__Original Research Article__

Effect of different levels of Sugar and Jaggery coating on freezing of Strawberry (*Fragaria x ananassa*) var. Winter Dawn

ABSTRACT

The present study was investigated the physiological changes occurring in strawberry fruits during storage and examined their effects on various quality attributes. The fruits were subjected to different storage treatments, namely T_0 to T_9. The study focused on analyzing parameters such as weight loss, firmness, total soluble solids (TSS), ascorbic acid content, pH, color, texture, taste, aroma, and overall acceptability. The results revealed significant variations in these quality attributes across the different storage treatments. In terms of weight loss, the minimum recorded was in T_3, which experienced a loss of 12.88%, while the maximum weight loss was observed in T_9 (38.00%), followed by T_7 (14.22%). When it came to firmness, T_3 exhibited the highest value of 20.88, indicating better fruit texture, while T_7 had the lowest firmness (19.7), followed by T_2 (20.84). The study also assessed the TSS content of the strawberry fruits, with T_3 exhibiting the highest value of 8.83, indicating a higher sugar content, while T_7 had the lowest TSS (7.20), followed by T_2 (8.10). In terms of ascorbic acid content, T_3 had the maximum value of 0.24, indicating higher vitamin C content, while T_7 had the lowest (0.20), followed by T_8 (0.23). Moreover, the study analyzed pH levels, with T_3 showing the highest value of 3.61, while T_9 had the lowest pH (3.46), followed by T_8 (3.55). Additionally, T_3 had the highest color intensity (9), whereas T_0 had the lowest (6.93), followed by T_8 (8.54). Furthermore, texture, taste, aroma, and overall acceptability were examined. Where, T_3 received the highest scores for texture, taste, aroma, and overall acceptability, indicating superior sensory attributes, while T_7 had the lowest scores, followed by T_6. In summary, the study provided insights into the physiological changes occurring in strawberry fruits during storage and their impact on quality attributes. The findings highlight the importance of selecting appropriate storage conditions to minimize weight loss, maintain firmness, optimize TSS and ascorbic acid content, control pH levels, enhance color intensity, and improve sensory characteristics. Implementing these findings can contribute to preserving the quality and market value of strawberries, ultimately satisfying consumer preferences and expectations.

Keywords: Strawberry fruits, Storage, Physiological changes, Quality attributes, Weight loss, jaggary and sugar coating, freezing.

INTRODUCTION

Botanical name: *Fragaria ananassa* Octoploid 2n= 8x= 56 Strawberries are very perishable fruits. The strawberry (*Fragaria ananassa*) is a widely cultivated hybrid of the genus Fragaria, collectively known as the strawberry, grown around the world for its fruit. Strawberries are one of the most important seasonal fruit crops. Most of its production is destined for the fresh market, but because of the short shelf life and seasonal nature of this fruit, part of its production is processed. In this way, it is used as a food ingredient in yogurts, pies, milk shakes, jams, ice creams, etc. because of its interesting sensory attributes. The types of strawberry processing most commonly used to increase product shelf life are freezing, partial or total dehydration and other combined methods. In these cases, the processed fruit undergoes changes in sensory attributes such as texture, color and changes in the profile of volatile compounds making the product different from nontreated products. **Delgado *et a*l. (2005),** Other quality attributes, such as product taste or flavor related to fruit composition on major sugars and acidity, may also be altered during such processes**.** As a preservation method, freezing combines low temperature and a water activity (Aw) reduction associated with the cryoconcentration of the fruit liquid phase during ice crystal formation. Granulated table sugar (sucrose) is the most frequently used sweetener in canning and freezing. Sugar helps preserve the color, texture and flavor of the food. The sugar in jams and jellies helps the gel to form, and increases the flavor. When sugar is added to fresh foods, like fruits and vegetables, it creates an osmotic effect. This means sugar absorbs water in the food resulting in the reduction of water activity (Aw). Bacteria need water to grow and multiply, so lowering the water activity in a food product means there is less free water molecules for the bacteria. It creates an environment that limits microbial survival and growth. **Feliziani *et al.*, (2015).**

Sugar has a long history of preserving foods. In some foods, sugar facilitates the production of other substances that act as preservatives, like alcohol and acids. For example, sugar is converted by fermentative yeasts to ethanol in wine, beer and other fermented drinks, or converted to organic acids like lactic acid in fermented foods such as sauerkraut, kimchi, pickles, sourdough bread, yogurts, miso and tempeh. In these cases, the alcohol or acid produced are both preservatives themselves. Another example of using sugar as a preservative is the practice of 'sugaring'. As a preservation method, freezing combines low temperature and a water activity (Aw) reduction associated with the cryoconcentration of the fruit liquid phase during ice crystal formation. Granulated table sugar (sucrose) is the most frequently used sweetener in canning and freezing. Sugar helps preserve the color, texture and flavor of the food. The sugar in jams and jellies helps the gel to form, and increases the flavor. When sugar is added to fresh foods, like fruits and vegetables, it creates an osmotic effect. This means sugar absorbs water in the food resulting in the reduction of water activity (Aw). Bacteria need water to grow and multiply, so lowering the water activity in a food product means there is less free water molecules for the bacteria. It creates an environment that limits microbial survival and growth.

