Research Paper

Enhancing Conventional Freezing: Assessing Pre-treatments for Optimal Preservation of Selected Vegetables

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Abstract

Vegetables are highly perishable, and their quality during storage depends on effective preservation techniques. This study explored enhancing conventional freezing in eight vegetables (bitter gourd, tender jackfruit, green chili, carrot, pumpkin, jackfruit, jackfruit seeds, and beans) through two blanching methods: steam blanching (SB) and hot water blanching (HB). The blanched vegetables were packed and stored at -18°C for four months.

Post-storage, the vegetables were analyzed for physicochemical, sensory, and microbiological properties. Physicochemical parameters included drip loss, pH, ascorbic acid content, and firmness. SB resulted in lower drip losses (0.5-5%) compared to HB, except in carrots and bitter gourd, which showed higher drip losses (14-15%) with HB. pH remained stable in tender jackfruit and green chili but varied in other vegetables. Firmness declined significantly in most vegetables, with pumpkin and jackfruit showing the least decrease (36.86%), while SB carrots experienced higher softness. Vitamin C content decreased across vegetables, except in tender jack, carrot, and jackfruit seeds, which retained their levels. Microbiological analysis confirmed safety, with no significant growth in total plate count, yeast/mold, or coliforms. Sensory evaluation favored HB-treated frozen vegetables over SB-treated and fresh samples. Freezing also reduced cooking time, enhancing preparation convenience. This study highlights the potential of optimized blanching and freezing techniques to preserve vegetable quality during frozen storage.

Keywords: Blanching, Perishable, Storage period, Vegetables

Introduction

There is a good demand for frozen food all over the world, because it is very easy and ready to cook in few minutes. Also which is highly increased due to busy life schedule of people and do not want to spend much time in the kitchen. The frozen market consists of meats, fish, fruits, vegetables, beans and some seeds and all related foods. The availability does not depend on the season, area or any other matter but on the availability to facilitate the frozen condition. Vegetables are incredibly perishable commodities, as their post-harvest stability and subsequent storage conditions play a crucial role. Freezing emerges as a simple, time-efficient, and noteworthy technique for preserving not only the nutrients but also the flavor, color, and texture of vegetables. It stands out among various methods of food preservation, employing technologies that impede the degradation of quality and inhibit microbial growth. This approach induces a dormant state in microorganisms, necessitating meticulous handling of the food, equipment, and personnel both prior to freezing and subsequent thawing. Among these preservation methods, freezing has demonstrated its effectiveness in long-term storage (Magnussen *et al*., 2009). Freezing is a widely used long-term preservation method for foods, where it retains attributes associated with freshness much better than other conventional preservation methods like canning and drying (Silva *et al*., 2008). But especially the texture of cellular foods, like meat, vegetables and fruits, can be strongly impacted by the freezing process. Above all, vegetables often require blanching prior to freezing to prevent enzymatic browning. Blanching already impacts the vegetable texture. Freezing generally decelerates the majority of modification processes (Bonat Celli *et al*., 2016; Prakobsang & Pornchalermpong, 2018). The impact of freezing on tissue-based food materials such as vegetables, fruits, and meat is still an area that requires further understanding, particularly regarding the freeze concentration and the mechanical stress exerted by growing ice crystals (Gómez & Sjöholm 2004). One significant effect of freezing on vegetables and fruits is drip loss after thawing, which is attributed to changes in the food's water-holding capacity caused by freezing.

The objectives of this study concentrated on the application of conventional freezing technology with pretreatments for home-scale production and small to medium-scale industry applications. The findings of this study will contribute to enhance the utilization of conventional freezing technology in various settings, ultimately reducing postharvest losses and promoting sustainability in the vegetable industry.

Materials and methods

Plant Materials

The freshly harvested vegetables; bitter gourd, tender jak, green chili, carrot, pumpkin, jack, jack seed, and bean were received from the market and directly started the processing steps. Vegetables were cleaned, washed in a chlorine solution (concentration at 100 ppm) separately for 2 minutes, dried, and manually cut into desired equal-sized pieces/ cubes/ strips or chunks using a stainless steel knife.

