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EVALUATING THE EFFECTIVENESS OF ECO-FRIENDLY WHEY PROTEIN COATING IN EXTENDING POTATO SHELF LIFE TO PROMOTE SUSTAINABLE AGRICULTURE AND ENHANCE FOOD SECURITY

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Abstract

As global population surges, ensuring food security through sustainable agriculture becomes increasingly critical. Whey protein-based coatings emerge as a promising solution to reduce food waste, particularly in countries like Jordan, where financial support, technological advancement, and inclusive practices are vital for agricultural sustainability. This study delves into how whey protein concentrate can enhance potato quality by increasing dry matter content, firmness, and soluble solids, potentially extending shelf life and fostering sustainable agriculture. To this end, potatoes treated with whey protein coatings were subjected to various storage conditions to assess their impact on quality parameters and statistically analyze the results. Dry matter was affected minimally by treatments, storage conditions, and their interactions. Firmness was affected marginally by treatments and storage conditions but significantly by storage period. Total soluble solids were affected significantly by all factors, with significant interactions between storage period and treatments/storage conditions. Treatment 2 preserved firmness better but slightly reduced total soluble solids compared to treatment 1, while both maintained dry matter levels similar to the control. Refrigeration was most effective at preserving total soluble solids, while room temperature and incubator conditions led to greater degradation. Over time, dry matter peaked at 24 days and then declined, firmness softened steadily, and total soluble solids dropped sharply after 32 days. Refrigeration and coatings helped maintain quality, but storage beyond 32 days significantly deteriorated product quality. Figures 3-11 illustrate the changes in these parameters under various conditions and treatments. The partial correlation coefficients between dry matter, firmness, and total soluble solids, indicating minimal to no significant correlations except for a significant correlation between firmness and total soluble solids at the 32-day storage period. The study concludes that while dry matter was affected minimally, firmness and total

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Vol: 61 | Issue: 12 | 2024

soluble solids were significantly influenced by treatments, storage conditions, and storage period, with refrigeration proving most effective in preserving quality, especially beyond 32 days, emphasizing the importance of optimized storage conditions for producers.

Keywords: *Food Preservation, Edible Coatings, Post-Harvest Technology, Crop Storage, Sustainable Practices.*

1. INTRODUCTION

The rapid growth of the global population presents an opportunity to enhance crop production and ensure food security and sustainability [1]. Sustainable agriculture is essential in meeting these challenges, offering innovative solutions to improve resource efficiency and significantly reduce food waste [2].

Food waste is a major global issue, with one-third of food produced for human consumption wasted annually [2]. Edible coatings made from natural materials offer a promising solution by extending the shelf life of fruits and vegetables, providing an eco-friendly and cost-effective alternative to synthetic packaging [3].

Whey protein, a high-quality biopolymer derived from food waste, possesses unique properties such as biodegradability, thermal stability, and excellent gas barrier performance, making it a promising candidate for food coating applications [4].

Many studies have demonstrated the effectiveness of whey protein-based coatings in reducing weight loss and maintaining quality in various crops, including apples and tomatoes [5].

Whey protein concentrate (WPC) offers a promising way to enhance potato quality. By stabilizing moisture, it boosts dry matter content, improves texture, and extends storage life [6, 7]. WPC also strengthens firmness by altering the cellular structure, making potatoes more suitable for various culinary applications [8]. Furthermore, WPC can modify soluble solids, enhancing both flavor and sweetness for a more appealing taste [9].

In Jordan, agricultural sustainability is influenced by financial support, technology adoption, and inclusive practices. Access to agricultural loans has been shown to significantly boost productivity [10], while financial aid programs and partnerships with NGOs play a crucial role in supporting small farmers [11]. Adopting advanced technologies tailored to specific production types has improved efficiency and sustainability across the sector [12]. Additionally, initiatives to empower rural youth contribute to building a more inclusive agricultural landscape [13]. However, despite moderate household food security levels [14], challenges remain, such as substantial storage losses in potato production. These losses and increasing demand highlight the pressing need for innovative preservation and storage solutions [15].

This study examines the impact of whey protein concentrate on key quality attributes of potatoes, including dry matter content, firmness, and soluble solids. By treating potatoes with varying concentrations of whey protein, the research evaluates how this edible coating influences these parameters, potentially enhancing potato quality and shelf life while promoting sustainable agricultural practices.