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Materials and Methods

The experiment on prolonging the shelf life of the strawberry was conducted at Post Harvest Laboratory, Department of Horticulture, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology & Sciences, and PRAYAGRAJ (UP) during 2022.

Statistical analysis was done by using method of analysis of variance (ANOVA) for completely randomized block design (CRBD) by Panse and Sukhtme (1984). The overall significance of difference among the treatment was tested, using critical difference (C. D. at 5%) level of significance. The result were statistically analyzed with the help of a window based computed package OPSTAT (Sheoran, 2004).

RESULT AND DISSCUSSION:

PHYSIOLOGICAL LOSS IN WEIGHT (PLW) OF STRAWBERRY

The table and figure presented, labeled as Table 1 demonstrate the impact of applying carbon dioxide after harvest on the physiological weight loss (PLW) of strawberry fruit during ripening and storage. The data in both formats are expressed as percentages.

The application of sugar and jaggery treatments after harvesting had a significant impact on the physiological weight loss (PLW) of strawberry fruit, as depicted in Table 1. As the storage period increased, the PLW also increased progressively. The average PLW values for different storage periods showed a linear increase from 42 to 42.32 between the 15th and 45th day of storage at a controlled freezing temperature of -4 degree Celsius.

As the storage period is extended, the physiological weight loss of strawberry fruits increases, primarily due to the progression of ripening. This loss of fruit weight can be attributed to the natural processes of transpiration and respiration, which lead to the loss of water from the fruits.

Fruits undergo continuous respiration both before and after harvest, and this process results in the loss of water. Once the fruit is harvested, it cannot replenish the lost water. However, the physiological weight loss in strawberry fruit was found to be minimal when it was treated with T_3 Freezing + Sugar Coating, specifically with a dosage of 2 grams per fruit. **Bovi *et al.* (2018).**

TABLE 1: Effect of Change in Physiological loss of weight (%) of Strawberry fruits during storage

S. No.	TREATMENT	0 DAT	15 DAT	30 DAT	45 DAT
T_0	No treatment	10.5	9.15	27.40	27.44
T_1	Freezing + Sugar Coating (1g/fruit)	10.61	9.50	19.01	37.00
T_2	Freezing + Sugar Coating (1.5g/fruit)	12.00	7.83	13.66	27.88
T_3	Freezing + Sugar Coating (2 g/fruit)	15.00	7.23	7.23	12.88
T_4	Freezing + Jaggery (1 g/fruit)	17.61	5.63	11.32	19.00
T_5	Freezing + Jaggery (1.5 g/fruit)	17.00	5.55	11.60	18.00
T_6	Freezing + Jaggery (2 g/fruit)	14.00	4.8	11.11	20.00
T_7	Freezing + Sugar Coating (0.5g/fruit) + Jaggery (0.5g/fruit)	20.00	4.85	8.8	14.22
T_8	Freezing + Sugar Coating (0.75g/fruit) + Jaggery (0.75g/fruit)	20.33	4.88	8.0	16.41
T_9	Freezing + Sugar Coating (1 g/fruit) + Jaggery (1g/fruit)	10.61	9.50	19.01	38.00
	F-Test	S	S	S	S
	SE(d)	4.143	1.818	6.189	7.765
	C.D. at 0.5%	1.310	0.574	1.957	2.455
	CV	0.260	0.281	0.487	0.368

FIRMNESS OF STRAWBERRY

Flesh firmness is a crucial indicator of fruit quality, especially in strawberries. It is typically measured using a penetrometer, which records the maximum force exerted when a probe is inserted into the fruit's flesh.

In this study, the impact of sugar and jaggery application on the firmness of strawberries during storage was investigated. The findings, presented in Table 2, revealed that the storage period significantly influenced the fruit's firmness. As the storage period increased, the firmness of strawberries decreased from 15.00 to 12.88 under controlled freezing temperature (-4°C). It was observed that lower storage temperatures increased the firmness of the fruit, possibly due to increased resistance of the strawberry's outer layer to puncturing.

