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Forced-air, vacuum, and hydro precooling of cauliflower (*Brassica oleracea* L. var. *botrytis* cv. Freemont): Part II. Determination of quality parameters during storage

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Abstract

Cauliflower heads, which were precooled using four different methods including vacuum, forced-air, and high and low flow hydro precooling, were stored under controlled atmosphere and room conditions. Controlled atmosphere conditions (*CA*) were as follows: 1°C temperature, 90 ± 5% relative humidity, and 0:21 [(%CO_2:%O_2) – (0:21) control] atmosphere composition. Room conditions (*RC*) were: 22±1°C temperature and 55-60% humidity. Various quality parameters of the cauliflower heads were assessed during storage (days 0, 7, 14, 21, 28, and 35) under controlled atmosphere and room conditions (days 0, 5, and 10). During storage, weight loss, deterioration rate, overall sensory quality score, hardness, and colour (*L*, *a*, *b*, *C* and α) were evaluated. In the present study, the strength and quality parameters of cauliflower under *CA* and *RC* conditions were obtained. Vacuum precooling was found to be most suitable method before cauliflower was submitted to cold storage and sent to market. Furthermore, the storage of cauliflower without precooling resulted in a significant decrease in quality parameters.

Keywords: cauliflower; colour; hardness; controlled atmosphere conditions; quality parameters; room conditions.

1 Introduction

Cauliflower (*Brassica oleracea* L. var. *botrytis* cv. Freemont) is member of the family Brassicaceae (Kop et al., 2003). It has recently become popular as a food of high nutritional value (Zhuang et al., 1995, 1997). Cauliflower is rich in vitamin C (Cebula et al., 2006) vitamin A, thiamine, riboflavin, niacin, calcium, folic acid, phosphorous, and fatty acids (Mohamed Mahroop Raja et al., 2011). It is high in fibre but low in calories (Schreiner et al., 2007).

The main postharvest problems of fresh cauliflower are yellowing of the leaves, sharp increase in bitter test (Hodges et al., 2006), browning of the curd, floret opening, hardness loss, and undesirable odour development, which decrease shelf-life and affect consumer buying behaviour (Licciardello et al., 2013; Zhan et al., 2014). Since cauliflower deteriorates very quickly soon after harvest, it should be stored immediately after they are harvested (Al-Harahsheh et al., 2009; Alibas, 2014). Therefore, it is of great importance to chill cauliflower immediately following harvest focusing on maintaining its quality and increasing sales (Brosnan & Sun, 2003; Sun & Wang, 2004; Wang & Sun, 2001; Sankat & Mujaffar, 1999). Precooling is the fastest cooling method after harvest of agricultural products. Precooled products are immediately sent to market or cold storage. The ideal conditions for storing cauliflower are 3-4 weeks under common commercial storage conditions at 0°C and 95-100% relative humidity (Hodges et al., 2006). On the other hand, storage period can be extended with the use of appropriate precooling methods before cold storage.

The objectives of the present study were: I) determination of quality parameters during storage of cauliflower heads precooled using vacuum, forced-air, and high and low flow hydro cooling methods under controlled atmosphere and room conditions; II) to assess overall sensory quality, weight loss, deterioration rate, hardness, and colour parameters; and III) to determine the most appropriate precooling method for cauliflowers according to quality parameters under cold storage and market conditions.

2 Materials and methods

2.1 Material

Cauliflower heads that were precooled using four different methods, vacuum, forced-air, and high and low flow hydro, and those that were not submitted to precooling (control) were stored under controlled atmosphere (*CA*) and room conditions (*RC*). Cauliflower heads weighing 1000 ± 5 g were stored under these two conditions with three replicates.

2.2 Storage methods

Controlled atmosphere conditions were temperature of 1°C, relative humidity of 90 ± 5%, and atmosphere composition of 0:21 (%CO_2 and %O_2). Measurements were performed during storage on days 0, 7, 14, 21, 28, and 35) (Nunes et al., 1995; McDonald et al., 2000; Rennie et al., 2001; He et al., 2004; Tao et al., 2006).

Room conditions (*RC*) were: 22 ± 1 °C temperature and 55-60% relative humidity. Measurements were performed during storage on days 0, 5, and 10 (Alibas & Okursoy, 2012).