2. MATERIAL AND METHODS

This study was conducted in 2022 at Jerash University's Faculty of Agriculture. Potatoes were examined under different storage conditions and treatments for 60 days. Dry matter (DM), firmness (FR), and total soluble solids (TS) were measured weekly.

DOI: 10.5281/zenodo.14545934
Vol: 61 | Issue: 12 | 2024

2.1 Plant Material Selection

Potatoes of uniform size (*Solanum Tuberosum L.*) were sourced from the central vegetable market in Irbid City, Jordan. The collected samples were examined thoroughly to remove any abnormal, rotten, or damaged ones.

2.2 Edible Coating Preparation

Two edible coatings were prepared: Treatment (TRT1) involved dissolving 50 g of whey protein concentrate (WPC) in 1000 ml of distilled water, which was then heated in a water bath at 80–90 °C for 30 minutes to induce denaturation. Treatment (TRT2) followed the same process for WPC preparation, but with additional additives.

Specifically, 5 g of high-molecular-weight chitosan (antimicrobial) was dissolved in 10 ml of distilled water, and then 5 ml of glycerol (plasticizer), 5 ml of glacial acetic acid (preservative), 1 ml of Tween 80, and 1 ml of coconut oil (antimicrobial) were added. The solution was mixed thoroughly using a magnetic stirrer.

2.3 Coating Application

Potato tubers were washed under running tap water, dried with tissue paper, and divided into three groups: C (Control), where no coating was applied; TRT1, where 100 g of potatoes were dipped in WPC for 30 seconds and air-dried; and TRT2, where 100 g of potatoes were dipped in WPC with additives for 1.5 minutes and then air-dried. The samples were stored under three conditions: SC1 at room temperature (55% relative humidity), SC2 in a refrigerator (4 °C), and SC3 in an incubator (20±2 °C and 74% relative humidity).

2.4 Measurements

Dry matter (DM) 100 g of cut potatoes (wet weight) were placed in a paper bag and dried in an oven at 70°C for 48 h, then the dry matter was calculated, according to the following formula:

$$Dry\ matter = \frac{Dry\ weight}{Wet\ wright} \times 100$$

Firmness (FR) was measured using a digital fruit hardness meter (Model GY-4) as shown in Figure (1). Readings were taken on both sides of the peeled potato samples, and the average was recorded.

Total soluble solids (TS) were measured using a portable digital refractometer (Atago PAL.1) as shown in Figure (2), and the results were expressed in °Brix. 5 g potato weight was mixed, diluted with 50 ml of distilled water, and mixed using an electric mixer, then filtered using filter paper.

A few drops of the extract were placed on the lens and the reading was taken to obtain the sugar concentration in °Brix. The weight of the sample was then multiplied by the dilution according to the following standard equation:

$$Total\ Soluble\ Solids = refractometer\ Reading \times Dilution\ Factor$$

Where, Refractometer Reading: The value obtained from the instrument in °Brix, Dilution Factor: Accounts for any dilution made to the sample.

DOI: 10.5281/zenodo.14545934
Vol: 61 | Issue: 12 | 2024

Figure 1: Gy-4 Portable digital fruit hardness tester fruit Sclerometer

Figure 2: The PAL-1 digital refractometer accurately features NFC data transfer

2.5 Statistical Analysis

Program SAS was used for statistical evaluation [16]. GLM was used to determine the effect of the treatments, storage conditions, storage periods and the interactions between them on dry mater, firmness and Total soluble solids of potato crop according to the following linear models:

$$\boldsymbol{Y_{ijkl} = \mu + TRT_i + SC_j + SP_K + (TRT \times SC)_{ij} + (TRT \times SP)_{ik} + (SC \times SP)_{jk} + I\sigma^2 e}$$

Where, μ = overall mean. TRT_i= effect of i^th treatments coded as i=1 (no coating was applied, control), i=2 (Whey protein concentrate applied alone for 30 seconds and air-dried) and i=3 (Whey protein isolate combined with glycerol, glacial acetic acid, and ethanol).

