%), where values increased from 4.60 to 5.12. In terms of storage conditions, smaller changes in pH were observed under ZECC conditions compared to ambient room conditions. Notably, the increase in pH under ZECC conditions was approximately 5% lower than that observed under room conditions.

Fruit Titratable Acidity

The titratable acidity of pear fruit was significantly affected ($P \leq 0.01$) by different concentrations of CaCl₂ and K₂CO₃, as well as by storage duration. However, storage conditions did not exert a significant effect on the titratable acidity of the fruit Table 8.

Table 8. Effect of Chemical Treatments on Pear Fruit pH During Storage Periods

Treatments	Storage Period			
	Initial	5 Days	10 Days	15 Days
CaCl ₂ (2%)	0.365 ^{cA}	0.325 ^{cB}	0.291 ^{bC}	0.262 ^{aD}
CaCl ₂ (3%)	0.364 ^{bcA}	0.326 ^{bcB}	0.292 ^{abC}	0.263 ^{aD}
K ₂ CO ₃ (2%)	0.368 ^{abA}	0.328 ^{abB}	0.294 ^{abC}	0.265 ^{aD}

K ₂ CO ₃ (3%)	0.369 ^{aA}	0.329 ^{aB}	0.295 ^{aC}	0.265 ^{aD}
Control	0.369 ^{aA}	0.329 ^{aB}	0.294 ^{aC}	0.265 ^{aD}
Factors	F-Test	LSD (0.01)	CV	
Storage Condition (Main)	Ns	-	0.56	
Treatments (Sub)	**	-	1.40	
Storage Time (Sub Sub)	**	-	0.17	
Main x Sub	Ns	-		
Main x Sub Sub	Ns	-		
Sub x Sub Sub	**	0.0031	-	
Main x Sub x Sub Sub	Ns	-		

Ns: Not Significance.

The results further indicated a progressive decline in titratable acidity during the storage period. The greatest reduction was observed in the control treatment, where titratable acidity decreased from 0.369% to 0.265%. In contrast, the smallest decrease was recorded in the CaCl₂ (3%) treatment, where values declined from 0.364% to 0.263%.

Fruit Losses Weight

The results of the present study indicated that weight loss in pear fruit during storage was significantly influenced ($P \leq 0.01$) by different concentrations of CaCl₂ and K₂CO₃ under both ambient room and ZECC conditions Table 9.

Table 9. Effect of Chemical Treatments on Pear Fruit Losses Weight during Storage under Different Conditions

Storage Condition	Treatments	Storage Period			
		Initial	5 Days	10 Days	15 Days
Room	CaCl ₂ (2%)	-	1.68 ^{bcC}	3.90 ^{dB}	6.20 ^{cA}
	CaCl ₂ (3%)	-	1.88 ^{bC}	4.25 ^{cB}	6.75 ^{bA}
	K ₂ CO ₃ (2%)	-	1.35 ^{cC}	3.05 ^{eB}	5.10 ^{dA}
	K ₂ CO ₃ (3%)	-	1.55 ^{bcC}	4.63 ^{bB}	6.10 ^{cA}
	Control	-	2.40 ^{aC}	5.28 ^{aB}	8.30 ^{aA}
ZECC	CaCl ₂ (2%)	-	0.81 ^{abC}	2.20 ^{bB}	3.33 ^{bA}
	CaCl ₂ (3%)	-	1.01 ^{abC}	2.33 ^{bB}	3.53 ^{bA}
	K ₂ CO ₃ (2%)	-	0.73 ^{bC}	1.45 ^{cB}	2.40 ^{cA}
	K ₂ CO ₃ (3%)	-	0.83 ^{abC}	1.30 ^{cB}	3.23 ^{bA}
	Control	-	1.13 ^{aC}	2.79 ^{aB}	4.40 ^{aA}
Factors	F-Test	LSD (0.01)		CV	
Storage Condition (Main)	**	-		27.33	
Treatments (Sub)	**	-		8.25	
Storage Time (Sub Sub)	**	-		7.54	
Main x Sub	**	-			
Main x Sub Sub	**	-			
Sub x Sub Sub	**	-		-	
Main x Sub x Sub Sub	**	0.34			

Throughout the storage period, the lowest weight loss was observed at day 5, whereas the highest weight loss was recorded at day 15. Regarding the effect of chemical treatments,

the highest weight loss was observed in the control treatment under room conditions, reaching 8.4%. In contrast, the lowest weight loss was recorded in the K_2CO_3 (2%) treatment under ZECC conditions, with a value of 2.40%. In terms of storage conditions, weight loss under ZECC conditions was substantially lower compared to room conditions, showing an approximate reduction of 47%.