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Under these two storage conditions, colour, weight loss, overall sensory quality, deterioration rate, and hardness of cauliflower heads (*L*, *a*, *b*, *C* and α) were determined.

2.3 Determination of quality parameters

The overall sensory quality score was 10 on day 0, and this value was taken as a control value. Sensory evaluation was carried out with a panel consisting of five trained plant physiologists. The biological material was evaluated using a scoring system, as follows: 10-9: very good, 8-7: good, 6-5: saleable, 4-3: unsaleable 2-1: unavailable (Alibas & Okursoy, 2009, 2012). Weight loss and deterioration rate were 0% on day 0, and this value was taken as control. Overall sensory quality score was assumed as 10 on 0^{th} day and this value was taken as a control value. Colour values of untreated cauliflowers on day 0 represent those of fresh products; thus it was taken as a control value. The hardness of untreated cauliflowers on day 0 was determined as 5.75 kg, representing the hardness of fresh products, and thus it was taken as a control value. The methods used to determine the colour and hardness parameters were thoroughly explained in previous studies. Initial colour and hardness values of the precooled cauliflowers heads have been previously reported.

2.4 Statistical method

The experiments were performed with three replicates. Analysis of variance was performed using SPSS 17.0.

3 Results and discussion

3.1 Determination of the quality parameters under controlled atmosphere

The data related to weight loss, deterioration rate, hardness, and overall sensory quality of cauliflower heads under controlled atmosphere conditions are presented in Table 1.

When all the precooling methods were evaluated at the end of the storage period under controlled atmosphere (day 35), the vacuum precooling method (25.8%) showed the lowest weight loss, followed by the low flow hydro (35.1%), high flow hydro (36.9%), and forced-air precooling methods (42.5%). Under cold storage and controlled atmosphere conditions without precooling, the weight loss (46.9%) of the cauliflowers at the end of the storage period, on day 35, was higher than that obtained with the precooling methods during the storage period (McDonald et al., 2000).

According to Table 1, among all precooling methods used, vacuum precooling (35.6%) had the minimum deterioration rate on day 35, followed by the low flow hydro precooling (50.5%), high flow hydro precooling (52.5%), and forced-air precooling methods (60.1%). The deterioration rate of the cauliflower heads was the highest in the control group on day 35 (65.9%). Therefore, it was found that the storage of cauliflowers using the vacuum precooling method reduced deterioration rate by approximately 50% more than the storage without precooling.

This result has been widely reported (Alibas & Okursoy, 2009; McDonald et al., 2000). The deterioration rate value obtained using the vacuum precooling method was 1.85 times lower than that of the control and 1.42 times lower than that of the low flow hydro precooling method. The 35 day-storage of vacuum precooled cauliflower under controlled atmosphere prevented loss of 250 kg $tonne^{-1}$ compared to that of forced-air precooled products. Even greater yields of up to 300 kg $tonne^{-1}$ were obtained using the vacuum precooling method before cold storage compare with those of storage without precooling.

The overall sensory quality of vacuum precooled cauliflowers was rated as "saleable", (score 5) at the end of the 35^{th} day. The overall sensory quality of low and high flow hydro precooled cauliflowers was rated as "unsaleable" (score 3) at the end of the cold storage period. The overall sensory quality of cauliflowers stored under forced-air precooling and those stored without precooling was rated as "unavailable" (scores 2 and 1, respectively).

According to Table 1, highest hardness value at the end of the cold storage period was obtained using vacuum precooling compared to that of fresh products. The vacuum precooling method had the highest values, followed by low flow hydro, high flow hydro, and forced-air precooling methods. On the other hand, the hardness value of the cauliflowers that were not precooled was 2.13 kg on day 35. These results are consistent with those of previous studies (McDonald et al., 2000). The storage of vacuum precooled cauliflowers in terms of hardness was approximately one month longer than the storage without precooling.

The colour parameters of precooled and not-precooled cauliflower heads under controlled atmosphere conditions are shown in Table 2. According to Table 2, the colour values closer to those of fresh products were obtained with vacuum precooling. The vacuum precooling method had the highest values, followed by low flow hydro, high flow hydro, and forced-air precooling methods. In the present study, it was essential that the cauliflower heads were precooled before cold storage in order to avoid loss of colour.