SC_j= effect of j^{th} storage conditions coded as j=1 (Stored at room temperature (24°C) with 55% relative humidity), j=2 (Stored in a refrigerator at a constant temperature of 4°C) and j=3 (Stored in an incubator at 20°C±2 with 74% relative humidity). SP_K= effect of k^{th} storage periods coded as k= SP8, PS16 … SP60 indicate the storage periods of 8, 16 … 60 days, respectively.

$(TRT \times SC)_{ij}$= effect of ij^{th} interaction between treatments and storage conditions. $(TRT \times SP)_{ik}$ = effect of ik^{th} interaction between treatments and storage periods. $(SC \times SP)_{jk}$ = effect of jk^{th} interaction between storage conditions and storage periods. e= random error term associated with Y_{ijkl} observations with zero mean and variance $I\sigma^2 e$. To determine significant differences between means (LSM) of the group effects, Duncan's multiple range test was used [17]. The results were presented as LSM±SE.

3. RESULTS

The overall least square means was 16.69±1.25 (%), 6.10±0.53 (Newton), and 3.54±0.38 (°Brix) for dry matter, firmness, and total soluble solids of potato crop, respectively during the study.

Neither treatment (TRT) nor storage conditions (SC) significantly affected dry matter (DM). However, storage period (SP) had a slight effect (p=0.05). Moreover, interactions between factors had minimal impact on DM content.

DOI: 10.5281/zenodo.14545934
Vol: 61 | Issue: 12 | 2024

Both TRT and SC marginally affected firmness (FR) (p=0.09 and 0.08, respectively). However, SP had a more significant effect on FR (p<0.01). In contrast, interactions between factors had no significant effect on FR.

TRT, SC, and SP significantly affect total soluble solids (TS) (p<0.01). Furthermore, the interaction effects of SP with both TRT and SC are similarly significant (p<0.01). In contrast, the interaction effect of TRT and SC is not significant (p>0.05). By understanding these factors, producers can optimize processes to enhance product quality.

Table (1) show that TRT2 preserved firmness (FR) better than TRT1 but slightly reduced total soluble solids (TS), while both maintained dry matter (DM) levels similar to the control.

According to (DM) and (FR) were similar under different storage conditions. While refrigeration (SC2) was most effective at preserving (TS), whereas room temperature (SC1) and incubator conditions (SC3) led to greater degradation.

Over time, DM peaked at 24 days but declined by 60 days, FR softened steadily, and TS dropped sharply after 32 days. Refrigeration and coatings helped maintain quality, but storage beyond 32 days significantly deteriorated product quality.

Table 1: Mean and standard error for variables (Dry Matter, Firmness, and Total Soluble Solids) across different effects (Treatments, Storage Conditions, and Storage Period)

Variable	Effect	Mean	Std Error
Dry Matter (%)	"C"	18.43A	0.36
	"TRT1"	18.02A	0.34
	"TRT2"	18.77A	0.37
Firmness	"C"	7.19A	0.14
	"TRT1"	7.27A	0.13
	"TRT2"	7.63A	0.26
Total Soluble Solids	"C"	4.85A	0.15
	"TRT1"	4.78A	0.17
	"TRT2"	4.41B	0.18
Dry Matter (%)	"SC1"	18.10A	0.30
	"SC2"	18.81A	0.37
	"SC3"	18.31A	0.39
Firmness	"SC1"	7.20A	0.13
	"SC2"	7.27A	0.14
	"SC3"	7.63A	0.25
Total Soluble Solids	"SC1"	4.41B	0.09
	"SC2"	5.67A	0.15
	"SC3"	3.95C	0.13
Dry Matter (%)	"SP8"	18.28B	0.37
	"SP16"	18.14B	0.45
	"SP24"	20.07A	0.68
	"SP32"	17.70B	0.43
	"SP40"	18.51B	0.57
	"SP50"	18.24B	0.6
	"SP60"	17.89B	0.55
Firmness	"SP8"	8.03A	0.08
	"SP16"	7.72A	0.07
	"SP24"	7.76A	0.08
	"SP32"	7.81A	0.1

DOI: 10.5281/zenodo.14545934
Vol: 61 | Issue: 12 | 2024

Variable	Effect	Mean	Std Error
	"SP40"	7.59A	0.09
	"SP50"	6.67B	0.59
	"SP60"	5.97C	0.10
Total Soluble Solids	"SP8"	4.60AB	0.17
	"SP16"	4.51B	0.15
	"SP24"	5.06A	0.27
	"SP32"	5.07A	0.31
	"SP40"	4.59AB	0.14
	"SP50"	4.58AB	0.33
	"SP60"	4.36B	0.33