Bitter gourd (3×1 cm^2), tender jak (3×3 cm^2), green chili (whole), carrot (3×1.5 cm^2), pumpkin (3×cm^2), jack (3×0.5 cm^2), jack seed (whole), and bean (3×0.5 cm^2).

Pre-treatments

Two blanching treatments (steam blanching/ SB and hot water blanching/ HB) were given to vegetable pieces. Durations of blanched were: bitter gourd for 3 min., tender jack for 15 min., green chili for 30 sec., carrot for 3 min., pumpkin for 3 min., jack for 2 min., jack seed for 5 min. and bean for 3 min. according to the preliminary trials.

Freezing treatment

Following the blanching pre-treatments, the vegetable slices were drained and rinsed with cold water until they reached ambient temperature. They were then gently blotted with tissue paper to remove adhering water before being placed into labeled low density polyethylene (LDPE) bags. Air was expelled out the bags by manual gentle pressing the bags and the samples were securely sealed using a polythene sealer (300 FE, SEPACK, Sevana, India).

The next step was the conventional freezing where the sealed samples were exposed to a temperature of -18 °C using a conventional freezer (RS55K5010S9/TL, SAMSUNG, Digital Inverter Technology Co., Ltd.). Subsequently, both groups of samples were stored in the freezer at -18 °C for four months. After this period the samples were evaluated for quality, sensory attributes, and microbiological attributes such as total plate count, coliform, and yeast and mold count to assess their overall condition.

Thawing process

The frozen products were placed on muslin cloth in a plastic crate and thawed under controlled conditions of temperature at 25 °C and 50% relative humidity. Thermocouples of the K type were used to detect the core temperature of the sample until the temperature reached 0-4 °C and then the quality analyses were conducted.

Qualitative analysis

Drip loss

After the samples were thawed, the formed water was allowed to drip off, and the samples were then weighed using an analytical balance (AS 220 R2, RADWAG, Germeny). Drip loss was defined as a percentage and calculated using the following equation:

$$\text{Drip loss (\%)} = \frac{\left(\text{Weight before thawing} - \text{Weight after thawing}\right)}{\text{Weight before thawing}} \times 100$$

Firmness

The firmness of the samples of fresh, as soon as frozen and after four month stored under frozen condition was determined using a Fruit firmness tester (FHP-803, AG/ EC, India). Three pieces of vegetables were tested for each treatment and calculated the percentage reduction using the following equation.

$$\text{\% Reduction of Firmness} = \frac{W_1 \times W_0}{W_0} \times 100$$

Where W_0=firmness of fresh sample, W_1=firmness of treated (SB/ HB) sample

pH

Frozen samples after thawing were blended with a blender (MG 139, Philips Electronics Co., Ltd., Netherland), and pH of the juice prepared from each vegetable sample separately was measured using a pH/ Temperature Bench Meter (Mi 150, Milwaukee, India), with a combined pH electrode at 27 °C.

Ascorbic acid (Vitamin C) content

A thoroughly crushed sample was measured (W_0) into a cleaned dry volumetric flask of 50 mL. It was then made up to the marked volume using a 2.5 % metaphosphoric acid solution, and after closing the lid it was shaken well and kept. Then 10 mL of prepared sample solution was taken into a volumetric flask and titrated against the dichlorophenol indophenol dye solution. The ascorbic acid content (mg/ 100g) in (W_0) of sample was calculated using the following equation:

$$\text{Acorbic acid content} = \frac{W_2 \times 100}{W_0}$$

Where, W_2= ascorbic acid content in (W_0) of sample.

Comparison of cooking time of fresh and frozen vegetables

Freshly harvested vegetables (bitter gourd, tender jackfruit, green chilli, carrot, pumpkin, jackfruit, jackfruit seeds, and beans) were taken to the laboratory, and cooked to make curries with coconut milk and other spices according to the general household practice. Frozen products of the research activity were thawed, and same practice was applied. As the second practice, both fresh and frozen vegetables were cooked until coming to the desired palatable stage. The duration required for these were measured. Cooked samples were subjected for the sensory analysis.

Sensory analysis of frozen vegetables; Fresh, four months after storage

Cooked fresh and frozen vegetable samples were used to make sensory analysis with 30 untrained panelists. The sensory attributes were tested according to the food color, odor, taste, texture and overall acceptance through a five-point hedonic scale.