Fruit Appearance

The appearance of pear fruit was significantly influenced ($P \leq 0.01$) by different concentrations of $CaCl_2$ and K_2CO_3 , as well as by varying storage conditions Table 10.

Table 10. Effect of Chemical Treatments on Pear Fruit Appearance during Storage under Different Conditions.

Storage Condition	Storage Period	Treatments					Storage Condition Means
		2% $CaCl_2$	2% K_2CO_3	3% $CaCl_2$	3% K_2CO_3	Control	
Room	Initial	8.25	6.75	6.50	6.50	5.50	6.69 ^b
	5 Days	8.00	6.75	6.50	6.50	5.50	
	10 Days	8.00	6.75	6.50	6.50	5.50	
	15 Days	8.50	6.75	6.50	6.50	5.50	
ZECC	Initial	8.75	8.75	6.75	7.00	6.00	7.51 ^a
	5 Days	8.50	8.75	6.75	7.00	6.25	
	10 Days	9.00	9.00	6.75	7.00	6.25	
	15 Days	9.00	8.75	6.75	7.00	6.25	
Treatments Means		8.50 ^A	7.78 ^A	6.62 ^B	6.75 ^B	5.84 ^B	
Factors		F-Test		LSD (0.01)		CV	
Storage Condition (Main)		**		0.41		19.18	
Treatments (Sub)		**		0.95		28.33	
Storage Time (Sub Sub)		Ns		-		4.71	
Main x Sub		Ns		-			
Main x Sub Sub		Ns		-			
Sub x Sub Sub		Ns		-		-	
Main x Sub x Sub Sub		Ns		-			

The results indicated that fruit appearance scores were higher under ZECC conditions compared to ambient room conditions. On average, fruits stored under room conditions received a score of 6.69, whereas those stored under ZECC conditions achieved a higher average score of 7.51. Regarding the effect of chemical treatments, the highest appearance score (8.50) was recorded in the $CaCl_2$ (2%) treatment. This was followed by the K_2CO_3 (2%) treatment, which was statistically grouped with the former and obtained a score of 7.78. In contrast, the lowest score (5.84) was observed in the control treatment.

Fruit Color

The results of the present study revealed that storage conditions and different concentrations of $CaCl_2$ and K_2CO_3 had a highly significant effect ($P \leq 0.01$) on fruit color of pear fruit. However, storage duration did not show a significant effect on fruit color, and no significant interaction was observed among the three factors Table 11.

Table 11. Effect of Chemical Treatments on Pear Fruit Color during Storage under Different Conditions

Storage Condition	Storage Period	Treatments					Storage Condition Means
		2%CaCl ₂	2%K ₂ CO ₃	3%CaCl ₂	3%K ₂ CO ₃	Control	
Room	Initial	8.50	6.75	6.50	6.50	5.50	6.73 ^b
	5 Days	8.25	6.75	6.50	6.50	5.50	
	10 Days	8.50	6.75	6.50	6.50	5.50	
	15 Days	8.25	6.75	6.50	6.50	5.50	
ZECC	Initial	8.75	8.75	6.75	7.00	6.00	7.47 ^a
	5 Days	8.50	8.75	7.50	6.75	6.25	
	10 Days	9.00	8.75	6.75	6.75	5.75	
	15 Days	8.75	8.75	7.00	7.00	6.00	
Treatments Means		8.56 ^a	7.75 ^a	6.75 ^b	6.69 ^{bc}	5.75 ^c	
Factors		F-Test		LSD (0.01)		CV	
Storage Condition (Main)		**		0.42		17.97	
Treatments (Sub)		**		0.99		29.65	
Storage Time (Sub Sub)		Ns		-		6.15	
Main x Sub		Ns		-		-	
Main x Sub Sub		Ns		-		-	
Sub x Sub Sub		Ns		-		-	
Main x Sub x Sub Sub		Ns		-		-	

Regarding storage conditions, the highest fruit color score (7.47) was recorded under ZECC conditions, while the lowest score (6.37) was observed under ambient room conditions. In terms of chemical treatments, the highest color score (8.56) was obtained in the CaCl₂ (2%) treatment, whereas the lowest score (5.75) was recorded in the control treatment.