C: Control (no coating was applied); **TRT1**: Whey protein concentrate (WPC) applied alone for 30 seconds and air-dried; **TRT2**: Whey protein isolate combined with glycerol, glacial acetic acid, and ethanol. **SC1**: Stored at room temperature (24°C) with 55% relative humidity; **SC2**: Stored in a refrigerator at a constant temperature of 4°C; **SC3**: Stored in an incubator at 20°C±2 with 74% relative humidity. **SP8, SP16, … SP60** indicate the storage periods of 8, 16, … 60 days, respectively. The presence of at least one identical letter means that there is no significant difference between the means (P>0.05).

Figure (3), (4), and (5) illustrate the changes in dry matter (DM) percentage, firmness (FR)/ (newton), and total soluble solids (TS)/ (°Brix) of potatoes stored under various conditions (SC1, SC2, SC3) and subjected to different treatments (Control, TRT1, TRT2).

The lack of significant interaction between treatments and storage conditions indicates that the effects of different treatments were consistent across all storage conditions.

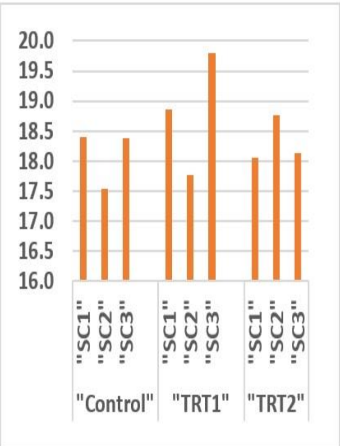

Figure 3: Effect of the interaction between storage conditions and treatments on dry matter (DM) percentage

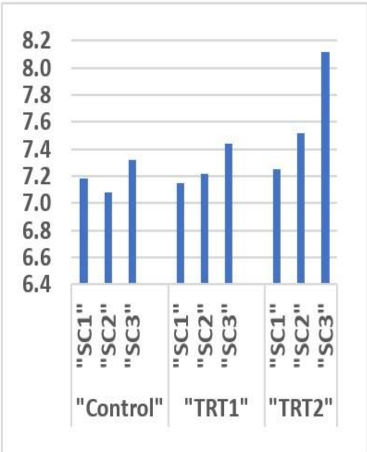

Figure 4: Influence of storage conditions and treatments interaction on firmness (FR)/ (newton)

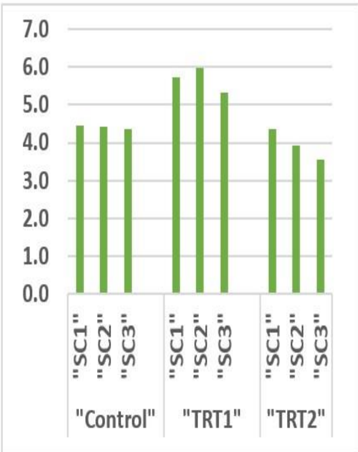

Figure 5: Total soluble solids (TS)/ (°Brix) as affected by the interaction between storage conditions and treatments

Figure (6), (7), and (8) compare the dry matter (DM) percentage, firmness (FR)/ (newton), and total soluble solids (TS)/ (°Brix) of potatoes stored for different periods (SP8, SP16, SP24, SP32, SP40, SP50, SP60) under different treatments (Control, TRT1, TRT2).

DOI: 10.5281/zenodo.14545934
Vol: 61 | Issue: 12 | 2024

The interaction between treatments and storage periods was insignificant for DM and FR, but highly significant (P<0.01) for TS. DM and FR were similar across storage periods within treatments, while TS varied significantly. This emphasizes the importance of storage period in maintaining TS of potatoes.