Experimental design and statistical analysis

Experimental trials were conducted using Complete Block Design (CBD). There are two pretreatments; steam blanching and hot water blanching of vegetables and -18 °C conventional freezing. At each combination, triplicate samples were characterized as to drip loss, pH, color, Vitamin C and firmness/ texture. All experiments were performed in triplicate for each treatment. The data were analyzed by analysis of variance (ANOVA), Tukey's mean comparison test (p <0.05) using Minitab 17.0. Sensory analysis results were analyzed using computer-aided Minitab-21 statistical analysis software.

Results and Discussion

Physicochemical parameters of fresh vegetables

According to the table 1, the moisture content of the majority of fresh vegetables were 80-92%, with jackfruit and jak seeds having MC% only 70% and 50% respectively.

Table 1. Initial physicochemical parameters of fresh vegetables

No	Vegetable	Moisture (%)	Firmness (kgf)	Vit. C (mg)	pH
1	Bitter gourd	92.90	11.49	41.0	6.36
2	Tender jack	85.45	12.22	18.8	5.09
3	Green chili	86.77	10.99	45.0	5.64
4	Carrot	89.78	19.27	12.7	5.75
5	Pumpkin	87.09	07.05	18.4	5.77
6	Jack	70.35	12.57	21.2	6.10
7	Jack seed	50.59	20.87	22.5	6.02
8	Bean	91.81	12.43	35.2	5.87

The firmness of fresh pumpkin was 7.05 kgf, which was the lowest firmness, and 24.87 kgf of jack seeds, which was the highest firmness and others were in between. Ascorbic acid content was ranged in between 12-126 mg/100g, 12.00 in carrot and 126.00 mg/ 100g in green chili. pH ranged from about 5-6 of selected fresh vegetables.

Drip Loss % of frozen vegetables; four months after storage

Table 2 indicates that there is no significant difference in drip loss between the two pretreatments, Steam Blanching (SB) and Hot Water Blanching (HB), for all the vegetables studied. Most of the vegetables exhibited low levels of drip loss%, bitter gourd and carrot showed significantly higher amounts of drip loss in HB treatment. Drip loss is influenced by various factors, including the size of the defrosting food product, the distribution of ice crystals, and the rate of thawing (Van Buggenhout *et al*., 2006). Among the vegetables studied, jackfruit exhibited the lowest drip loss at 0.48 % and 0.81 %, followed by green chili, tender jackfruit, jackfruit seed, and beans. In a study by Tang *et al*. (2020) on cherries, the application of a permanent magnetic field and an alternating magnetic field resulted in drip losses of 4.79 % and 4.64 %, respectively (Tang *et al*., 2020). The results suggest that both pretreatment methods were successful, with jackfruit, green chili, tender jackfruit, jackfruit seed, and beans demonstrating minimal drip loss. Also only SB treated bitter gourd and carrot showed significantly lower drip loss than HB. Liu *et al*. (2021) proposed that a combined treatment involving pulsed electric fields and vacuum drying can significantly accelerate the freezing and thawing process. Frozen vegetables may undergo quality degradation, such as loss of tissue firmness, flavor, water holding capacity, and color degradation, as well as changes in important nutrients like vitamin C and carotenoids, along with the retention of enzyme activity. These changes are typically associated with cell structure disruption caused by mechanical damage, changes in ionic strength, or pH changes resulting from freeze concentration. The extent of these changes depends on the amount of drip loss during freezing (Prakobsang & Pornchalermpong, 2018).

Table 2. Drip loss of frozen vegetables; four months after storage

Vegetable	SB	HB
Bitter gourd	$5.97^{a} \pm 1.62$	$14.77^{b} \pm 5.63$
Tender jack	$2.94^{a} \pm 2.90$	$3.59^{a} \pm 2.71$
Green chili	$1.20^{a} \pm 0.71$	$1.26^{a} \pm 0.94$
Carrot	$8.47^{a} \pm 5.29$	$15.32^{b} \pm 4.09$
Pumpkin	$4.30^{a} \pm 3.33$	$5.90^{a} \pm 6.19$
Jack fruit	$0.48^{a} \pm 0.50$	$0.81^{a} \pm 0.59$
Jack seed	$3.32^{a} \pm 2.08$	$1.13^{a} \pm 0.49$
Beans	$3.83^{a} \pm 1.48$	$2.92^{a} \pm 1.73$

