

Effect of different levels of carbon dioxide concentrations on qualitative traits of strawberry (*Fragaria × ananassa*) during storage var. Winter Dawn

Abstract

The present investigation the effect of different levels of carbon dioxide concentration on qualitative traits of strawberry during storage was studied. Strawberry (*Fragaria × ananassa*) were stored at ambient temperature for 5 days and controlled temperature at 5°C for 14 days in eight different atmospheres: air, 5% CO₂, 10% CO₂, 15% CO₂, 20% CO₂, 25% CO₂, 30% CO₂, 35% CO₂. Changes in several parameters were evaluated. Atmosphere with high carbon dioxide were the most effective in preventing the fungal growth and enhancing strawberry firmness. However, other quality parameters such as color, titrable acidity, ascorbic acid, TSS, pH, aroma were only mildly affected by superatmospheric CO₂ levels. The result showed that atmosphere with treatment 35% CO₂ proved as the most effective one to control the weight loss, firmness, and to minimized the fruit decay. In conclusion, strawberries stored under superatmospheric carbon dioxide conditions maintained the fungal growth, firmness, weight loss and increase the shelf life as compared to air stored. In future, these experimental results may prove very useful for increasing the shelf life of strawberry fruits for certain period in better quality.

Keywords: Strawberry, shelf life, color, flavor, aroma, high- carbon dioxide atmospheres, quality

Introduction

Strawberry (*Fragaria × ananassa*) is a widely grown hybrid species of the genus *Fragaria*, collectively known as the strawberries, which are very perishable fruits, susceptible to mechanical damage, physiological deterioration, drying and rotting. At high temperatures, the respiration process increases, leading to a marked depletion of nutrient reserves, resulting in rapid aging of the fruit. Rapid cooling of strawberries near 0°C can slow unwanted quality changes and increase shelf life, but even at low temperatures and high relative humidity, shelf life is only about 7 days. The physiological behaviour of fresh horticultural produce such as

respiration and transpiration affects its quality and shelf life (Belay, Caleb, Mahajan, & Opara, 2017; Mahajan et al., 2017; Mashabela, Mahajan, & Sivakumar, 2019). Aerobic respiration of fresh produce is oxidative breakdown of substrate molecules such as starch, sugars, and organic acids to simpler molecules such as CO₂. Respiration causes senescence, loss of firmness and oxidative mass loss of fresh produce. Chemical reaction of aerobic respiration also generates some heat, major part of which is released from produce surface by evaporating water vapour from surface layers (Kader & Saltveit, 2003). Low O₂ and high CO₂ concentration in the ambient surrounding the produce can decrease the respiration rate (Kader, Zagory, Kerbel, & Wang, 1989; Nielsen & Leufvén, 2008) and thereby extend the shelf life (Aday & Caner, 2013; Bovi, Caleb, Ilte, Rauh, & Mahajan, 2018; Kader & Saltveit, 2003). Nunes, Morais, Brecht, and Sargent (1995) compared the effect of two different controlled atmosphere (CA) treatments.

Shelf life can be expressed as the keeping quality which is the time taken before quality falls below the consumer acceptance limit under given storage conditions (Hertog, Uysal, Mccarthy, Verlinden, & Nicolai, 2014). Hertog, Boerrigter, Van Den Boogaard, Tijskens, and Van Schaik (1999) developed an integrated model approach to predict the keeping quality of strawberries packed under modified atmosphere. In general, most studies in the past evaluated the effects of temperature and CO₂ on the nutritional quality of strawberries separately. However, an understanding of the interactive effects of these two environmental factors (high temperature and CO₂ on phytochemicals is limited. Thus, it is critical to investigate the interactive effects of CO₂ and temperature on the nutritional quality, more importantly the antioxidant contents, especially polyphenols in strawberries.

Carbon dioxide (CO₂) plays an essential role in agriculture. During cultivation, CO₂ enrichment is used in plant factory systems to improve yield and quality. CO₂ also acts as a substrate for photosynthesis. In postharvest processes and cultivation, CO₂ is used during controlled atmosphere storage or short-term high-CO₂ treatment to maintain freshness and increase the shelf life of different fruit. However, the mechanism whereby CO₂ maintains fruit freshness during the postharvest process remains unclear.