Many researchers investigated the effect of different precooling methods on the shelf life of agricultural products. Nunes et al. (1995) stored forced-air precooled strawberries under controlled atmosphere at 1°C for 7 days. They found that the forced-air precooled strawberries had better physical and chemical quality parameters than those of not-precooled strawberries. He et al. (2004) stored vacuum precooled iceberg lettuce at 1°C and 85% RH for 2 weeks. They investigated the effect of pressure on the quality parameters. These authors also found that moderate pressure reduction rate was appropriate for maintaining shelf life of iceberg lettuce. Vacuum precooled white mushrooms were stored under modified atmosphere, cold room, and hypobaric room conditions by Tao et al. (2006). They found that vacuum precooled mushrooms had better quality parameters than those of the not-precooled products in all different storage conditions used. Alibas & Okursoy (2009) stored spinach precooled using four different methods, vacuum, forced-air, and high and low flow hydro precooling methods, at 1°C and 90-95% RH for 15 days. The low flow hydro precooling method proved the most appropriate method during the storage of spinach under controlled atmosphere in terms of colour, deterioration rate,

Table 1. Quality parameters of cauliflower stored under controlled atmosphere.

Precooling Methods	Storage Period (day)	Weight Loss* (%)	Deterioration Rate* (%)	Hardness* (kg)	Overall Sensory Quality Score* (1-10)
Control	0	0.0 ± (0.000)[a]	0.0 ± (0.000)[a]	5.75 ± (0.145)[a]	10.0 ± (0.000)[a]
	7	14.6 ± (0.757)[e]	23.2 ± (0.473)[f]	4.65 ± (0.211)[efg]	7.0 ± (0.577)[cd]
	14	30.8 ± (0.351)[ij]	48.1 ± (0.781)[m]	3.90 ± (0.175)[hij]	4.0 ± (0.289)[fg]
	21	35.2 ± (0.473)[kl]	53.7 ± (1.220)[op]	3.10 ± (0.193)[kl]	3.0 ± (0.577)[gh]
	28	40.1 ± (0.700)[n]	59.1 ± (0.757)[q]	2.55 ± (0.055)[lm]	2.0 ± (0.289)[hi]
	30+5	46.9 ± (0.608)[p]	65.9 ± (0.737)[r]	2.13 ± (0.155)[m]	1.0 ± (0.000)[I]
AC	0	0.0 ± (0.000)[a]	0.0 ± (0.000)[a]	5.40 ± (0.093)[abcd]	10.0 ± (0.000)[a]
	7	12.5 ± (0.351)[d]	20.7 ± (0.306)[e]	5.08 ± (0.100)[bcdef]	7.0 ± (0.577)[cd]
	14	25.9 ± (0.265)[h]	45.1 ± (0.513)[l]	4.65 ± (0.112)[efg]	5.0 ± (0.289)[ef]
	21	33.8 ± (0.416)[k]	50.2 ± (0.473)[n]	4.25 ± (0.203)[ghi]	3.0 ± (0.577)[gh]
	28	36.6 ± (0.557)[lm]	54.8 ± (0.173)[p]	3.59 ± (0.201)[jk]	3.0 ± (0.000)[gh]
	30+5	42.5 ± (0.346)[o]	60.1 ± (0.493)[q]	2.58 ± (0.263)[lm]	2.0 ± (0.289)[hi]
VC	0	0.0 ± (0.000)[a]	0.0 ± (0.000)[a]	5.60 ± (0.132)[ab]	10.0 ± (0.000)[a]
	7	5.5 ± (0.404)[b]	12.1 ± (0.173)[b]	5.45 ± (0.119)[abcd]	9.0 ± (0.577)[ab]
	14	10.9 ± (0.503)[c]	25.2 ± (0.451)[g]	4.25 ± (0.078)[abcde]	8.0 ± (0.289)[bc]
	21	16.7 ± (0.569)[f]	30.4 ± (0.379)[h]	5.02 ± (0.116)[bcdef]	7.0 ± (0.577)[cd]
	28	21.3 ± (0.404)[g]	32.5 ± (0.306)[i]	4.85 ± (0.148)[defg]	6.0 ± (0.289)[de]
	30+5	25.8 ± (0.379)[h]	35.6 ± (0.361)[j]	4.62 ± (0.215)[efg]	5.0 ± (0.577)[ef]
Lf-HC	0	0.0 ± (0.000)[a]	0.0 ± (0.000)[a]	5.53 ± (0.221)[abc]	10.0 ± (0.000)[a]
	7	9.4 ± (0.208)[c]	15.0 ± (0.231)[c]	5.20 ± (0.159)[abcde]	8.0 ± (0.289)[bc]
	14	20.8 ± (0.451)[g]	36.3 ± (0.321)[j]	4.94 ± (0.176)[cdef]	6.0 ± (0.577)[de]
	21	29.5 ± (0.416)[i]	40.8 ± (0.473)[k]	4.70 ± (0.212)[efg]	5.0 ± (0.577)[ef]
	28	31.2 ± (0.231)[j]	45.5 ± (0.306)[l]	3.97 ± (0.193)[hij]	4.0 ± (0.289)[fg]
	30+5	35.1 ± (0.513)[kl]	50.5 ± (0.321)[n]	3.08 ± (0.118)[kl]	3.0 ± (0.289)[gh]
Hf-HC	0	0.0 ± (0.000)[a]	0.0 ± (0.000)[a]	5.48 ± (0.150)[abcd]	10.0 ± (0.000)[a]
	7	10.5 ± (0.666)[c]	17.5 ± (0.200)[d]	5.15 ± (0.101)[abcde]	8.0 ± (0.289)[bc]
	14	22.1 ± (0.208)[g]	40.1 ± (0.513)[k]	4.85 ± (0.166)[defg]	5.0 ± (0.000)[ef]
	21	30.8 ± (0.208)[ij]	45.8 ± (0.300)[l]	4.50 ± (0.275)[fgh]	4.0 ± (0.577)[fg]
	28	32.2 ± (0.361)[j]	48.2 ± (0.361)[m]	3.85 ± (0.195)[ij]	4.0 ± (0.289)[fg]
	30+5	36.9 ± (0.379)[m]	52.5 ± (0.306)[o]	2.95 ± (0.165)[l]	3.0 ± (0.000)[gh]