Where; Pretreatments SB-Steam Blanching and HB-Hot water blanching

Note: Values are averages of triplicate. Results are expressed as the mean ± standard deviation. Mean values within a column with different superscripts are significantly different (p<0.05)

Firmness of frozen vegetables; Fresh and four months after storage

Table 3 presents the firmness of raw/ fresh vegetables compared to frozen vegetables after four months of storage. Both blanching treatments, HB and SB, resulted in a significant reduction in firmness for almost all the vegetables when compared to their fresh counterparts. Whereas there is no significant decrease in firmness of fresh and thawed bitter gourd, the firmness significantly decreases in all other vegetables. The firmness of SB treated tender jack, pumpkin, jack and jack seed were in similar, but the firmness of SB treated other vegetables decrease significantly in the storage period of 4 months. Also the firmness of HB treated tender jack, carrot, pumpkin, jack and jack seed were in similar, but the firmness of HB treated other vegetables decrease significantly in the storage period of 4 months. The reduction in firmness exceeded 50 % for most vegetables after four months of frozen storage, except for pumpkin, which showed a 31 % and 36% reduction compared to fresh pumpkin. Additionally, SB carrots exhibited a significantly higher reduction in firmness compared to HB carrots. Blanching plays a role in facilitating the cooking process after freezing of vegetables, as indicated in Table 6.

Water constitutes over 90% of the weight of most fruits and vegetables, and this water, along with other chemical substances, is held within the relatively rigid cell walls that provide support and texture to the produce (Alexandre *et al*., 2013). Freezing fruits and vegetables involves the freezing of water contained within the plant cells. When water freezes, it expands, and the resulting ice crystals can cause the cell walls to rupture. Consequently, the texture of the produce becomes much softer when thawed compared to its raw state. Pretreatment blanching further facilitates textural changes and improves the cooking rate after freezing vegetables. As shown in Table 6, raw/ fresh vegetables require a longer cooking duration compared to blanched, frozen, and thawed vegetables.

Table 3. Firmness of frozen vegetables; fresh and four months after storage

No	Vegetable	Texture/ Firmness					Fresh initial	
		Initial (Fresh)	SB Initial	SB	HB Initial	HB	% Decrease (SB)	% Decrease (HB)
1	Bitter gourd	$11.49^{a}\pm 0.58$	$10.41^{a}\pm0.18$	$3.4^{b}\pm 0.27$	$10.09^{a}\pm0.23$	$3.5^{b}\pm 0.68$	70.4	69.5
2	Tender jack	$12.22^{a}\pm0.28$	$3.74^{b}\pm 0.33$	$4.2^{b}\pm 0.68$	$3.73^{b}\pm 0.28$	$4.1^{b}\pm 0.39$	65.6	66.4
3	Green chili	$10.99^{a}\pm0.18$	$5.69^{b}\pm 0.38$	$2.4^{c}\pm 0.46$	8.9b± 0.15	$2.9^{c}\pm 0.57$	78.2	73.6
4	Carrot	$19.27^{a}\pm0.68$	$13.6^{b}\pm 0.28$	$4.6^{d}\pm 0.80$	$6.31^{c}\pm 0.22$	$6.1^{c}\pm 0.16$	76.1	68.3
5	Pumpkin	$7.05^{a}\pm 0.58$	$6.15^{b}\pm 0.51$	$4.5^{b}\pm 0.72$	$6.95^{b}\pm 0.78$	$4.8^{b}\pm 0.55$	36.2	31.9
6	Jack	$12.57^{a}\pm 0.68$	$1.79^{b}\pm 0.22$	$2.0^{b}\pm 0.25$	$1.48^{b}\pm 0.39$	$3.7^{b}\pm 1.66$	84.1	70.6
7	Jack seed	$20.87^{a}\pm0.68$	$5.8^{b}\pm 0.21$	$5.2^{b}\pm 0.81$	$6.39^{b}\pm 0.5\ 3$	$7.3^{b}\pm 1.43$	75.0	65.0
8	Bean	$12.43^{a}\pm0.68$	$7.68^{b}\pm 0.18$	$3.3^{c}\pm 0.67$	$5.98^{b}\pm 0.22$	$2.1^{c}\pm 0.33$	73.5	83.1