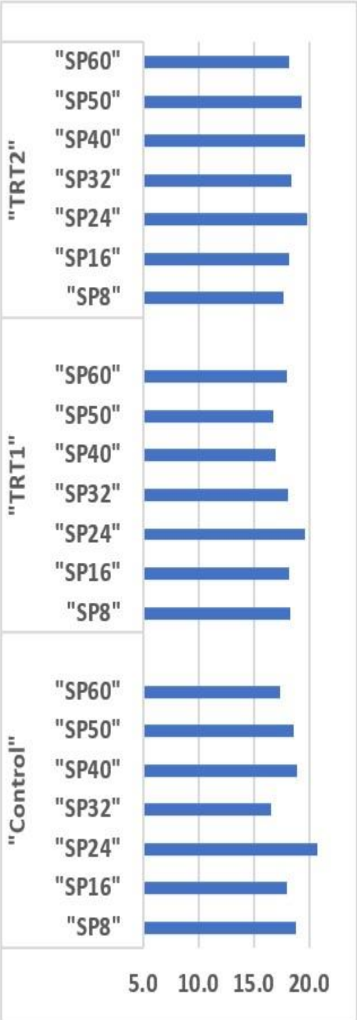

Figure 6: Comparison of dry matter (DM) percentage across different treatments and storage periods

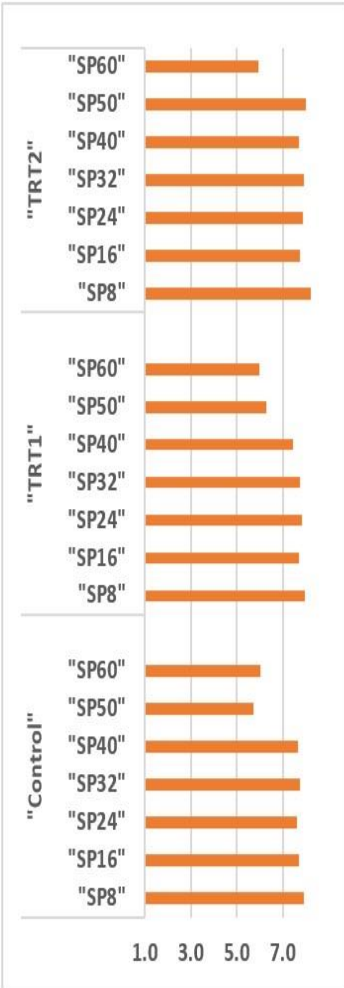

Figure 7: Variation in treatments and storage period interactions on a firmness (FR)/ (Newton)

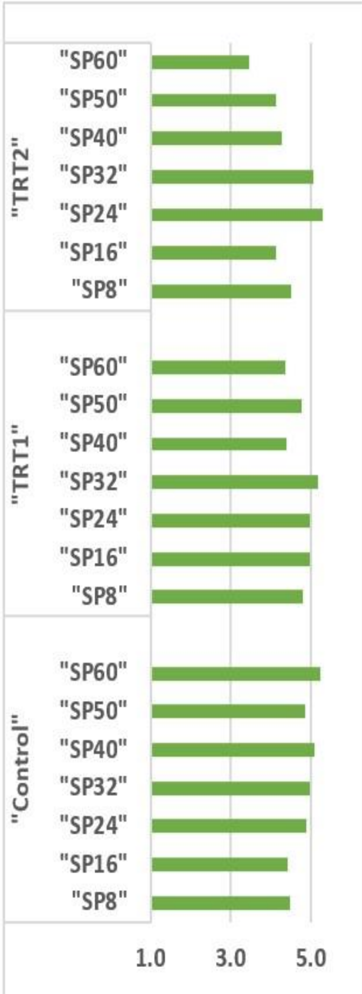

Figure 8: Interaction effects of storage period and treatments on total soluble solids (TS)/ (°Brix)

Figure (9), (10), and (11) depict the changes in dry matter (DM) percentage, firmness (FR)/ (Newton) and total soluble solids (TS)/ (°Brix) of potatoes stored for different periods (SP8, SP16, SP24, SP32, SP40, SP50, SP60) under various storage conditions (SC1, SC2, SC3). While DM and FR remained relatively stable across different storage periods (PR) within each storage condition (SC), TS exhibited significant variations.

This indicates that the interaction between SC and SP was insignificant for DM and FR but highly significant (P<0.01) for TS. This emphasizes the importance of storage period under different storage conditions on TS in potatoes.