The firmness of strawberries was found to be minimal when treated with T_3 Freezing + Sugar Coating (2 g/fruit), followed by T_7 Freezing + Sugar Coating (0.5 g/fruit) + Jaggery (0.5 g/fruit). A study by **Belay *et al.* (2017)** examined the mass transfer between fruit pieces and solution during the rehydration process, as well as the physicochemical characteristics of the reconstituted products. The results demonstrated that by adjusting the concentration of the sugar solution and reconstitution time, different characteristics such as water activity, freezing point, amount of freezable water, and firmness could be achieved in rehydrated fruit pieces from the same freeze-dried product. These characteristics were also found to be linearly correlated with the soluble solids content in the rehydrated products. Consequently, the reconstituted freeze-dried strawberries could be utilized as an ingredient in formulated foods at various levels of water activity and in frozen desserts or ice cream.

Overall, this study highlights the influence of storage conditions and the application of sugar and jaggery on the firmness of strawberries. These findings contribute to our understanding of maintaining fruit quality during storage and offer potential applications in the food industry.

TABLE 2: Effect of Change in Firmness (kg/cm^2) of Strawberry during storage

S. No.	TREATMENT	0 DAT	15 DAT	30 DAT	45 DAT
T_0	No treatment	23.02	23.1	23.16	20.1
T_1	Freezing + Sugar Coating (1g/fruit)	22.15	22.53	23.23	20.22
T_2	Freezing + Sugar Coating (1.5g/fruit)	22.34	22.65	22.74	20.84
T_3	Freezing + Sugar Coating (2 g/fruit)	23.17	22.44	21.74	20.88
T_4	Freezing + Jaggery (1 g/fruit)	23.32	22.13	22.42	20.60
T_5	Freezing + Jaggery (1.5 g/fruit)	23.12	22.11	22.54	20.38
T_6	Freezing + Jaggery (2 g/fruit)	23.45	22.43	22.32	20.16
T_7	Freezing + Sugar Coating (0.5g/fruit) + Jaggery (0.5g/fruit)	22.52	22.84	20.72	19.7
T_8	Freezing + Sugar Coating (0.75g/fruit) + Jaggery (0.75g/fruit)	23.16	21.12	20.20	19.82
T_9	Freezing + Sugar Coating (1 g/fruit) + Jaggery (1g/fruit)	23.33	21.07	21.53	19.48
	F-Test	S	S	S	S
	SE(d)	0.453	0.673	1.005	0.469
	C.D. at 0.5%	0.143	0.212	0.317	0.148

	CV	**0.019**	**0.030**	**0.0456**	**0.023**

TOTAL SOLUBLE SOLID OF STRAWBERRY

The presented data in Table no. 3 show the changes in total soluble solids (TSS) in strawberry fruit as influenced by the post-harvest application of sugar and jaggery coatings during ripening and storage.

The storage period had a significant impact on the percentage of TSS in the strawberry fruit. As the storage period extended, the TSS percentage increased, regardless of the treatments applied.

Among the different treatments, there was a significant variation in the mean TSS values. The highest percentage of TSS, recorded as 8.22, was found in fruits treated with T_1 freezing + sugar coating (1g/fruit), while the lowest percentage of TSS, recorded as 7.83, was observed in fruits treated with T_3freezing + sugar coating (2g/fruit) under controlled freezing temperature.

The initial increase in TSS during storage can be attributed to the conversion of starch and other polysaccharides into sugars. However, as the storage period advanced, the TSS decreased, likely due to the increased rate of respiration in the later stages of storage. **Bovi & Mahajan (2018).**

TABLE 3: Effect of change in Total Soluble Solid (º Brix) of Strawberry duringstorage

S. No.	TREATMENT	0 DAT	15 DAT	30 DAT	45 DAT
T_0	No treatment	6.65	7.25	7.98	8.11
T_1	Freezing + Sugar Coating (1g/fruit)	6.63	6.79	7.23	8.09
T_2	Freezing + Sugar Coating (1.5g/fruit)	6.61	7.1	7.23	8.1
T_3	Freezing + Sugar Coating (2 g/fruit)	6.66	7.77	7.98	8.83
T_4	Freezing + Jaggery (1 g/fruit)	6.62	6.53	6.98	7.23
T_5	Freezing + Jaggery (1.5 g/fruit)	6.63	6.66	7.01	7.34
T_6	Freezing + Jaggery (2 g/fruit)	6.61	6.78	6.88	7.24
T_7	Freezing + Sugar Coating (0.5g/fruit) + Jaggery (0.5g/fruit)	6.62	6.68	6.82	7.2
T_8	Freezing + Sugar Coating (0.75g/fruit) + Jaggery (0.75g/fruit)	6.63	6.7	6.92	7.28
T_9	Freezing + Sugar Coating (1 g/fruit) + Jaggery (1g/fruit)	6.65	6.6	6.98	7.28
	F-Test	S	S	S	S