Fruit Aroma

The aroma of pear fruit during storage was significantly influenced ($P \leq 0.01$) by storage conditions and different concentrations of CaCl₂ and K₂CO₃, with a significant interaction observed among the studied factors. However, storage duration did not show a significant effect on fruit aroma Table 12.

Table 12. Effect of Chemical Treatments on Pear Fruit Aroma during Storage under Different Conditions

Table 22: Effect of Chemical Treatments on Ear Rot Index during Storage under Different Conditions					
Storage Condition	Treatments	Storage Period			
		Initial	5 Days	10 Days	15 Days
Room	CaCl ₂ (2%)	7.25 ^{aC}	8.50 ^{aA}	7.75 ^{aBC}	8.25 ^{aAB}
	CaCl ₂ (3%)	6.75 ^{abA}	6.75 ^{bA}	6.75 ^{abA}	6.75 ^{bA}
	K ₂ CO ₃ (2%)	6.50 ^{abA}	6.50 ^{bA}	6.50 ^{abA}	6.50 ^{bA}
	K ₂ CO ₃ (3%)	6.50 ^{abA}	6.50 ^{bA}	6.50 ^{abA}	6.50 ^{bA}
	Control	5.50 ^{bA}	5.50 ^{bA}	5.50 ^{bA}	5.50 ^{bA}
ZECC	CaCl ₂ (2%)	9.00 ^{aA}	8.75 ^{aA}	8.75 ^{aA}	8.75 ^{aA}
	CaCl ₂ (3%)	8.75 ^{aA}	8.75 ^{aA}	8.75 ^{aA}	8.75 ^{aA}
	K ₂ CO ₃ (2%)	6.75 ^{bA}	6.75 ^{bA}	6.75 ^{bA}	6.75 ^{bA}
	K ₂ CO ₃ (3%)	7.00 ^{bA}	7.00 ^{bA}	7.00 ^{bA}	7.00 ^{bA}
	Control	6.25 ^{bA}	5.00 ^{cB}	5.75 ^{bA}	4.25 ^{cC}
Factors	F-Test	LSD (0.01)		CV	
Storage Condition (Main)	**	-		18.19	

Treatments (Sub)	**	-	29.81
Storage Time (Sub Sub)	Ns	-	7.15
Main x Sub	*	-	
Main x Sub Sub	**	-	
Sub x Sub Sub	**	-	
Main x Sub x Sub Sub	**	1.49	

Regarding chemical treatments, the highest aroma scores were consistently recorded in the CaCl_2 (2%) treatment at both the initial stage and after 15 days of storage under ZECC conditions. In contrast, the lowest aroma scores were observed in the control treatment under both ZECC and ambient room conditions. In terms of storage conditions, fruits stored under ZECC conditions obtained, on average, approximately 9% higher aroma scores compared to those stored under ambient room conditions.

Fruit Taste

The results of the present study revealed that storage duration, different concentrations of CaCl_2 and K_2CO_3 , as well as storage conditions, had a highly significant effect ($P \leq 0.01$) on fruit taste of apple Table 13.

Table 13. Effect of Chemical Treatments on Pear Fruit Taste during Storage under Different Conditions

