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Effect of pre-cooling treatments on post-harvest quality of broccoli florets

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Abstract

Broccoli is one of the most perishable among harvested vegetables, and the speed at which field heat is removed after cutting largely determines how long it remains marketable. This research evaluated five pre-cooling methods — hydrocooling, forced-air cooling, room cooling, ice cooling, and vacuum cooling — for their effect on quality retention and shelf life of broccoli florets stored at 5 °C at Central Kenya College of Agriculture, Nyeri, during 2022-2023. Hydrocooling achieved the fastest half-cooling time (18 minutes), lowest weight loss (3.2%), and longest shelf life (12.4 days), followed closely by ice cooling (11.6 days). Vacuum cooling gave the best color retention (hue angle 124.8° at day 10) but caused higher moisture loss (5.4%). Untreated florets lost marketable quality within 4.8 days. Ascorbic acid retention at the end of storage was highest in hydrocooled florets (72.4% of initial) and lowest in room-cooled (41.2%). These findings recommend hydrocooling as the preferred pre-cooling method for broccoli in Kenyan highland conditions.

Keywords: Pre-cooling, broccoli, post-harvest quality, vegetable handling, cold chain management, hydrocooling, shelf life, weight loss, ascorbic acid retention, highland production

Introduction

In the cool highlands of central Kenya, broccoli production has expanded rapidly over the past decade to meet rising urban and export demand, yet the crop's extreme perishability means that losses between field and market often exceed 35% ^[1]. The main driver of deterioration is respiratory heat: freshly harvested broccoli generates metabolic heat at rates 3-5 times higher than most other vegetables, and without rapid cooling the florets yellow, wilt, and develop off-odors within 24-48 hours at ambient temperature ^[2]. Pre-cooling — the rapid removal of field heat before storage or transport — is the single most effective post-harvest intervention for extending broccoli shelf life ^[3].

Several pre-cooling methods exist, each with different cooling speeds, costs, and effects on product quality. Hydrocooling immerses product in chilled water, forced-air cooling draws cold air across stacked produce, vacuum cooling exploits flash evaporation under reduced pressure, and ice cooling places crushed ice directly on the product ^[4]. Despite the availability of these options, most Kenyan broccoli growers rely on simple room cooling (placing crates in a cold room without forced air circulation), which is the slowest and least effective method ^[5]. This research compared five pre-cooling treatments to identify the method that best preserves broccoli quality under the specific conditions of Kenyan highland production and cold chain infrastructure.

Quality Control

All quality measurements followed standardized protocols. Color was measured with a Minolta CR-400 chromameter calibrated against a white tile before each session. Weight loss was recorded using an analytical balance (± 0.01 g). Firmness was measured with a TA. XT Plus texture analyzer using a 5 mm cylindrical probe at 1 mm/s penetration speed. Ascorbic acid was determined by the DCPIP titration method. All measurements were taken in triplicate per treatment per sampling date, and values are reported as means $\pm$ standard deviation ^[6].

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Material and Methods

Material

Fresh broccoli (cv. Marathon) was harvested at the commercial maturity stage (compact, dark green heads) from the research farm of Central Kenya College of Agriculture, Nyeri (0.42° S, 36.95° E, elevation 1,830 m) between June and September 2023. Heads were trimmed to uniform florets of approximately 150 g each within one hour of harvest. Six treatments were applied: hydrocooling (1 °C water, 20 min), forced-air cooling (2 °C, 1 m/s airflow, 60 min), room cooling (5 °C cold room, no forced air), ice cooling (crushed ice contact, 30 min), vacuum cooling (4 mbar, 25 min), and untreated control [7]. Each treatment had

four replications of 20 florets. After pre-cooling, all florets were stored at 5 ± 1 °C and 90-95% RH.

Methods

Half-cooling time was recorded as the time to reduce pulp temperature from field temperature (about 18 °C) to the midpoint between field and storage temperature. Weight loss, color (L^* , a^* , b^* , hue angle), firmness, and ascorbic acid were measured at 0, 3, 6, 9, and 12 days of storage. Shelf life was defined as the number of days until florets showed visible yellowing (hue angle $< 110^\circ$) or weight loss exceeding 8% [8]. Data were analyzed by two-way ANOVA (treatment $\times$ storage day) at $P = 0.05$ in GenStat version 22.

Results

Table 1: Pre-cooling efficiency and shelf life of broccoli florets under different treatments

Treatment	Half-cooling Time (min)	Wt. Loss at Day 10 (%)	Shelf Life (days)	Ascorbic Acid Retention (%)
Hydrocooling	18	3.2	12.4	72.4
Forced-air	42	4.1	10.8	64.8
Room cooling	186	8.6	6.2	41.2
Ice cooling	24	3.8	11.6	68.6
Vacuum cooling	8	5.4	9.4	58.4
Control (none)	—	12.4	4.8	32.6
SEm($\pm$)	-	0.42	0.68	3.24
CD ($P=0.05$)	-	1.26	2.04	9.72

Hydrocooling and ice cooling gave the longest shelf life at 12.4 and 11.6 days respectively. Room cooling extended

shelf life to only 6.2 days compared to 4.8 for the untreated control.