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Vol: 61 | Issue: 12 | 2024

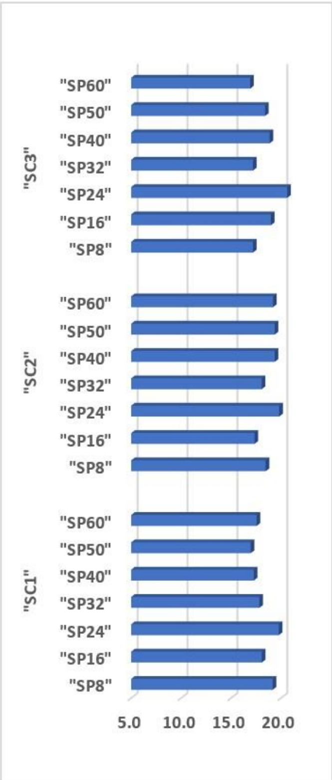

Figure 9: Effect of storage periods in storage conditions on dry matter (DM) percentage

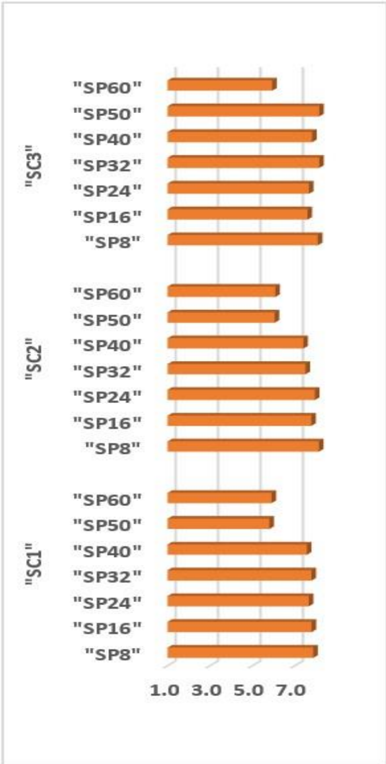

Figure 10: Firmness (FR)/ (Newton) changes over storage periods within the conditions periods

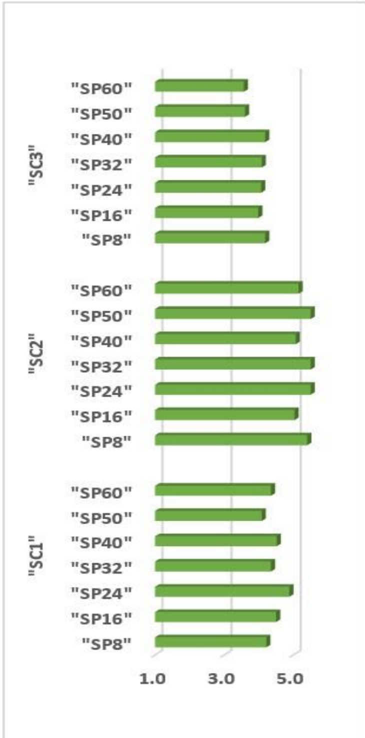

Figure 11: Effect of storage periods within storage conditions on total soluble solids (TS)/ (°Brix)

Table (2) presents the partial correlation coefficients between Dry Matter (DM), Firmness (FR), and Total Soluble Solids (TS) in potatoes across various treatments and storage conditions. The analysis indicates minimal to no significant correlations among these traits (P>0.05), suggesting that they are likely influenced by independent factors and do not exhibit strong interrelationships.

Table 2: Partial correlation coefficients for the variables of dry matter (DM) percentage, firmness (FR)/ (Newton), and total soluble solids (TS)/ (°Brix) of potatoes in each treatment and storage condition studied

Variables	"C"		"TRT1"		"TRT2"		"SC1"		"SC2"		"SC3"	
	DM	FR	DM	FR	DM	FR	DM	FR	DM	FR	DM	FR
FR	0.083		0.191		-0.099		0.304		-0.117		-0.008	
TS	-0.119	-0.171	0.026	0.026	0.264	0.014	0.129	0.242	-0.096	-0.037	-0.032	-0.047

C: Control (no coating was applied)**; TRT1**: Whey protein concentrate (WPC) applied alone for 30 seconds and air-dried; **TRT2**: Whey protein isolate combined with glycerol, glacial acetic acid, and ethanol. **SC1**: Stored at room temperature (24°C) with 55% relative humidity; **SC2**: Stored in a refrigerator at a constant temperature of 4°C; **SC3**: Stored in an incubator at 20°C±2 with 74% relative humidity.