High-CO₂ treatment is widely applied to reduce postharvest losses in horticultural fruits, as it effectively reduces the respiration rate and fruit decay and increases firmness. In strawberry fruits, a short-term high-CO₂ treatment of approximately 3 h increased fruit firmness with

CO₂ concentrations ranging from 10 to 100 kPa. Higher CO₂ concentrations are usually more effective, but can cause physiological injuries, such as fruit discoloration and off-flavors.

To solve this problem, high-CO₂ treatment is used as a postharvest technology to increase firmness and reduce decay. Respiration at oxygen concentrations up to 20 kPa in combination with different levels of CO₂ has been studied for several strawberry cultivars in the past (Li and Kader, 1989; Talasila et al., 1992; Chambroy et al., 1993; Renault et al., 1994; Hertog et al., 1999).

The aim of this work was to investigate the effect of atmosphere containing high carbon dioxide concentration levels on strawberry organoleptic quality by means of determination of strawberry main components: Firmness color, TSS, ascorbic acid, titable acidity, pH.

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 2022-2023.

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 DISCUSSION

Physiological loss in weight (%): The data illustrated in the Table 1. Revealed that there was significant loss in weight of strawberry fruits. Fruits of strawberry treated with 35% of CO₂ in ambient temperature and controlled temperature exhibited mean minimum physiological loss in weight (i.e. 11.76 and 12.87 percent at the end of storage respectively) as compared to 5% of CO₂ fruits, which showed a mean maximum PLW of 30.3 and 38.04 percent respectively.

The loss in fruit weight can be attributed to the loss of water from fruits due to respiration and transpiration.

As storage period extended, the physiological losses in weight of strawberry fruits of variety Winter Dawn increased because of increase in ripening. This loss of fruit weight can be attributed to the loss of water from fruits due to transpiration and respiration.

Fruits are continuously respiring before and after harvest and in this process they loose water, this cannot be replenished in the harvested fruit. The physiological loss in weight in strawberry fruit was minimum when treated with 35% of CO₂ followed by 30% CO₂.

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

Treatments	Room temperature					Controlled temperature (5°C)					
	0	2	4	5	Mean	0	4	8	12	14	Mean
T ₁ - Control	10.66	18.18	-	-	14.42	11	9.14	27.42	-	-	15.85
T ₂ - 5% CO ₂	10.66	9.09	21.21	30.3	17.82	10.66	9.51	19.02	28.53	38.04	21.15
T ₃ - 10% CO ₂	9.33	14.81	22.22	29.62	19.00	12	7.93	13.64	22.14	27.85	16.71
T ₄ - 15% CO ₂	13.66	10.25	17.94	25.63	16.87	15	4.6	11.28	15.59	20.05	13.30
T ₅ - 20% CO ₂	18.33	5.55	18.51	23.23	16.41	17.66	5.66	11.32	21.02	18.94	14.92
T ₆ - 25% CO ₂	10.66	9.09	9.09	18.18	11.76	17	5.89	11.62	17.68	17.68	13.97
T ₇ - 30% CO ₂	21.33	6.05	10.60	16.66	13.66	15	7.24	7.24	14.48	14.48	11.69
T ₈ - 35% CO ₂	17.66	5.88	5.88	11.76	10.30	20	4.84	8.03	9.69	12.87	11.09
CD at 0.5%	1.00	7.56	5.36	8.76		2.28	2.79	4.53	9.60	5.56	

Firmness: Storage period significantly influenced the firmness of the fruits. As the storage period extended, the firmness reduces from 23.96 to 21.82 in room temperature and 23.72 to 20.32 in controlled temperature (5°C). The firmness in strawberry was minimum when they are treated with 35% of CO₂ followed by 30% of CO₂ respectively.

Fruits of strawberry treated with 35% of CO₂ in room temperature and controlled temperature exhibited mean maximum firmness (i.e. 22.76 and 20.86 respectively) as compared to the 5% of CO₂ fruits, which showed minimum firmness of 21.16 and 19.8 respectively. The loss in fruit firmness can be attributed due to ripening of fruits during storage.

