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Effect of Different Levels of Carbon Dioxide Concentrations on Qualitative Traits of Strawberry (Fragaria × Ananassa) during Storage var. Winter Dawn

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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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^oC for 14 days in eight different atmospheres: air, 5% CO_2, 10% CO_2, 15% CO_2, 20% CO_2, 25% CO_2, 30% CO_2, 35% CO_2.

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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 CO_2 levels. The result showed that atmosphere with treatment 35% CO_2 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.

1. 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 [1,2] (Mahajan et al. 2017). Aerobic respiration of fresh produce is oxidative breakdown of substrate molecules such as starch, sugars, and organic acids to simpler molecules such as CO_2. 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 [3-6]. Low O_2 and high CO_2 concentration in the ambient surrounding the produce can decrease the respiration rate (Nielsen & Leufvén, 2008) [7] and thereby extend the shelf life (Aday & Caner, 2013; Bovi, Caleb, Ilte, Rauh, & Mahajan, 2018) [6,7] 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 [8]. Hertog, Boerrigter, Van Den Boogaard, Tijskens, and Van Schaik [9] 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 CO_2 on the nutritional quality of strawberries separately [10-12]. However, an understanding of the interactive effects of these two environmental factors (high temperature and CO_2 on phytochemicals is limited. Thus, it is critical to investigate the interactive effects of CO_2 and temperature on the nutritional quality, more importantly the antioxidant contents, especially polyphenols in strawberries.

Carbon dioxide (CO_2) plays an essential role in agriculture. During cultivation, CO_2 enrichment is used in plant factory systems to improve yield and quality. CO_2 also acts as a substrate for photosynthesis [13-17]. In postharvest processes and cultivation, CO_2 is used during controlled atmosphere storage or short-term high-CO_2 treatment to maintain freshness and increase the shelf life of different fruit [18,19]. However, the mechanism whereby CO_2 maintains fruit freshness during the postharvest process remains unclear.

High-CO_2 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-CO_2 treatment of approximately 3 h increased fruit firmness with CO_2 concentrations ranging from 10 to 100 kPa. Higher CO_2 concentrations are usually more effective, but can cause physiological injuries, such as fruit discoloration and off-flavors [20,21].

To solve this problem, high-CO_2 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 CO_2 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) [22].

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.

2. 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 [23]. 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).

3. RESULTS 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 CO_2 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 CO_2 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 CO_2 followed by 30% CO_2.

Firmness (kg/cm^2): 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^{o}C). The firmness in strawberry was minimum when they are treated with 35% of CO_2 followed by 30% of CO_2 respectively.

Table 1. Effect of Change in physiological loss of weight (%) of strawberry fruits during storage

Treatments	Room temperature					Controlled temperature (5^{o}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
T3- 10% CO_2	9.33	14.81	22.22	29.62	19.00	12	7.93	13.64	22.14	27.85	16.71
T4- 15% CO_2	13.66	10.25	17.94	25.63	16.87	15	4.6	11.28	15.59	20.05	13.30
T5- 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
T6- 25% CO_2	10.66	9.09	9.09	18.18	11.76	17	5.89	11.62	17.68	17.68	13.97
T7- 30% CO_2	21.33	6.05	10.60	16.66	13.66	15	7.24	7.24	14.48	14.48	11.69
T8- 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**	

Fruits of strawberry treated with 35% of CO_2 in room temperature and controlled temperature exhibited mean maximum firmness (i.e. 22.76 and 20.86 respectively) as compared to the 5% of CO_2 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.

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% CO_2), it showed more vivid color (chroma) and higher L* compared to the fruits stored in air.

Table 2. Effect of change in firmness of strawberry during storage

Treatments	Room temperature					Controlled temperature (5^oC)					
	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
T3- 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
T4- 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
T5- 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
T6- 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
T7- 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
T8- 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**	

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 (^{o} Brix): The changes in total soluble solids (TSS) of strawberry fruits packed with different levels of CO_2 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 CO_2 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, Li and Kader (1989) [22] 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.

Ascorbic acid (mg/100ml): The data recorded during the period of study revealed that the ascorbic acid content of strawberry fruits packed in different levels of CO_2 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% CO_2 (0.24mg/100ml) and (0.23mg/100ml) in controlled temperature respectively, which was at par the fruits packed with 25% CO_2 (0.23mg/100ml) in room temperature and 30% CO_2 (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.

3.1 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.

The mean value of treatments, indicated that the change in pH of strawberry fruit was maximum in 35% of CO_2 (3.28 & 3.60) and minimum in 5% of CO_2 (3.23 & 3.46) followed by T_1 control (3.21 & 3.31) in room temperature and controlled temperature respectively.

Table 4. Effect of change in total soluble solid (^{o} Brix) of strawberry during storage

Treatments	Room temperature					Controlled temperature (5^{o}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
T3- 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
T4- 15% CO2	6.64	7.04	7.36	8.21	7.31	6.65	6.72	6.97	7.03	7.84	7.04
T5- 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
T6- 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
T7- 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
T8- 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**	

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
T3- 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
T4- 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
T5- 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
T6- 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
T7- 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
T8- 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**	

Table 6. Effect of Change in pH 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	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
T3- 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
T4- 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
T5- 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
T6- 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
T7- 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
T8- 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**	

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
T3- 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
T4- 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
T5- 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
T6- 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
T7- 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
T8- 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**	

The increased pH was due to the decrease in acidity of the fruit juice. Fruit juices have low pH because they are comparatively rich in organic acids. The increase in pH might be due to the decrease in total titratable acid of the bevearage samples as acidity and pH are inversely proportional to each other [24].

Titratable acidity (%): The titratable acidity of strawberry fruits packed in different levels of CO_2 concentration went on decreasing with the advancement of storage period. Under room temperature storage condition (Table 4), significant variation in titratable 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 CO_2. 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 CO_2 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 at., 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) [6,7].

4. CONCLUSION

From the present investigation, it is concluded that post-harvest treatment of strawberry fruit with 35% CO_2 performed best in terms of Physiological loss in weight, firmness, fruit color, TSS, ascorbic acid, pH, titratable acidity, organoleptic quality and overall acceptability.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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