DOI: 10.5281/zenodo.14545934
Vol: 61 | Issue: 12 | 2024

Table (3) shows the partial correlation coefficients between Dry Matter (DM), Firmness (FR), and Total Soluble Solids (TS) in potatoes across storage periods. The analysis indicates minimal to no significant correlations (p>0.05) between these parameters, indicating they are likely influenced by independent factors. However, a significant correlation (p<0.01) was found between FR and TS at the 32-day storage period, likely due to physiological changes affecting both firmness and sugar content.

Table 3: Partial correlation coefficients for the variables of dry matter (DM) percentage, firmness (FR)/ (newton), and total soluble solids (TS)/ (°Brix) of potatoes in various storage Period studied

Variables	"SP8"		"SP16"		"SP24"		"SP32"		"SP40"		"SP50"		"SP60"	
	DM	FR	DM	FR	DM	FR	DM	FR	DM	FR	DM	FR	DM	FR
FR	-0.276		-0.008		0.209		0.028		-0.253		-0.047		0.065	
TS	-0.052	0.081	-0.165	0.345	-0.068	0.392	0.140	**-0.623****	0.058	-0.054	0.078	-0.329	0.055	0.093

SP8, SP16, … SP60 indicate the storage periods of 8, 16, … 60 days, respectively. The presence of at least one identical letter means that there is no significant difference between the means (P>0.05). ******: highly significant correlation (p<0.01).

4. DISCUSSION

Treatment (TRT) and storage conditions (SC) did not affect dry matter (DM), while storage period (SP) had a minor impact. Firmness (FR) was influenced slightly by TRT and SC but more strongly by SP. TRT, SC, and SP found no significant interactions for DM or FR. Total soluble solids (TS) were strongly affected, with SP interactions influencing TS. Managing these factors can improve potato quality.

Table (1) shows that Treatment 2 (TRT2) preserved firmness (FR) better than Treatment 1 (TRT1) but slightly reduced total soluble solids (TS). Both treatments kept dry matter (DM) similar to the control. Refrigeration (SC2) best preserved TS, while room temperature (SC1) and incubator (SC3) caused more degradation.

Dry matter (DM) peaked at 24 days and declined until 60 days. Firmness (FR) softened steadily, while total soluble solids (TS) dropped sharply after 32 days. Refrigeration and coatings slowed quality loss, but storage beyond 32 days caused significant deterioration.

In the literature, Firmness was affected minimally by 9-month tuber aging, with vacuum packaging and sodium ascorbate best-preserving texture [18]. Dry matter was optimal in Asterix and Cronos cultivars stored at 8°C for up to 120 days, reducing browning and maintaining quality [19]. Additionally, soluble solids decreased during 35-day storage, improving processing quality while reducing oxidative defense enzyme activity [20].

The effects of different treatments (Control, TRT1, TRT2) on potato dry matter, firmness, and total soluble solids were consistent across various storage conditions (SC1, SC2, SC3), as illustrated in Figures (3), (4), and (5). This consistency suggests that the effectiveness of a particular treatment can be predicted reliably, regardless of the storage environment.

Figures (6), (7), and (8) compare the changes in dry matter (DM), firmness (FR), and total soluble solids (TS) in potatoes stored for different periods (PR8, PR16, PR24, PR32, PR40, PR50, PR60) under various treatments (Control, TRT1, TRT2). The interaction between treatments and storage periods had no significant effect on DM and FR. However, it was highly significant for TS. While DM and FR remained relatively consistent across storage periods within each treatment, TS showed notable variation,

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Vol: 61 | Issue: 12 | 2024

indicating that storage duration had a stronger impact on the soluble solids content than on dry matter or firmness.

Potato dry matter and firmness remained stable during storage, while total soluble solids fluctuated significantly, as shown in Figures (9), (10), and (11). Storage duration primarily influenced total soluble solids, with no significant interaction between storage conditions and storage periods for dry matter and firmness. This suggests that storage duration primarily affects total soluble solids, while dry matter and firmness are less sensitive to storage time and conditions.