Where; Pretreatments SB – Steam Blanching & HB – Hot water blanching

Note: Values are averages of triplicate. Results are expressed as the mean ± standard deviation. Mean values within a column with different superscripts are significantly different (p<0.05)

This textural difference is especially noticeable in products that are typically consumed raw. For instance, when a frozen tomato is thawed, it becomes mushy and watery (Alexandre *et al*., 2013). The freezing rate plays a crucial role in preventing tissue damage and minimizing drip loss during thawing. Faster freezing leads to the formation of smaller ice crystals, resulting in a better overall quality of the frozen food (Alexandre *et al*., 2013).

pH and Vitamin C/ Ascorbic acid content of frozen vegetables; Fresh and four months after storage

Tables 4 and 5 show the pH and ascorbic acid changes of the fresh and frozen vegetables after four months respectively. There was no significant difference in pH between fresh and frozen stored tender jack and green chili. The significant reduction of pH is shown in the other vegetables except carrot and bean. There is a relationship between pH and the ascorbic acid content according to Tables 3 and 4. The ascorbic acid content of fresh and frozen tender jack are in similar amounts. Whereas the pH is not changed after frozen condition of green chili, but the amount of vitamin c is decreased in about 19 %. The pH of carrot (11.7 % and 10.3 % in SB, HB respectively) and bean (9 % and 8 % in SB, HB respectively) increased and the Ascorbic acid of carrot is not changed but that of bean is decreased (about 35.45 %, 22.5 % of HB, SB respectively). Ascorbic acid of bitter gourd, tender jack, hot water blanched pumpkin and jack seed are not changed with frozen storage, and in steam blanched pumpkin (42.4 %) and ascorbic acid oxidation and changes in pH of insufficiently blanched vegetable tissues would be taken place. Ascorbate oxidase catalyzes oxidation of ascorbic acid during storage, and this process is accelerated when oxygen-permeable packaging is employed (Tassou *et al*., 2010). Also the oxidation rate depends on storage temperature and product pH (Alfy *et al*., 2016).

After a 4-month frozen storage period, green chili, pumpkin and bean showed the highest percentage significant reduction (19 %, 19.2 % in green chili, 42.4 %, 34.2 % in pumpkin and 35.4 % 23.5 % in bean of SB, HB respectively) in vitamin C content among the vegetables studied (Table 5).

Table 4. pH of frozen vegetables; fresh, blanched and four months after storage

No	Vegetable	pH				
		Initial (Fresh)	SB Initial	SB	HB Initial	HB
1	Bitter gourd	$6.36^{a}\pm 3.03$	$4.24^{b}\pm 2.03$	$4.80^{b}\pm 0.15$	$5.09^{b}\pm 1.01$	$3.86^{b}\pm 2.14$
2	Tender jak	$5.09^{a}\pm 0.03$	$4.6^{a}\pm 3.03$	$5.42^{a}\pm 2.05$	$4.97^{a}\pm 0.01$	$5.40^{a}\pm 3.02$
3	Green chili	$5.64^{a}\pm 1.03$	$5.54^{a}\pm 0.03$	$5.68^{a}\pm 1.04$	$5.59^{a}\pm 1.01$	$5.60^{a}\pm 0.05$
4	Carrot	$5.75^{b}\pm 3.03$	$5.73^{a}\pm 3.04$	$6.42^{a}\pm 0.05$	$5.81^{a}\pm 3.03$	$6.34^{a}\pm 0.05$
5	Pumpkin	$5.77^{a}\pm 1.03$	$5.68^{a}\pm 3.3$	$4.80^{b}\pm 0.15$	$5.53^{a}\pm 2.03$	$3.86^{c}\pm 0.14$
6	Jak	$6.10^{a}\pm 1.03$	$5.88^{a}\pm 2.01$	$5.40^{b}\pm 0.05$	$5.65^{a}\pm 3.03$	$5.40^{b}\pm 0.02$
7	Jak seed	$6.02^{a}\pm 1.03$	$5.97^{a}\pm 1.63$	$5.60^{b}\pm 0.12$	$6.14^{a}\pm 3.03$	$5.60^{b}\pm 0.12$
8	Bean	$5.87^{b}\pm 1.03$	$5.97^{a}\pm 3.01$	$6.40^{a}\pm 1.05$	$6.14^{a}\pm 1.73$	$6.34^{a}\pm 1.05$