*P<0.01 - Mean values within a column with different superscripts are significantly different.

weight loss, and overall sensory quality score, and it was followed by the vacuum, high flow hydro, and forced-air precooling methods. Alibas & Okursoy (2012) stored faba beans precooled using vacuum, forced-air, hydro precooling at 1°C and 90-95% RH for 30 days. They found that vacuum precooling was the most appropriate method for the cold storage of the faba beans in terms of colour, hardness, deterioration rate, weight loss, and overall sensory quality score, followed by the forced-air precooling method, the control treatment (no precooling), and hydro precooling method. Sirinanuwat et al. (2012) stored organic corianders precooled using vacuum at 6 mmbar pressure under cold processing at 5°C for 7 days. They found that the vacuum precooled products were approximately 2 times better than the control products in terms of weight loss and shelf life. In the present study, the best results in terms of quality parameters associated with cold storage of cauliflowers were found using the vacuum precooling method.

Some quality parameters of the not-precooled cauliflower have been investigated during storage in previous studies that are similar to the present study. Jany et al. (2008) stored cauliflower under refrigeration at 4°C for 12 days. They found that the cauliflower curds and stalks started rotting and ultimately became unsuitable for consumption during storage. Candido et al. (2013) found that colour and weight loss of cauliflowers were significantly reduced after 15 days of the storage at 0±1°C temperature and 90-95% relative humidity. Dhall et al. (2010) stored cauliflower curds at 0±1°C temperature and 90-95% relative humidity. They found that the changes in the cauliflower curd colour, texture, weight (loss), deterioration rate, hardness, and sensory quality were evaluated weekly for 28 days. At the end of the storage period, all quality parameters of the curds were significantly reduced compared to those of fresh cauliflower.

3.2 Determination of the quality parameters under room conditions

Weight loss, deterioration rate, overall sensory quality score, and hardness of precooled cauliflowers using different precooling methods under room conditions are shown in Table 3.

Table 2. Colour parameters of cauliflower stored under controlled atmosphere.