In reviews, combining cold storage with natural inhibitors like DMN and PMO effectively prevents potato sprouting, especially in short-dormancy cultivars, increasing consumption in tropical regions [21]. Plant growth regulators (PGRs) are the most effective method to break change, with identified hormonal changes [22]. Furthermore, e-beam irradiation is another option that extends storage life by inhibiting sprouting, reducing weight loss, and softening, while minimally affecting sugar content [23].

Table (2) shows that dry matter, firmness, and total soluble solids in potatoes have minimal to no significant correlations, suggesting they are influenced by independent factors and respond differently to treatments and storage conditions.

Table (3) shows that dry matter, firmness, and total soluble solids in stored potatoes have minimal to no significant correlations, except for a significant correlation between firmness and total soluble solids at 32 days, suggesting potential physiological changes affecting both.

Several studies have shown correlations between potato quality and various factors. For instance, Abbasi et al., [24] found links between tuber firmness, dry matter, starch content, and antioxidant properties. Xiao et al., [25] linked storage time to changes in tissue structure and scattering properties. Rosales et al., [26] found that high dry matter and total soluble solids correlated with lower stickiness, higher antioxidant levels, and sweeter taste.

Potatoes lose dry matter as their starch breaks down into sugars, releasing carbon dioxide (CO_2) and water vapor to sustain the tuber [27]. This process, known as respiration, leads to weight loss and can affect the potato's quality and shelf life.

To mitigate these losses, researchers have developed coatings made from chitosan, coconut oil, and whey protein [28]. These coatings have been shown to significantly reduce weight loss, respiration rates, decay, and shrinkage, ultimately helping to preserve the potato's quality and extend its shelf life.

Saha et al., [28] also demonstrated that combining chitosan with coconut oil and whey protein effectively reduced weight loss, respiration, decay, and shrinkage in potatoes compared to uncoated tubers. Whey protein, in particular, helps extend shelf life by controlling the levels of O_2 and CO_2, which slows down spoilage [29].

The reduction in total soluble solids (TS) in uncoated potatoes, as observed by Yadav et al., [30], may be attributed to a slower rate of sugar synthesis. This suggests that coating potatoes could potentially mitigate this issue.

Research by Camila et al., [31] has demonstrated the effectiveness of edible coatings in preserving the TS content of cherry tomatoes. By applying a 2% protein hydrolysate coating, they were able to maintain the fruit's sugar levels.

Butt et al., [32] have highlighted the potential of edible coatings to enhance the texture and nutritional value of foods. While promising results have been observed in fortifying foods with nutrients like zinc,

DOI: 10.5281/zenodo.14545934
Vol: 61 | Issue: 12 | 2024

additional research is necessary to develop optimal coating formulations for a wider variety of food products.

In this study, coated potatoes exhibited a significantly longer shelf life compared to uncoated tubers, lasting approximately one month longer.

Among the various coating treatments, potatoes coated with T2 (whey protein concentrate) demonstrated the most extended shelf life and the least amount of spoilage. Potatoes coated with T1 closely followed this.

The superior performance of T2 can be attributed to the gas barrier properties of whey protein. As reported by Kandasamy et al., [29], whey protein effectively regulates the levels of oxygen (O_2) and carbon dioxide (CO_2) within the storage environment, thereby delaying spoilage processes.

5. CONCLUSIONS

Potato dry matter (DM) content remained largely unaffected by treatment, storage conditions, or their interactions, although storage period (SP) had a slight impact, peaking at 24 days before declining until 60 days. Firmness (FR) was mainly influenced by SP, with refrigeration (SC2) being most effective in preserving it.

Total soluble solids (TS) were affected significantly by SP, treatment (TRT), and storage conditions (SC), with refrigeration again proving most effective in preserving TS. While treatments had minimal impact on DM and FR, they did influence TS, with TRT2 better preserving firmness but slightly reducing TS.

Longer storage periods, particularly beyond 32 days, led to a decline in quality. There were no significant interactions for DM and FR, but interactions between SP, TRT, and SC affected TS. Additionally, correlation analysis revealed minimal relationships between DM, FR, and TS, except at 32 days, where FR and TS were correlated significantly due to physiological changes.

6. RECOMMENDATION

To preserve potato quality, producers should prioritize optimal storage conditions, especially refrigeration. Prolonged storage, especially beyond 32 days, can significantly degrade quality.

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Conflict of Interest

The authors declare no conflicts of interest.

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Vol: 61 | Issue: 12 | 2024

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