Table 2: Effect of Change in Firmness of Strawberry during storage

Treatments	Room temperature					Controlled temperature (5°C)					
	0	2	4	5	Mean	0	4	8	12	14	Mean
T ₁ - Control	23.33	23.16	-	-	23.25	23.1	22.83	20.7	-	-	22.21
T ₂ - 5% CO ₂	23.4	23.2	22.26	21.16	22.51	23.83	22.53	21.83	20.73	19.8	21.74
T ₃ - 10% CO ₂	24.33	23.86	22.26	21.43	22.97	23.43	22.26	21.73	20.53	19.86	21.56
T ₄ - 15% CO ₂	23.3	23.06	22.63	21.53	22.63	23.63	22.53	21.3	20.66	19.86	21.60
T ₅ - 20% CO ₂	24.33	23.86	22.63	21.63	23.11	23.3	22.8	22.06	21.73	20.3	22.04
T ₆ - 25% CO ₂	24.16	23.83	22.4	21.73	23.03	24.16	23.66	22.73	21.63	20.76	22.59
T ₇ - 30% CO ₂	24.33	24.06	23.3	22.5	23.55	24.53	23.33	22.63	21.73	20.83	22.61
T ₈ - 35% CO ₂	24.5	24.2	23.66	22.76	23.78	23.8	23.16	22.43	21.73	20.86	22.40
CD at 0.5%	0.13	0.12	0.46	0.11		0.13	0.11	0.12	0.10	0.12	

Fruit Color: Fruit surface color was evaluated using a color analyzer application version 2.0.1. As shown L* indicates lightness, a* is the red/green coordinate, and b* is the yellow/blue coordinate. The letter L*, a*, b* represents each of the three values the CIELAB color space uses to measure objective color and calculate color differences.

Table 3. shows the effect of different levels of carbon dioxide concentrations on the color of strawberry fruit. As can be observed, when stored under high carbon dioxide atmospheres (5- 35% CO₂), it showed more vivid color (chroma) and higher L* compared to the fruits stored in air.

Table 3: Effect of Change in fruit color of Strawberry during storage

DAY & TREATMENT (Room temperature)	L*	A*	B*	Hue	DAY & TREATMENT Controlled temperature	L*	A*	B*	Hue
Day 0 (Control)	31.92	38.08	29.82	38.06	Day 0 (Control)	35.03	48.67	36.07	36.54
5% CO ₂	30.51	44.51	38.26	40.68	5% CO ₂	34.98	42.47	17.75	32.99
10% CO ₂	32.35	38.03	35.36	42.92	10% CO ₂	34.67	32.60	18.80	42.06
15% CO ₂	31.91	46.58	44.85	43.85	15% CO ₂	34.64	44.28	21.72	44.14
20% CO ₂	34.92	31.36	19.49	30.99	20% CO ₂	35.24	34.4	21.43	30.83
25% CO ₂	33.48	40.07	19.91	41.90	25% CO ₂	34.92	31.36	19.49	30.99
30% CO ₂	30.21	33.90	18.09	43.85	30% CO ₂	34.44	32.35	19.73	32.74
35% CO ₂	33.54	43.32	31.63	36.13	35% CO ₂	35.25	34.84	21.43	30.83
Day 5 (Control)	-	-	-	-	Day 14 (Control)	-	-	-	-
5% CO ₂	30.41	33.57	35.91	46.92	5% CO ₂	34.55	31.75	22.17	34.11
10% CO ₂	31.54	43.32	31.63	36.13	10% CO ₂	34.31	27.43	15.61	28.98
15% CO ₂	31.56	51.43	19.28	36.80	15% CO ₂	34.35	30.43	18.51	30.54
20% CO ₂	34.63	44.28	21.72	44.14	20% CO ₂	35.01	29.25	17.53	30.46
25% CO ₂	33.1	39.51	20.21	43.91	25% CO ₂	34.24	30.65	17.34	28.92
30% CO ₂	30.22	34.00	17.74	42.49	30% CO ₂	34.25	30.65	17.34	28.92
35% CO ₂	33.52	40.13	19.93	41.54	35% CO ₂	35.01	29.25	17.53	30.46

Total soluble solid: The changes in total soluble solids (TSS) of strawberry fruits packed with different levels of CO₂ concentration exhibited significant difference (at 5% level) with respect to period of storage only, but no significant variation was recorded with respect to the different levels of CO₂ concentrations used. Under room temperature condition (Table 4), the TSS showed a continuous increase in the soluble solids content during storage till 5th day under room temperature and 14th day under controlled temperature respectively. However, it has been reported that in other fruits high CO₂ atmospheres could increase, decrease, or have no effect on the respiration rate, depending on the species, variety, ripening stage, CO₂ concentration, storage period and temperature.

Similarly, **Magazine *et al.* (2015) and Li and Kader (1989)** also reported, strawberry fruits packed in LDPE in room storage retain the TSS per cent compared to the other packaging material. TSS of strawberry increase up to a short period of storage and then a steady decrease was observed. The initial rise in TSS might be attributed to the completion of ripening process of the unripe fruits.