Where; Pretreatments SB – Steam Blanching and HB – Hot water blanching

Note: Values are averages of triplicate. Results are expressed as the mean ± standard deviation. Mean values within a column with different superscripts are significantly different (p<0.05).

Table 5. Vitamin C of frozen vegetables; fresh, blanched and four months after storage

Vegetable	Vitamin C (mg/ 100g)				
	Initial (Fresh)	SB Initial	SB	HB Initial	HB
Bitter gourd	$41.5^{a} \pm 1.03$	$21^{b} \pm 1.76$	$36.36^{a} \pm 3.03$	18b ± 3.03	$38.05^{a} \pm 2.51$
Tender jak	$18.8^{a} \pm 3.02$	$18^{a} \pm 3.03$	$18.75^{a} \pm 2.75$	$19.5^{a} \pm 0.86$	$18.18^{a} \pm 0.55$
Green chili	$45.0^{c} \pm 2.85$	$87^{a} \pm 3.03$	$35.15^{b} \pm 0.90$	$73.5^{a} \pm 4.03$	$36.36^{b} \pm 0.00$
Carrot	$12.7^{a} \pm 3.93$	$13.5^{a} \pm 3.03$	$13.63^{a} \pm 1.51$	$12^{a} \pm 3.03$	$13.63^{a} \pm 1.51$
Pumpkin	$18.4^{a} \pm 3.33$	$19.5^{a} \pm 2.93$	$10.60^{b} \pm 1.51$	$18^{a} \pm 3.63$	$12.12^{b} \pm 0.00$
Jak	$21.2^{a} \pm 3.53$	$22.5^{a} \pm 3.03$	$31.81^{b} \pm 1.91$	$15^{c} \pm 3.03$	$22.72^{a} \pm 1.51$
Jak seed	$22.5^{a} \pm 4.03$	$24^{a} \pm 4.03$	$20.27^{a} \pm 2.00$	$19.5^{a} \pm 3.11$	$20.57^{a} \pm 2.01$
Bean	35.2b ± 3.05	$15^{b} \pm 3.01$	$22.72^{a} \pm 1.51$	15b ± 3.11	$27.27^{a} \pm 1.03$

Where; Pretreatments SB – Steam Blanching & HB – Hot water blanching

Note: Values are averages of triplicate. Results are expressed as the mean ± standard deviation. Mean values within a column with different superscripts are significantly different ($p<0.05$).

Initially both Hot Water Blanching (HB) and Steam Blanching (SB) treatments resulted in similar percentage reductions of ascorbic acid for pumpkin, jackfruit, jackfruit seed, and beans. However, for bitter gourd, both SB and HB treatments lead to a significantly higher percentage reduction in ascorbic acid then significantly increase during 4 months' storage period. On the other hand, there were no significant differences in ascorbic acid content between the initial fresh samples and the frozen vegetables for bitter gourd, tender jackfruit, carrot, HB jackfruit, and jackfruit seeds.

Comparison of cooking time of fresh and frozen vegetables

According to the Table 3 almost all the vegetables reveals that the firmness decreases significantly with the blanching and storage after four months resulting the lesser time taken to make the curry (Table 6). Therefore, this is ideal methodology of keeping these vegetables for longer duration and easy cooking after storage.