Precooling Methods	Storage Period (day)	Colour Parameters				
		L*	a*	b*	C*	α°*
Control	0	80.34 ± (0.233)^{a}	−1.85 ± (0.068)^{a}	12.19 ± (0.236)^{a}	12.33 ± (0.228)^{a}	98.64 ± (0.422)^{a}
	7	63.17 ± (0.499)^{jk}	−2.43 ± (0.161)^{efghi}	11.39 ± (0.205)^{bcdef}	11.65 ± (0.232)^{abcde}	102.02 ± (0.590)^{efghi}
	14	58.90 ± (0.393)^{m}	−2.59 ± (0.042)^{hij}	10.83 ± (0.375)^{efghi}	11.14 ± (0.357)^{efgh}	103.49 ± (0.620)^{ij}
	21	53.22 ± (0.567)^{o}	−3.27 ± (0.146)^{l}	9.95 ± (0.147)^{jk}	10.47 ± (0.183)^{hijk}	108.18 ± (0.540)^{lm}
	28	49.15 ± (0.211)^{p}	−3.84 ± (0.149)^{m}	8.94 ± (0.192)^{l}	9.73 ± (0.235)^{lm}	113.23 ± (0.380)^{n}
	30+5	44.22 ± (0.427)^{q}	−4.07 ± (0.142)^{m}	8.10 ± (0.197)^{m}	9.07 ± (0.237)^{m}	116.67 ± (0.310)^{o}
AC	0	78.90 ± (0.464)^{b}	−1.99 ± (0.035)^{abcd}	11.83 ± (0.183)^{abc}	12.00 ± (0.183)^{abc}	99.55 ± (0.182)^{abc}
	7	68.98 ± (0.316)^{g}	−2.29 ± (0.095)^{defgh}	11.13 ± (0.087)^{defg}	11.36 ± (0.104)^{cdef}	101.62 ± (0.390)^{defg}
	14	63.15 ± (0.175)^{jk}	−2.58 ± (0.166)^{ghij}	10.74 ± (0.112)^{fghi}	11.05 ± (0.147)^{efghi}	103.49 ± (0.710)^{ij}
	21	60.71 ± (0.205)^{l}	−3.00 ± (0.164)^{kl}	10.03 ± (0.111)^{jk}	10.47 ± (0.154)^{hijk}	106.63 ± (0.690)^{kl}
	28	55.45 ± (0.335)^{n}	−3.10 ± (0.082)^{kl}	9.49 ± (0.185)^{kl}	9.98 ± (0.185)^{jkl}	108.10 ± (0.480)^{l}
	30+5	52.79 ± (0.352)^{o}	−3.35 ± (0.050)^{l}	9.25 ± (0.102)^{l}	9.84 ± (0.082)^{kl}	109.92 ± (0.460)^{m}
VC	0	80.15 ± (0.053)^{a}	−1.90 ± (0.095)^{ab}	12.04 ± (0.231)^{ab}	12.19 ± (0.221)^{ab}	98.98 ± (0.550)^{ab}
	7	78.84 ± (0.141)^{b}	−1.99 ± (0.084)^{abcd}	11.98 ± (0.115)^{abc}	12.15 ± (0.102)^{ab}	99.44 ± (0.469)^{abc}
	14	76.72 ± (0.167)^{c}	−2.08 ± (0.081)^{abcde}	11.71 ± (0.156)^{abcd}	11.89 ± (0.166)^{abcd}	100.07 ± (0.280)^{abcd}