The increase in TSS during the initial stages may be attributed due to the conversion of starch and other polysaccharides into sugars and decrease in TSS at advance stage, is owing to the increased rate of respiration in later stages of storage (**Mukherjee and Dutta, 1967**).

TABLE 4: Effect of change in Total Soluble Solid (° Brix) of Strawberry during storage

Treatments	Room temperature					Controlled temperature (5°C)					
	0	2	4	5	Mean	0	4	8	12	14	Mean
T ₁ - Control	6.64	6.86	-	-	6.76	6.64	7.26	7.97	-	-	7.29

T ₂ - 5% CO ₂	6.62	7.03	8.01	8.36	7.51	6.63	6.78	7.22	8.21	8.22	7.41
T ₃ - 10% CO ₂	6.61	7.05	8.01	8.23	7.48	6.61	7.08	7.22	7.88	8.11	7.38
T ₄ - 15% CO ₂	6.64	7.04	7.36	8.21	7.31	6.65	6.72	6.97	7.03	7.84	7.04
T ₅ - 20% CO ₂	6.62	7.04	7.05	7.76	7.12	6.62	6.43	6.97	7.11	7.22	6.87
T ₆ - 25% CO ₂	6.62	7.04	7.05	7.7	7.10	6.63	6.66	6.92	7.22	7.34	6.95
T ₇ - 30% CO ₂	6.61	7.04	7.04	7.63	7.08	6.61	6.67	6.88	7.02	7.22	6.88
T ₈ - 35% CO ₂	6.61	7.04	7.05	7.36	7.02	6.62	6.67	6.82	7.22	7.22	6.91
CD at 0.5%	0.01	0.02	0.36	0.10		0.01	0.04	0.02	0.01	0.02	

Ascorbic acid: The data recorded during the period of study revealed that the ascorbic acid content of strawberry fruits packed in different levels of CO₂ concentration varied significantly (at 5% level of significance) over the period of storage. Under the room temperature storage (Table 5), maximum ascorbic acid was recorded in fruits packed with 35% CO₂ (0.24mg/100ml) and (0.23mg/100ml) in controlled temperature respectively, which was at par the fruits packed with 25% CO₂ (0.23mg/100ml) in room temperature and 30% CO₂ (0.22mg/100ml) in controlled temperature respectively.

The ascorbic acid content of strawberry fruit was markedly influenced by storage period. As the storage period extended, irrespective of the treatments, the ascorbic acid content decreases progressively from 1st day to 5th day of storage in room temperature and 1st day to 14th day of storage in controlled temperature.

A progressive decrease in ascorbic acid content of strawberry fruits in all the treatments with the progress in storage period is evident from the data Table 5. A gradual but continuous reduction in ascorbic acid may be attributed to its degradation in various metabolic processes of stored fruit.

Mapson (1970) reported that the decrease in ascorbic acid content of strawberry fruit may be due to higher rate of respiration and oxidation. Similar decrease in ascorbic acid content was obtained by **Kirad *et al.* (2007)** with packaging of fruits.

Table 5: Effect of change in Ascorbic acid(mg/100ml) of strawberry during storage

Treatments	Room temperature					Controlled temperature (5°C)					
	0	2	4	5	Mean	0	4	8	12	14	Mean
T ₁ - Control	0.24	0.22	-	-	0.23	0.24	0.25	0.23	-	-	0.24

T ₂ - 5% CO ₂	0.24	0.24	0.22	0.21	0.23	0.24	0.24	0.23	0.22	0.21	0.23
T ₃ - 10% CO ₂	0.25	0.25	0.24	0.22	0.24	0.25	0.25	0.24	0.23	0.21	0.24
T ₄ - 15% CO ₂	0.25	0.25	0.24	0.22	0.24	0.25	0.25	0.24	0.23	0.22	0.24
T ₅ - 20% CO ₂	0.24	0.23	0.23	0.22	0.23	0.26	0.26	0.25	0.24	0.23	0.25
T ₆ - 25% CO ₂	0.25	0.25	0.24	0.23	0.24	0.24	0.25	0.24	0.23	0.22	0.24
T ₇ - 30% CO ₂	0.26	0.25	0.24	0.24	0.25	0.26	0.24	0.23	0.22	0.22	0.23
T ₈ - 35% CO ₂	0.26	0.25	0.25	0.24	0.25	0.25	0.25	0.24	0.23	0.23	0.24
CD at 0.5%	0.01	0.01	0.01	0.01		0.01	0.01	0.01	0.01	0.01	

pH OF STRAWBERRY:

The effect of post-harvest application of carbon dioxide on pH is presented in Table 6.