Storage Condition	Treatments	Storage Period			
		Initial	5 Days	10 Days	15 Days
Room	CaCl_2 (2%)	8.25 ^{aA}	7.25 ^{aB}	8.50 ^{aA}	8.00 ^{aA}
	CaCl_2 (3%)	6.75 ^{bA}	6.75 ^{aA}	6.75 ^{bA}	6.75 ^{abA}
	K_2CO_3 (2%)	6.50 ^{bA}	6.50 ^{abA}	6.50 ^{bA}	6.50 ^{bA}
	K_2CO_3 (3%)	6.50 ^{bA}	6.50 ^{abA}	6.50 ^{bA}	6.50 ^{bA}
	Control	5.50 ^{bA}	5.50 ^{bA}	5.50 ^{bA}	5.50 ^{bA}
ZECC	CaCl_2 (2%)	8.75 ^{aA}	9.00 ^{aA}	8.50 ^{aA}	9.00 ^{aA}
	CaCl_2 (3%)	9.00 ^{aA}	8.75 ^{aA}	9.00 ^{aA}	8.75 ^{aA}
	K_2CO_3 (2%)	7.25 ^{bA}	6.75 ^{bA}	6.75 ^{bcA}	6.75 ^{bA}
	K_2CO_3 (3%)	6.75 ^{bcA}	6.75 ^{bA}	7.00 ^{bA}	7.00 ^{bA}
	Control	5.50 ^{cA}	5.50 ^{bA}	5.50 ^{cA}	5.75 ^{bA}
Factors	F-Test	LSD (0.01)		CV	
Storage Condition (Main)	**	-		19.70	
Treatments (Sub)	**	-		28.56	
Storage Time (Sub Sub)	*	-		6.64	
Main x Sub	*	-			
Main x Sub Sub	Ns	-		-	
Sub x Sub Sub	Ns	-			
Main x Sub x Sub Sub	**	1.43			

The findings indicated that under ambient room conditions, the highest taste scores were consistently recorded in the CaCl_2 (2%) treatment during the storage period, whereas the lowest scores were observed in the control treatment. Similarly, under ZECC conditions, the highest taste scores were obtained in both CaCl_2 (2%) and CaCl_2 (3%) treatments, while the lowest scores were again recorded in the control treatment. Overall, fruits stored under ZECC

conditions achieved approximately 12% higher taste scores compared to those stored under ambient room conditions.

Fruit Overall Acceptability

The overall acceptability of pear fruit was significantly influenced by storage conditions, different concentrations of CaCl_2 and K_2CO_3 , as well as storage duration Table 14.

Table 14. Effect of Chemical Treatments on Pear Fruit Overall Acceptability during Storage

Storage Condition	Treatments	Storage Period			
		Initial	5 Days	10 Days	15 Days
Room	CaCl_2 (2%)	8.00 ^{aBC}	8.25 ^{aAB}	7.75 ^{aC}	8.50 ^{aA}
	CaCl_2 (3%)	6.75 ^{abA}	6.75 ^{bA}	6.75 ^{abA}	6.75 ^{bA}
	K_2CO_3 (2%)	6.50 ^{bA}	6.50 ^{bA}	6.50 ^{bA}	6.50 ^{bA}
	K_2CO_3 (3%)	6.50 ^{bA}	6.50 ^{bA}	6.50 ^{bA}	6.50 ^{bA}
	Control	6.50 ^{bA}	6.50 ^{bA}	6.50 ^{bA}	6.50 ^{bA}
ZECC	CaCl_2 (2%)	8.50 ^{aB}	9.00 ^{aA}	9.00 ^{aA}	8.75 ^{aAB}
	CaCl_2 (3%)	8.75 ^{aA}	9.00 ^{aA}	9.00 ^{aA}	9.00 ^{aA}
	K_2CO_3 (2%)	6.75 ^{bcA}	6.75 ^{bA}	6.75 ^{bA}	6.75 ^{bA}
	K_2CO_3 (3%)	7.00 ^{bA}	7.00 ^{bA}	7.00 ^{bA}	7.00 ^{bA}
	Control	5.50 ^{cB}	6.50 ^{bA}	6.25 ^{bA}	5.75 ^{bB}
Factors	F-Test	LSD (0.01)		CV	
Storage Condition (Main)	**	-		17.48	
Treatments (Sub)	**	-		29.07	
Storage Time (Sub Sub)	*	-		4.10	
Main x Sub	**	-			
Main x Sub Sub	**	-			
Sub x Sub Sub	**	-		-	
Main x Sub x Sub Sub	**	1.40			

The results indicated that under ambient room conditions, the highest overall acceptability score was recorded in the CaCl_2 (2%) treatment, whereas the lowest scores were observed in K_2CO_3 treatments along with the control. Similarly, under ZECC conditions, the highest acceptability scores were obtained in both CaCl_2 treatments (2% and 3%), while the lowest score was consistently recorded in the control treatment. In terms of storage conditions, fruits stored under ZECC conditions achieved, on average, approximately 8% higher overall acceptability scores compared to those stored under ambient room conditions.