	21	74.13 ± (0.264)^{d}	−2.27 ± (0.137)^{cdefgh}	11.48 ± (0.141)^{bcde}	11.71 ± (0.111)^{abcde}	101.20 ± (0.800)^{cdef}
	28	71.98 ± (0.165)^{ef}	−2.46 ± (0.081)^{fghi}	11.34 ± (0.220)^{cdef}	11.61 ± (0.200)^{bcde}	102.26 ± (0.600)^{fghi}
	30+5	70.83 ± (0.289)^{f}	−2.61 ± (0.066)^{hij}	11.03 ± (0.231)^{defgh}	11.34 ± (0.215)^{cdef}	103.33 ± (0.540)^{ghi}
Lf–HC	0	79.85 ± (0.197)^{ab}	−1.93 ± (0.059)^{abc}	11.91 ± (0.218)^{abc}	12.07 ± (0.209)^{ab}	99.22 ± (0.404)^{ab}
	7	72.89 ± (0.552)^{e}	−2.08 ± (0.060)^{abcde}	11.33 ± (0.085)^{cdef}	11.52 ± (0.093)^{bcde}	100.40 ± (0.240)^{abcde}
	14	69.02 ± (0.306)^{g}	−2.23 ± (0.061)^{bcdefg}	10.82 ± (0.317)^{efghi}	11.05 ± (0.315)^{efghi}	101.66 ± (0.350)^{defgh}
	21	66.77 ± (0.334)^{h}	−2.49 ± (0.080)^{ghi}	10.44 ± (0.179)^{ghij}	10.73 ± (0.190)^{fghi}	103.41 ± (0.270)^{hi}
	28	65.23 ± (0.539)^{i}	−2.78 ± (0.075)^{ijk}	10.19 ± (0.110)^{ij}	10.56 ± (0.126)^{ghij}	105.25 ± (0.240)^{jk}
	30+5	64.13 ± (0.324)^{ij}	−2.90 ± (0.049)^{jk}	9.98 ± (0.214)^{jk}	10.39 ± (0.192)^{ijkl}	106.22 ± (0.590)^{k}
Hf–HC	0	79.52 ± (0.196)^{ab}	−1.96 ± (0.056)^{abcd}	11.95 ± (0.103)^{abc}	12.11 ± (0.111)^{ab}	99.31 ± (0.184)^{ab}
	7	72.10 ± (0.110)^{e}	−2.13 ± (0.049)^{abcdef}	11.38 ± (0.160)^{bcdef}	11.58 ± (0.150)^{bcde}	100.61 ± (0.380)^{bcdef}
	14	68.12 ± (0.300)^{g}	−2.28 ± (0.060)^{cdefgh}	10.99 ± (0.240)^{efgh}	11.23 ± (0.224)^{defg}	101.74 ± (0.530)^{defghi}
	21	65.03 ± (0.290)^{i}	−2.55 ± (0.091)^{ghij}	10.78 ± (0.071)^{fghi}	11.08 ± (0.081)^{efghi}	103.31 ± (0.420)^{ghi}
	28	62.17 ± (0.217)^{k}	−2.88 ± (0.095)^{jk}	10.43 ± (0.100)^{hij}	10.82 ± (0.122)^{fghi}	105.43 ± (0.350)^{k}
	30+5	60.87 ± (0.220)^{l}	−3.09 ± (0.055)^{kl}	10.22 ± (0.146)^{ij}	10.68 ± (0.124)^{fghi}	106.83 ± (0.500)^{kl}