	SE(d)	**0.017**	**0.223**	**0.336**	**0.421**
	C.D. at 0.5%	**0.005**	**0.07**	**0.106**	**0.133**
	CV	**0.002**	**0.032**	**0.047**	**0.055**

ASCORBIC ACID OF STRAWBERRY

The impact of sugar and jaggery coating on the ascorbic acid content of strawberry fruit during storage is presented in Table 4.

The storage period had a notable effect on the ascorbic acid content of the strawberry fruit. As the storage period extended, regardless of the treatments applied, the ascorbic acid content progressively decreased from 15 days to 45 days in controlled freezing temperature.

The mean value of ascorbic acid varied significantly among the different treatments.

The highest percentage of ascorbic acid, recorded as 0.22, was found in fruits treated with freezing + sugar coating (1.5g/fruit), while the lowest percentage of ascorbic acid, recorded as 0.21, was observed in fruits treated with freezing + sugar coating (0.5g/fruit) + jaggery (0.5g/fruit) under controlled freezing temperature.

The data in Table.4 clearly show a gradual decrease in ascorbic acid content of strawberry fruits in all the treatments as the storage period progressed. This reduction can be attributed to its degradation in various metabolic processes during the storage of the fruit.

Moraga *et al*., (2006) studied changes in sugar composition (glucose, fructose and sucrose), citric acid, water and total soluble content, as induced by partial dehydration and freezing– thawing processes, were analyzed in strawberries (var. Camarosa). Osmotic dehydration (OD) with 65 °Brix sucrose solution, air drying (AD) at 45C, or combined treatments (OD– AD) were applied to reduce strawberries' water content to 70–85%. Fresh and dehydrated samples were frozen (−40C, 24 h) and stored (−18C, 30 and 180 days). All samples processed by OD and OD–AD showed a significant sugar gain, and depending on the dehydration treatment, total or partial sucrose hydrolysis was observed. Dehydration treatments caused small losses of citric acid. During the freezing–thawing process, drip loss and enzymatic action also cause changes in sugar concentration, especially in OD-treated samples.

TABLE 4: Effect of change in Ascorbic acid (mg/100ml) of strawberry during storage

S. No.	TREATMENT	0 DAT	15 DAT	30 DAT	45 DAT
T_0	No treatment	0.25	0.26	0.23	0.21
T_1	Freezing + Sugar Coating (1g/fruit)	0.25	0.25	0.23	0.21
T_2	Freezing + Sugar Coating (1.5g/fruit)	0.26	0.25	0.24	0.22
T_3	Freezing + Sugar Coating (2 g/fruit)	0.23	0.26	0.26	0.24
T_4	Freezing + Jaggery (1 g/fruit)	0.26	0.24	0.24	0.22
T_5	Freezing + Jaggery (1.5 g/fruit)	0.25	0.25	0.25	0.22
T_6	Freezing + Jaggery (2 g/fruit)	0.26	0.24	0.25	0.22
T_7	Freezing + Sugar Coating (0.5g/fruit) + Jaggery (0.5g/fruit)	0.24	0.25	0.23	0.2
T_8	Freezing + Sugar Coating (0.75g/fruit) + Jaggery (0.75g/fruit)	0.25	0.26	0.25	0.23
T_9	Freezing + Sugar Coating (1 g/fruit) + Jaggery (1g/fruit)	0.25	0.26	0.24	0.22
	F-Test	S	S	S	S
	SE(d)	0.007	0.007	0.01	0.007
	C.D. at 0.5%	0.002	0.002	0.003	0.002
	CV	0.029	0.031	0.042	0.033

pH OF STRAWBERRY

The impact of post-harvest application of sugar and jaggery coating on pH is presented in Table 5.

The storage period had a significant influence on the pH percentage in strawberry fruit. As the storage period extended, regardless of the treatments applied, the pH also increased.

When considering the mean values of the treatments, the change in pH of strawberry fruit was highest in freezing + sugar coating (1.5g/fruit), recorded as 3.53, and lowest in freezing + sugar coating (1g/fruit) + jaggery (1g/fruit), recorded as 3.61, followed by T_7 freezing + sugar coating (0.5g/fruit) + jaggery (0.5g/fruit), recorded as 3.54, under controlled freezing temperature.