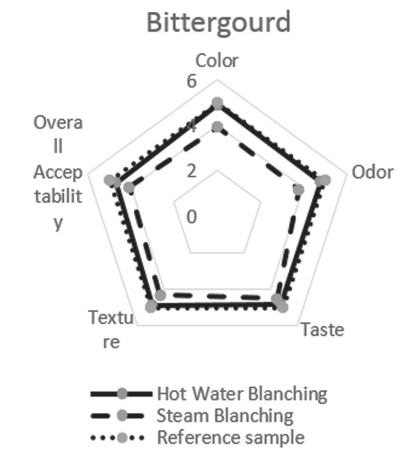
Sensory analysis of frozen vegetables; Fresh, four months after storage

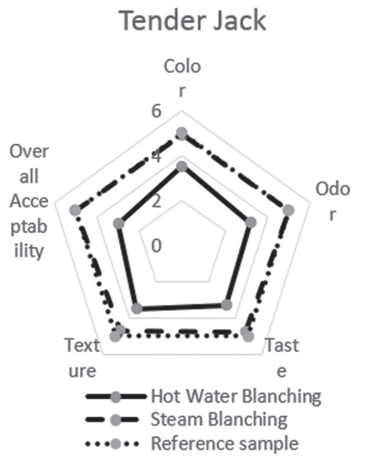
Figure 1, which depicted Radar charts comparing the sensory attributes of fresh and frozen vegetables. The charts indicated that most vegetables received higher rankings in terms of sensory attributes when assessed as fresh samples.

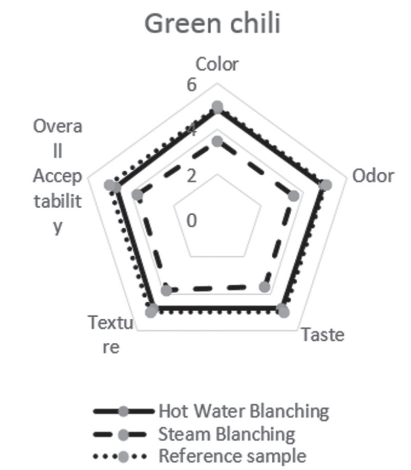
Table 6. Time taken to prepare respective vegetable curry after four months frozen storage condition with comparison of reference sample (fresh vegetable)

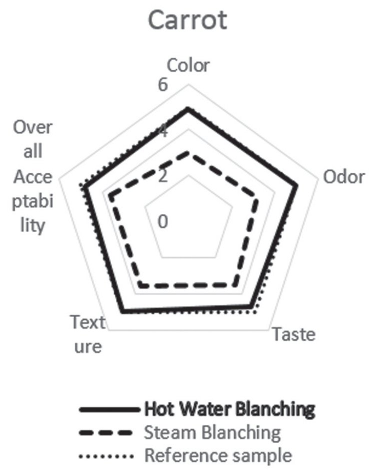
No	Vegetable	Time taken to make a curry (minutes)		
		Reference	SB	HB
1	Bitter gourd	20	10	10
2	Tender jak	45	20	20
3	Green chili	20	10	10
4	Carrot	30	15	15
5	Pumpkin	25	15	15
6	Jak	25	10	10
7	Jak seed	35	15	15
8	Bean	20	10	10

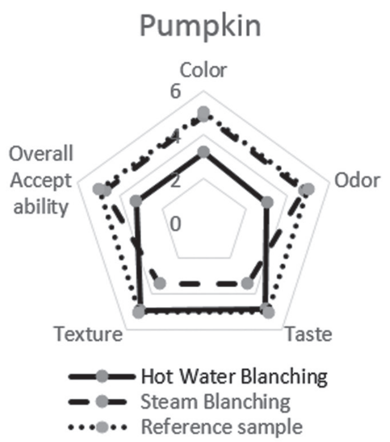
However, it's worth noting that the sensory attributes of HB samples were found to be much similar to those of fresh samples except tender jack and jack fruit, indicating that HB methods yielded comparable higher results in terms of the sensory quality of tested vegetables.