*P<0.01 - Mean values within a column with different superscripts are significantly different.

Table 3. Quality parameters of cauliflower stored under room conditions.

Precooling Methods	Storage Period (day)	Weight Loss* (%)	Deterioration Rate* (%)	Hardness* (kg)	Overall Sensory Quality Score* (1-10)
Control	0	0.0 ± (0.000)^{a}	0.0 ± (0.000)^{a}	5.75 ± (0.145)^{a}	10.0 ± (0.000)^{a}
	5	30.1 ± (0.173)^{e}	45.1 ± (0.265)^{f}	4.20 ± (0.146)^{def}	4.0 ± (0.577)^{ef}
	10	55.5 ± (0.208)^{l}	72.5 ± (0.300)^{k}	2.30 ± (0.125)^{h}	1.0 ± (0.000)^{h}
AC	0	0.0 ± (0.000)^{a}	0.0 ± (0.000)^{a}	5.40 ± (0.093)^{abc}	10.0 ± (0.000)^{a}
	5	24.0 ± (0.404)^{d}	38.4 ± (0.265)^{e}	4.70 ± (0.153)^{cde}	5.0 ± (0.577)^{de}
	10	50.2 ± (0.231)^{i}	67.5 ± (0.808)^{j}	2.75 ± (0.301)^{gh}	2.0 ± (0.000)^{gh}
VC	0	0.0 ± (0.000)^{a}	0.0 ± (0.000)^{a}	5.60 ± (0.132)^{ab}	10.0 ± (0.000)^{a}
	5	12.5 ± (0.874)^{b}	20.3 ± (0.777)^{b}	5.30 ± (0.297)^{abc}	8.0 ± (0.577)^{b}
	10	35.3 ± (0.557)^{f}	47.5 ± (1.070)^{g}	4.75 ± (0.181)^{bcde}	5.0 ± (0.289)^{de}
Lf-HC	0	0.0 ± (0.000)^{a}	0.0 ± (0.000)^{a}	5.53 ± (0.221)^{abc}	10.0 ± (0.000)^{a}
	5	18.9 ± (0.557)^{c}	25.7 ± (0.950)^{c}	5.05 ± (0.352)^{abcd}	7.0 ± (0.577)^{bc}
	10	35.5 ± (0.493)^{g}	57.5 ± (0.781)^{h}	4.15 ± (0.335)^{ef}	4.0 ± (0.577)^{ef}
Hf-HC	0	0.0 ± (0.000)^{a}	0.0 ± (0.000)^{a}	5.48 ± (0.150)^{abc}	10.0 ± (0.000)^{a}
	5	20.1 ± (0.351)^{c}	30.9 ± (0.513)^{d}	4.95 ± (0.235)^{abcde}	6.0 ± (0.289)^{cd}
	10	44.8 ± (0.404)^{h}	62.3 ± (0.404)^{i}	3.50 ± (0.256)^{fg}	3.0 ± (0.577)^{fg}

*P<0.01 - Mean values within a column with different superscripts are significantly different.

Table 4. Colour parameters of cauliflower stored under room conditions.

Precooling Methods	Storage Period (day)	Colour Parameters				
		L*	a*	b*	C*	α°*
Control	0	80.34 ± (0.233)[a]	−1.85 ± (0.068)[a]	12.19 ± (0.236)[a]	12.33 ± (0.228)[a]	98.64 ± (0.422)[a]
	5	60.94 ± (0.355)[g]	−2.97 ± (0.060)[bcd]	9.95 ± (0.217)[def]	10.38 ± (0.223)[efg]	106.62 ± (0.180)[de]
	10	41.30 ± (0.305)[i]	−4.28 ± (0.142)[f]	7.98 ± (0.225)[g]	9.06 ± (0.135)[h]	118.25 ± (1.440)[g]
AC	0	78.90 ± (0.464)[a]	−1.99 ± (0.035)[a]	11.83 ± (0.183)[ab]	12.00 ± (0.183)[abc]	99.55 ± (0.182)[ab]
	5	66.99 ± (0.578)[d]	−2.79 ± (0.139)[bc]	10.76 ± (0.436)[cde]	11.12 ± (0.456)[bcdef]	104.53 ± (0.180)[cd]
	10	50.78 ± (0.545)[h]	−3.48 ± (0.150)[e]	9.15 ± (0.290)[f]	9.79 ± (0.309)[gh]	110.82 ± (0.630)[f]
VC	0	80.15 ± (0.053)[a]	−1.90 ± (0.095)[a]	12.04 ± (0.231)[a]	12.19 ± (0.221)[a]	98.98 ± (0.550)[a]
	5	76.10 ± (0.387)[b]	−2.51 ± (0.178)[b]	11.66 ± (0.083)[abc]	11.93 ± (0.115)[abc]	102.14 ± (0.760)[bc]
	10	71.23 ± (0.306)[c]	−2.90 ± (0.100)[bcd]	10.97 ± (0.261)[bcd]	11.35 ± (0.277)[abcde]	104.80 ± (0.180)[cd]
Lf–HC	0	79.85 ± (0.197)[a]	−1.93 ± (0.059)[a]	11.91 ± (0.218)[ab]	12.07 ± (0.209)[ab]	99.22 ± (0.404)[a]
	5	65.02 ± (0.605)[e]	−2.69 ± (0.129)[bc]	10.63 ± (0.361)[cde]	10.97 ± (0.319)[cdef]	104.27 ± (1.110)[cd]
	10	63.06 ± (0.450)[f]	−3.01 ± (0.127)[cd]	9.86 ± (0.280)[ef]	10.31 ± (0.303)[fg]	106.97 ± (0.290)[de]
Hf–HC	0	79.52 ± (0.196)[a]	−1.96 ± (0.056)[a]	11.95 ± (0.103)[ab]	12.11 ± (0.111)[ab]	99.31 ± (0.184)[ab]
	5	63.24 ± (0.441)[f]	−2.84 ± (0.196)[bcd]	11.14 ± (0.372)[abc]	11.50 ± (0.318)[abcd]	104.37 ± (1.350)[cd]
	10	59.96 ± (0.612)[g]	−3.27 ± (0.149)[de]	10.01 ± (0.428)[def]	10.54 ± (0.392)[defg]	108.16 ± (1.240)[ef]