DISCUSSION

The post-storage fruit quality traits of pear include firmness, sugar composition, acidity, weight loss, and sensory properties. Of all these, fruit firmness is regarded as one of the major factors affecting post-harvest fruit quality. From the current results, firmness declined gradually during storage. The decline is attributed to the breakdown of pectin, which is one of the major cell wall components that keep it intact. Pectin breaks down via an enzymatic reaction during storage as metabolic activity increases, resulting in cell wall destruction and fruit softening. Ethylene biosynthesis enzymes such as acetyl-CoA synthase and ACC-related enzymes are the major players during this period since they accelerate respiration rate and

production of ethylene, leading to increased pectin breakdown (Cuozzo et al., 2025; Łysiak et al., 2021; Zdunek et al., 2016). Besides, the alteration in sugar composition results in decreased fruit firmness since increased glucose and reduced sucrose composition soften the fruit tissues (Yin et al., 2025a).

The storage condition played a critical role in firmness retention, as better retention was seen at ZECC than at room storage condition. This phenomenon can be justified by the fact that temperature is low and relative humidity is high in ZECC, which in turn, results in reduced respiration rate, ethylene production, and enzyme activities, hence preventing structural damage (Chen et al., 2025; Híc et al., 2023; Zhang et al., 2023). Further, chemical treatments also increased firmness retention, in which 2% CaCl_2 and 2% K_2CO_3 increased firmness retention at room condition, whereas 3% K_2CO_3 and 2% CaCl_2 performed better at ZECC. The efficacy of CaCl_2 can be attributed to the fact that it makes the cells strong by forming calcium-pectate bridges (Çolak et al., 2025; Jain et al., 2019; Kumar, 2021).

The concentration of TSS in pear fruit increased steadily with storage time. The increase in TSS level can be mainly attributed to the hydrolysis of complex carbohydrates like starch and pectin to simple sugars. Moreover, the break-down of non-reducing sugars such as sucrose into glucose and fructose also significantly contributes to the TSS increase. Sometimes, the change of organic acids into sugars results in an increase in TSS levels as well (Dave et al., 2017; Huan et al., 2021; Xu et al., 2025). Similar observations have been frequently made in the literature, indicating that carbohydrate metabolism is primarily responsible for the increase in TSS. Nevertheless, the rate of TSS increase was lower in ZECC than in room storage because of less metabolic activity in cooler conditions (Brizzolara et al., 2020; Łysiak et al., 2021; Phan et al., 2026). Treatments with chemicals such as 2% CaCl_2 in room conditions and 2% K_2CO_3 in ZECC proved to be effective in controlling TSS by decreasing respiration and creating a semi-protection layer on fruit surface (Çolak et al., 2025; Eroğul et al., 2024; Kumar, 2021). In a similar way, there was an increase in reducing sugars throughout storage because of the decomposition of polysaccharides and hydrolysis of sucrose into glucose and fructose. All these are results of the metabolic activities that accompany fruit ripening (Xu et al., 2025; Yin et al., 2025b). In ZECC treatment, there was a lesser increase in reducing sugars, which shows the efficiency of lower temperatures in reducing metabolic activities (Brizzolara et al., 2020; Phan et al., 2026). Chemical treatments including CaCl_2 and K_2CO_3 were also involved in the stability of reducing sugar levels (Çolak et al., 2025; Eroğul et al., 2024).

On the other hand, non-reducing sugars, especially sucrose, had a steady reduction as the storage time went on. Such reduction is attributed mainly to enzyme hydrolysis using invertase enzyme for the conversion of sucrose into reducing sugars. Therefore, there was an inverse relationship between reducing and non-reducing sugars as they reflected active biological processes of ripening and respiration (Brizzolara et al., 2020; Dave et al., 2017; Pott et al., 2020). More reduction of sugar content was observed under room condition owing to high temperature, which increased the rate of respiration and ethylene production. Under