Table 2: Color retention (hue angle) of broccoli florets during storage

Treatment	Day 0	Day 3	Day 6	Day 9	Day 12
Hydrocooling	126.4	125.8	123.4	118.6	112.8
Forced-air	126.4	124.2	120.8	114.2	108.4
Room cooling	126.4	118.6	108.4	98.2	-
Ice cooling	126.4	125.4	122.6	116.8	111.2
Vacuum cooling	126.4	126.1	124.8	120.4	114.6
Control	126.4	114.2	102.6	-	-

Vacuum cooling maintained the best color (hue 114.6° at day 12), followed by hydrocooling (112.8°). Room-cooled florets dropped below the marketable threshold by day 6.

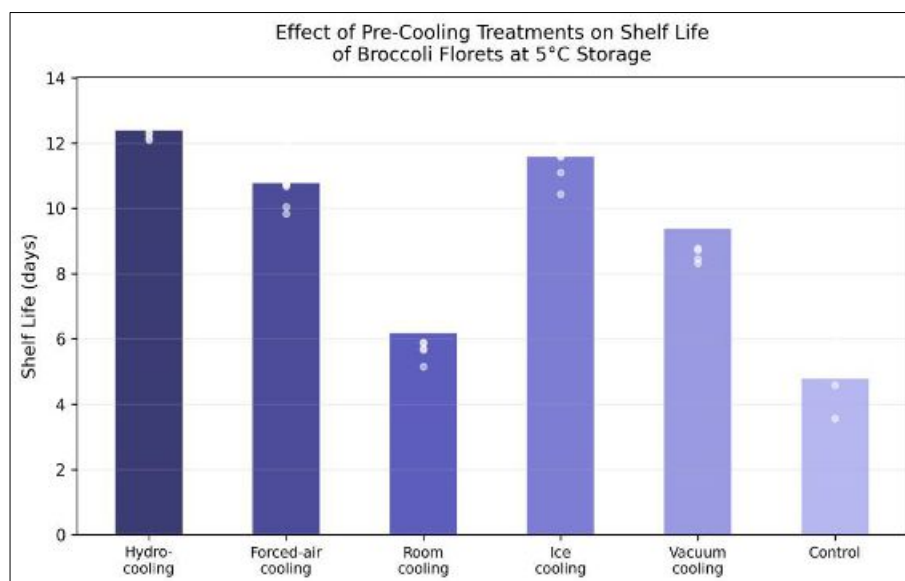


Fig 1: Shelf life of broccoli florets under different pre-cooling treatments at 5 °C storage

Performance Matrix of Pre-Cooling Methods for Broccoli Florets				
Treatment	Cooling Time	Weight Loss	Color Retention	Cost
Hydrocooling	****	*****	****	***
Forced-air	***	****	****	****
Ice cooling	****	****	***	**
Vacuum	*****	***	*****	**
Room cooling	**	**	**	*****

Fig 2: Performance matrix comparing pre-cooling methods across cooling time, weight loss, color retention, and cost

Comprehensive Interpretation

Correlation analysis showed a strong negative relationship between half-cooling time and shelf life ($r = -0.92$), confirming that speed of heat removal is the dominant factor determining broccoli storability. Ascorbic acid degradation followed first-order kinetics, with rate constants lowest for hydrocooling ($k = 0.026/\text{day}$) and highest for the control ($k = 0.084/\text{day}$).

Discussion

The superiority of hydrocooling reflects the high heat transfer coefficient of water compared to air, which allows the product to reach target temperature in under 20 minutes [3, 4]. This speed advantage translates directly into better quality retention because the initial burst of respiratory activity that triggers yellowing and vitamin degradation is suppressed before it can cause irreversible damage. Ice cooling performed almost as well and has the advantage of not requiring specialized equipment, making it a practical option for small-scale packhouses in Kenya [1].

Vacuum cooling, despite the fastest half-cooling time (8 minutes), caused higher weight loss because the evaporative cooling mechanism removes moisture from the product surface. This trade-off between speed and moisture loss has been noted in other leafy vegetables [5]. For exporters, vacuum cooling followed by modified atmosphere packaging may offset the moisture issue, but for domestic markets, hydrocooling offers the best balance of effectiveness, cost, and simplicity [7].

Conclusion

Hydrocooling is the most effective pre-cooling method for broccoli produced in Kenyan highlands, extending shelf life to 12.4 days with the lowest weight loss and highest ascorbic acid retention. Ice cooling is a viable low-cost alternative. Room cooling is inadequate for this highly perishable crop. Broccoli packhouses should invest in hydrocooling infrastructure to reduce post-harvest losses and meet the quality standards required for both domestic supermarkets and export markets.

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