The increase in pH was a result of the decrease in acidity of the fruit juice. Fruit juices usually have low pH due to their comparatively high organic acid content **Bovi & Mahajan (2018).** The rise in pH might be attributed to the decrease in total titratable acid of the beverage samples, as acidity and pH have an inverse relationship **Dung *et al.* (2020).**

TABLE 5: Effect of Change in pH of Strawberry fruits during storage

S. No.	TREATMENT	0 DAT	15 DAT	30 DAT	45 DAT
T_0	No treatment	3.21	3.22	3.42	3.46
T_1	Freezing + Sugar Coating (1g/fruit)	3.32	3.33	3.41	3.48
T_2	Freezing + Sugar Coating (1.5g/fruit)	3.4	3.41	3.53	3.52
T_3	Freezing + Sugar Coating (2 g/fruit)	3.45	3.47	3.51	3.61
T_4	Freezing + Jaggery (1 g/fruit)	3.31	3.33	3.46	3.47
T_5	Freezing + Jaggery (1.5 g/fruit)	3.4	3.41	3.45	3.51
T_6	Freezing + Jaggery (2 g/fruit)	3.41	3.43	3.5	3.53
T_7	Freezing + Sugar Coating (0.5g/fruit) + Jaggery (0.5g/fruit)	3.43	3.45	3.52	3.54
T_8	Freezing + Sugar Coating (0.75g/fruit) + Jaggery (0.75g/fruit)	3.44	3.46	3.54	3.55
T_9	Freezing + Sugar Coating (1 g/fruit) + Jaggery (1g/fruit)	3.23	3.43	3.11	3.49
	F-Test	S	S	S	S
	SE(d)	0.078	0.082	0.061	0.045
	C.D. at 0.5%	0.024	0.025	0.019	0.014
	CV	0.023	0.024	0.017	0.012

FRUIT COLOR OF STRAWBERRY

The color of strawberries was evaluated using a color analyzer application version 2.0.1. The analysis used three values in the CIELAB color space: L* for lightness, a* for the red/green coordinate, and b* for the yellow/blue coordinate, which together measure objective color and calculate color differences.

Table 6 shows the impact of different levels of sugar and jaggery coating on the color of strawberry fruit. It was observed that when the fruits were stored under high freezing atmospheres (T_0 to T_9), they exhibited more vibrant color (chroma) and higher L* values compared to the fruits stored in regular air.

In other cases, there was a continuous decrease in L* values for all treatments during the storage period, which is a typical pattern for many fruits during their post-harvest life. The L* values of strawberries stored under high freezing atmospheres decreased over a storage period of 50 days, but there were no significant differences among the treatments. Previous studies conducted by **Ansar *et al.(*2020)** also found no significant effect on strawberry color when stored at high freezing temperatures for 45 days at -4oC. **Patil *et al*. (2016)**

TABLE 6: Effect of Change in Fruit color of Strawberry during storage

S. No.	TREATMENT	0 DAT	15 DAT	30 DAT	45 DAT
T_0	No treatment	5.12	5.44	6.6	6.93
T_1	Freezing + Sugar Coating (1g/fruit)	5.22	6.11	7	8.23
T_2	Freezing + Sugar Coating (1.5g/fruit)	6	7	8	8
T_3	Freezing + Sugar Coating (2 g/fruit)	7.34	9	9	9
T_4	Freezing + Jaggery (1 g/fruit)	5	6	7.44	7.21
T_5	Freezing + Jaggery (1.5 g/fruit)	5.33	6.55	7.11	7.49
T_6	Freezing + Jaggery (2 g/fruit)	5	7	8.21	8
T_7	Freezing + Sugar Coating (0.5g/fruit) + Jaggery (0.5g/fruit)	5.23	7.21	8.11	7
T_8	Freezing + Sugar Coating (0.75g/fruit) + Jaggery (0.75g/fruit)	6.2	7.28	8.64	8.54
T_9	Freezing + Sugar Coating (1 g/fruit) + Jaggery (1g/fruit)	5.44	6.44	7	8
	F-Test	S	S	S	S
	SE(d)	0.736	0.97	0.795	0.626
	C.D. at 0.5%	0.232	0.306	0.251	0.197
	CV	0.131	0.142	0.103	0.079

CONCLUSION

From this current investigation, it is concluded that Treatment T_3 (freezing + sugar coating 2g/fruit) performed best in terms of quality parameters such as TSS (8.83^{o}Brix), ascorbic acid (0.24mg/), pH (3.53). And in quantitative parameters like the Physiological loss in weight and fruit firmness T_3 shows the best result 14.44 and 20.88 respectively.

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