ZECC, 3% K_2CO_3 and 2% $CaCl_2$ were the most effective concentrations for conserving non-reducing sugars through the inhibition of biological processes (Çolak et al., 2025; Eroğul et al., 2024). Total sugar content of pear fruit increased during storage. Just like in the case of TSS, this increment was less pronounced in ZECC due to lower metabolic processes (Dave et al., 2017; Huan et al., 2021; Xu et al., 2025; Brizzolara et al., 2020). The chemical applications played an important role in controlling the total sugar content, with 2% $CaCl_2$ and 2% K_2CO_3 being more effective in sustaining the quality of fruits internally (Çolak et al., 2025; Eroğul et al., 202

There was an increase in the pH of pear fruit with increasing storage periods; a phenomenon that has an inverse relationship with the reduction in titrable acidity. The rise in pH is associated primarily with the transformation of organic acids to sugars and their use in respiration reactions (Brizzolara et al., 2020; Çolak et al., 2025). There were fewer changes in pH under ZECC treatments since there was low metabolism under low temperature conditions (Çolak et al., 2025; Mazumder et al., 2021). Treatments such as 2% K_2CO_3 (room) and 2% $CaCl_2$ (ZECC) were effective in minimizing pH fluctuations. Conversely, titratable acidity decreased during storage, primarily due to the degradation and metabolic utilization of organic acids (Brizzolara et al., 2020; Dave et al., 2017; Çolak et al., 2025). Unlike other parameters, storage conditions and chemical treatments did not show a significant effect on acidity, suggesting that these changes are largely inherent to the fruit's physiological processes.

There was substantial loss in weight throughout the storage process, and there was the most weight loss at the last stage. This was mostly because of moisture losses caused by transpiration, respiration, and decomposition of organic compounds and microbial decay (Lufu et al., 2019, 2024; Manda-Hakki & Hassanpour, 2024). The storage process under ZECC conditions resulted in substantial reduction of weight loss because of low temperatures and high humidity, thus minimizing water loss and metabolic processes (Fang & Wakisaka, 2021; Prange et al., 2025). Chemicals, especially 2% K_2CO_3 and 2% $CaCl_2$, caused additional reduction of weight losses as a result of strengthening of cell wall and disease development (Eroğul et al., 2024; Guo et al., 2023).

As for the sensory properties, the duration of storage did not have any effect on quality during 15 days, but the conditions under which storage took place had a considerable impact on it. The fruits kept at ZECC were always superior in terms of appearance, color, aroma, taste, and acceptability in comparison with those kept in room conditions. It happened primarily because of decreased physiological and microbial activities under such conditions (Eum et al., 2025; Oliveira-Bouzas et al., 2023; Pinto de Andrade et al., 2022; Sortino et al., 2022). The chemical treatments also helped to improve sensory properties, namely, 2% and 3% $CaCl_2$ proved to be the most effective in this respect. It was explained by increased stability of cell walls, decreased enzymatic degradation, respiration, and ethylene emission (Çolak et al., 2025; Ngamchuachit et al., 2014; Thakur et al., 2019).

CONCLUSION

The results of the present study demonstrated that during the 15-day storage period, considerable changes were observed in physicochemical characteristics, whereas sensory qualities remained relatively stable. Among the studied factors, storage conditions played a critical role, with better stability of both physicochemical and sensory attributes observed under ZECC conditions. This can be attributed to the lower temperature (10–15 °C) and higher relative humidity (85–95%), which effectively reduced respiration rate, ethylene production, and moisture loss. Regarding chemical treatments, both 2% CaCl₂ and 2% K₂CO₃ showed favorable effects under both ambient and ZECC conditions, contributing to improved stability of fruit quality attributes.

Therefore, it is recommended that pear fruit be stored under ZECC conditions to extend shelf life and maintain quality. Additionally, the application of 2% CaCl₂ or 2% K₂CO₃, depending on availability and economic feasibility, is suggested to further preserve physicochemical and sensory properties. Future research should focus on evaluating these treatments under similar storage conditions in other horticultural crops, particularly early-maturing pear, apple cultivars and peach, to validate and expand the applicability of these findings.

Authors Contributions

- Rahmat Gul Hassanzai. conceptualized and supervised the study.
- Hayatullah Ahsas. investigated, analyzed data, wrote the manuscript with input from all authors.
- All authors reviewed and approved the final version.

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The authors declare that they have no conflict of interest.

Data Availability Statement

Data are available upon request from the corresponding author, subject to the approval of the relevant ethics committee.

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