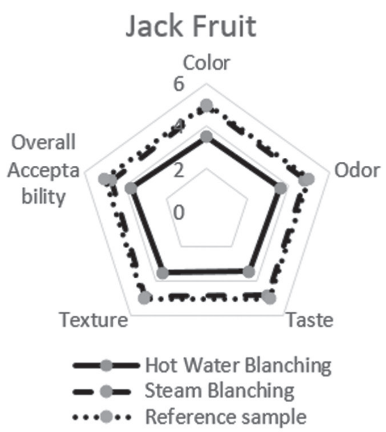












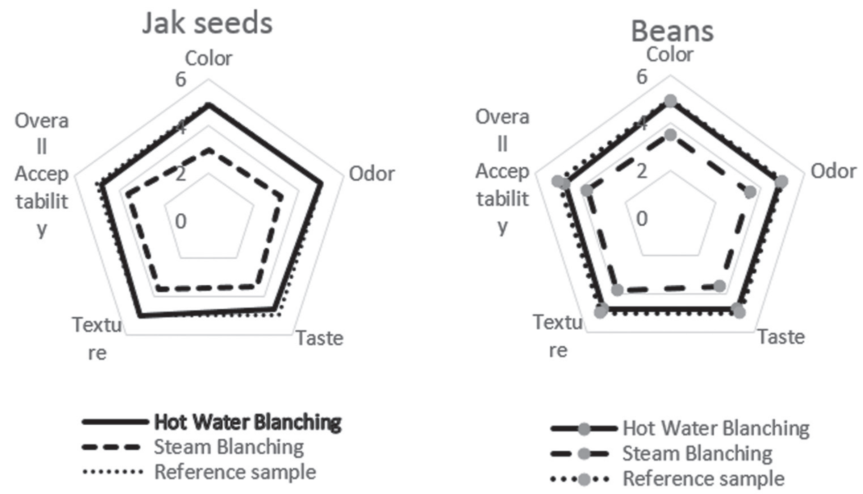


Figure 1. Sensory analysis data of fresh/ reference and frozen vegetables; four months after storage

Microbial counts of frozen vegetables, blanched followed by four months' storage

Table 7 provides the microbiological test results for fresh and frozen vegetables after four months. Accidental contaminations were only observed in very few samples (0.5 %), specifically in the total plate count (TPC) and yeast and mold (Y/M) plates for almost all the vegetables during the entire four-month storage period.

Throughout the storage period of four months, no coliforms were detected in any of the vegetables. It is beneficial to establish baseline data for the microbiological quality of frozen fruits and vegetables, particularly regarding contamination by *Escherichia coli* (*E. coli*) (Willis *et al*., 2020). Studies have shown that some non-European Union (EU) countries had E. coli levels above 100 colony-forming units (cfu) per gram (7/127; 6 %), whereas EU countries had lower levels (Willis *et al*., 2020).

These results indicate that the tested products are microbiologically safe to consume during the entire four-month storage period. Microorganism growth is unlikely to occur at the very cold temperatures typically employed in frozen storage (< -18 °C). It is recommended to maintain storage temperatures below -12 °C during transportation, distribution, and retailing (Anonymous, 1986). Pathogens commonly associated with vegetables, both fresh and frozen, include Salmonella spp., *Bacillus cereus, Listeria monocytogenes,* and *Yersinia enterocolitica*. However, these pathogens are generally rare in blanched, frozen vegetables (Archer, 1998).

Table 7. Microbial counts of frozen vegetables; Blanched followed by four months storage

No	Commodity	Total Plate Count (cfu)		Yeast and Mold count (cfu)		Coliform	
		SB Frozen	HB Frozen	SB Frozen	HB Frozen	SB Frozen	HB Frozen
1	Bitter gourd	0	0	0	0	(-) ve	(-) ve
2	Tender jack	0	0	0	0	(-) ve	(-) ve
3	Green chili	0	0	0	0	(-) ve	(-) ve
4	Carrot	0	0	0	0	(-) ve	(-) ve
5	Pumpkin	0	0	0	0	(-) ve	(-) ve
6	Jack fruit	0	0	0	0	(-) ve	(-) ve
7	Jack seed	0	0	0	0	(-) ve	(-) ve
8	Beans	0	0	0	0	(-) ve	(-) ve

Conclusions

The comparative analysis of frozen vegetables treated with steam blanching (SB) and hot water blanching (HB) reveals intriguing findings. While both methods yielded similar physicochemical attributes, sensory evaluation highlighted the superiority of HB over SB. This study unequivocally demonstrates that blanching followed by freezing is a highly effective technique for preserving the quality of vegetables, inhibiting microbial growth, and maintaining sensory attributes over an extended storage period of four months. Moreover, freezing the vegetables resulted in significant reductions in cooking time, adding to their convenience and making them an ideal choice for quick and easy preparation.

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