Storage period has significantly influenced the percentage of pH in strawberry fruit. As the storage period extended, irrespective of the treatments, the pH also increases respectively.

T ₁ - Control	3.21	3.21	-	-	3.21	3.20	3.21	3.31	-	-	3.24
T ₂ - 5% CO ₂	3.23	3.24	3.24	3.23	3.24	3.31	3.35	3.41	3.46	3.46	3.40
T ₃ - 10% CO ₂	3.22	3.23	3.24	3.26	3.24	3.40	3.42	3.53	3.55	3.53	3.49
T ₄ - 15% CO ₂	3.23	3.24	3.25	3.26	3.25	3.29	3.31	3.34	3.43	3.53	3.38
T ₅ - 20% CO ₂	3.23	3.24	3.25	3.26	3.25	3.30	3.32	3.35	3.41	3.47	3.37
T ₆ - 25% CO ₂	3.24	3.25	3.25	3.27	3.25	3.39	3.41	3.45	3.49	3.50	3.45
T ₇ - 30% CO ₂	3.23	3.25	3.25	3.27	3.25	3.41	3.43	3.44	3.52	3.59	3.48
T ₈ - 35% CO ₂	3.24	3.26	3.27	3.28	3.26	3.45	3.47	3.51	3.56	3.60	3.52
CD at 0.5%	0.01	0.02	0.01	0.02		0.01	0.02	0.02	0.01	0.01	

Titrateable acidity: The titrateable acidity of strawberry fruits packed in different levels of CO₂ concentration went on decreasing with the advancement of storage period. Under room temperature storage condition (Table 4), significant variation in titrateable acidity of

fruits packed with different packaging films was found, however, over the storage period, significant variation (at 5% level of significance) in titratable acidity was observed.

The minimal titratable acidity was recorded in fruits treated with 5% of CO₂. It can be observed from Table 7 that the titratable acidity decreases gradually in fruits.

It was observed that the total titratable acidity increased gradually in fruits treated with 35% of CO₂ while a faster decline in acidity was exhibited in control fruits. Decrease in acidity in fruits during storage has been attributed to conversion of acid to sugar (**Pool et al., 1972**) or its utilization in respiration.

The interaction between the packaging films and storage periods was not-significant. Similar trend in decrease in the acidity of strawberry fruit over a storage period was observed by **Garcia et al. (1998)**, **Kirad et al. (2007)** and **Shood et al. (2012)**.

Table 7: Effect of change in Titratable Acidity (%) of Strawberry fruits during storage

Treatments	Room temperature					Controlled temperature (5°C)					
	0	2	4	5	Mean	0	4	8	12	14	Mean
T ₁ - Control	0.29	0.28	-	-	0.29	0.29	0.25	0.24	-	-	0.26
T ₂ - 5% CO ₂	0.27	0.26	0.25	0.24	0.26	0.27	0.24	0.22	0.22	0.21	0.23
T ₃ - 10% CO ₂	0.28	0.26	0.25	0.24	0.26	0.28	0.25	0.24	0.23	0.22	0.24
T ₄ - 15% CO ₂	0.27	0.26	0.25	0.24	0.26	0.27	0.24	0.23	0.23	0.22	0.24
T ₅ - 20% CO ₂	0.27	0.26	0.27	0.26	0.27	0.27	0.25	0.24	0.23	0.22	0.24
T ₆ - 25% CO ₂	0.31	0.3	0.29	0.27	0.29	0.31	0.25	0.24	0.23	0.22	0.25
T ₇ - 30% CO ₂	0.32	0.31	0.30	0.29	0.31	0.32	0.25	0.24	0.23	0.22	0.25
T ₈ - 35% CO ₂	0.33	0.33	0.31	0.30	0.32	0.33	0.25	0.24	0.23	0.23	0.26
CD at 0.5%	0.03	0.03	0.03	0.03		0.03	0.01	0.01	0.009	0.01	

Conclusion:

From the present investigation, it is concluded that post-harvest treatment of strawberry fruit with 35% CO₂ performed best in terms of Physiological loss in weight, firmness, fruit color, TSS, ascorbic acid, pH, titratable acidity, organoleptic quality and overall acceptability.

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