*P<0.01 - Mean values within a column with different superscripts are significantly different.

According to Table 3, the vacuum precooling method showed the lowest weigh loss with the value of 35.3%, followed by low and high flow hydro and forced-air precooling methods with the values of 35.5, 44.8, 50.2, and 55.5%, respectively, at the end of storage period under room conditions. The weight loss value obtained using vacuum precooled cauliflower heads was 1.57 times lower than that of not-precooled cauliflowers.

The lowest deterioration rate of the cauliflower heads stored under room conditions for 10 days was 47.5% using the vacuum precooling method, followed by low flow hydro (57.5%), high flow hydro (62.3%), and forced-air precooling methods (67.5%) and the control treatment (72.5%). The deterioration rate of not-precooled cauliflower heads was 1.53, 1.07 times higher than that of precooled cauliflower using the vacuum and forced-air precooling methods.

Vacuum precooled cauliflower heads stored under room conditions were rated as "saleable" (score 5) at the end of storage period, whereas the precooled heads using the low and high flow hydro precooling method were rated as "unsaleable" (scores 4 and 3, respectively). On the other hand, the overall sensory quality score of the forced-air precooled and non-precooled cauliflower heads were rated "*unavailable*" with (scores 2 and 1, respectively).

The vacuum precooling method had hardness value of 4.75 kg, which was close to the hardness value of fresh products on day 10 under room conditions. The vacuum precooling method was followed by the low and high flow hydro and forced-air precooling methods, and the control treatment (no precooling) with the values of 4.15, 3.50, 2.75, and 2.30 kg, respectively. The hardness value of not-precooled cauliflowers on day 10 was 1.8 times less than that of precooled cauliflowers using vacuum.

The colour parameters of precooled and not-precooled cauliflower heads under room conditions are given in Table 4. According to Table 4, the colour values that are closer to those of fresh products were found using the vacuum precooling method. The vacuum precooling method was followed by the low and high flow hydro precooling and forced-air precooling methods. The lowest colour parameters of cauliflowers stored under room conditions were found in the control treatment at the end of the storage period.

Very few studies have been conducted on storage of agricultural products under room conditions. However, they are extremely important to predict quality loss of agricultural products under market conditions. In the present study, the substantial loss of quality observed in the precooled cauliflowers using different methods was determined under room conditions. Furthermore, most quality loss was observed in not-precooled cauliflowers comparison to the heads in all precooling methods under room conditions. Similarly, Jany et al. (2008) found that the cauliflower curds and stalks started rotting and ultimately became unsuitable for consumption after 6 days at room conditions. Nunes et al. (1995) found that forced-air precooled strawberries were much better than non-precooled products in terms of physical and chemical quality parameters at 20°C in the initial phase of storage period Alibas & Okursoy (2012) stored faba beans precooled using vacuum, forced-air, and hydro precooling methods at 22±1°C and 55-60% RH for 10 days. They found that vacuum precooling is the most appropriate method to store faba beans in terms of colour, hardness, deterioration rate, weight loss, and overall sensory quality score, followed by forced-air, the control treatment (no precooling), and hydro precooling methods.

4 Conclusion

According to the results obtained, vacuum precooling is the most appropriate method for the storage of the cauliflowers under controlled atmosphere and room conditions in terms of quality parameters, followed by the high and low flow hydro and forced-air precooling methods.

In the present study, precooling was found to have a positive impact on the quality parameters of cauliflower heads under both room and controlled atmosphere conditions. Since it is the most appropriate method in terms of quality parameters, vacuum precooling extended cold storage period by approximately one month in comparison to the length of storage period without precooling.

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