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Synergetic effect of microwave blanching and modified atmosphere packaging using laser micro-perforated bags on the storage quality of carrot**

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A b s t r a c t. The present study was undertaken to determine the combined effect of microwave blanching and micro-perforated modified atmosphere packaging in maximizing shelf life on the basis of quality attributes which were evaluated during storage. The carrots were blanched in water using a microwave at 360 W and then stored in micro-perforated modified atmosphere packaging. The results indicated that blanched carrots in micro-perforated modified atmosphere packaging showed an improved storage quality. In particular, it was observed that the firmness of the pretreated samples in the micro-perforated package were significantly improved. The enzyme activity (peroxidase) initially increased and then decreased with longer storage times. There was also a greater reduction in water content in sample C8, probably due to a higher rate of evaporation through the perforations. Water mobility which comprises tightly bound water, loosely bound water, and immobilized water were observed in all samples, while the free water level was insignificant in pretreated micro-perforated samples. The free water, T_{24} peak was observed for the control sample which increased with increase in storage duration. Also, the effects of this preservation method on other quality parameters such as β-carotene, water activity, moisture content, and microbial load was limited. However, sample C8 was more effective in retaining quality. Overall, this study demonstrated that blanching carrot in micro-perforated MAP at C8 was the most useful technique in preserving the storage qualities of carrot.

K e y w o r d s: laser micro-perforated bag, modified atmosphere packaging, blanching, carrot, storage quality

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INTRODUCTION

Fresh food products such as vegetables and fruits are a remarkable source of vital nutrients including micronutrients, vitamins, fibres and various phytochemicals which are essential for human health. In general, due to their high moisture content, fruits and vegetables are highly perishable, hence reduced quality and shelf life are a major challenge for storage purposes and limit the availability of these fresh products (Hussein *et al.*, 2015). Some studies have reported that this reduction in quality and shelf life may occur as a result of continued life processes in fruits and vegetables even after harvest as a result of ongoing metabolic activities such as respiration, ripening and also from presence of mechanical damage and physiological disorders (Irtwange, 2006; Sandhya *et al.*, 2010; Siddiqui, 2011). These underlying causes of deterioration lead to undesirable quality changes in factors such as texture, colour, flavour and beneficial healthy values (Defilippi *et al.*, 2005). Overall, if these factors are not properly controlled, they might eventually lead to reductions in edibility, availability, food losses, and subsequently in financial losses (Defilippi *et al*., 2005; Fallik, 2004; Irtwange, 2006; Mahajan *et al.*, 2014; Opara *et al*, 2009; Opara *et al.*, 2012).

Carrots are one of the most preferred root crops because of their high nutrient content such as beta-carotene, dietary fibre, vitamins and minerals as well as their versatility in culinary uses due to their special taste (Gaggiotti *et al.*, 2019). However, carrots are highly susceptible to moisture loss which leads to freshness and quality degradation (Larsen and Wold, 2016). Hence, an effective preservation technique is required to preserve such food products and maintain their quality while extending shelf life to make them readily available even during off seasons. Many food preservation techniques have been applied to date and have in turn been reviewed by many researchers. Chemical based treatments such as antioxidant treatments and washing with ozonized water and sanitizers for food pretreatment are among the preservation techniques which have been effective in the preservation of food products (Beltrán *et al.*, 2005; Garcia *et al.*, 2003; Garcia and Barrett, 2002).

However, consumer awareness concerning food safety and health benefits has resulted in the minimization of the use of these chemicals in the food industry (Hussein *et al.*, 2015). Moreover, research has shown that using these chemical washings and sanitizers cannot guarantee the production of foods free from microbial contamination and without affecting the sensory quality of food products (Martin-Diana *et al*., 2007). As a result, most of these washing sanitizers and inorganic chemical treatments presently face serious challenges to gain widespread acceptance in the fresh produce industry (Martin-Diana *et al*., 2007; Worth *et al.*, 2002).

Smart packaging, also referred to as IP (intelligent packaging) is another remarkable innovation primarily designed to track food, sense the internal and external surroundings of the package and is capable of conveying any notable changes to the food manufacturer or producer, hence it effectively monitors the safety status and quality of the food product (Aindongo *et al.*, 2014; Yam *et al.*, 2005). Active packaging is also another recognized innovation which involves the use of emitters and absorbers or a discharging system of active components, ethylene emitters/scavengers and also moisture absorbers in the packaging material (Rodriguez-Aguilera and Oliveira, 2009). The active ingredients extend shelf-life by modifying the atmosphere surrounding the product inside the package (Jacxsens *et al.*, 2003). However, the extensive use of these intelligent and active packaging methods and their practical application is limited mainly because of regulatory issues and practical limitations including high costs (Realini and Marcos, 2014; Yam *et al*., 2005). The need for appropriate pretreatment and non-invasive easily available packaging that will prevent desiccation, reduce contamination as well as retaining the appeal of freshness and prolonging shelf life continues to gain more interest in the food industry.

Blanching treatment stabilizes the texture, flavour, colour and nutritional quality content of the product and inactivates enzymes which catalyse deleterious changes. According to (Terefe *et al.*, 2014) the activity of deteriorative enzymes such as peroxidase (POD), Polyphenol oxidase (PPO), lipase, chlorophyllase, and lipoxygenase (LOX), together with the presence of microorganisms associated with enzymatic activity may be responsible for colour changes, adverse changes in flavour and a reduced shelf life in fresh vegetables and fruit. Some studies have reported that browning discoloration and anthocyanin degradation in lychee fruit correlated to a significant extent with increased POD activity during storage (Zhang *et al.*, 2003; Zhang *et al.*, 2005). (Funamoto *et al.*, 2002; Funamoto *et al.*, 2003) reported that chlorophyll degradation in broccoli correlated with increased POD activity. (Xiao *et al*., 2017) stated that blanching helps to inactivate both enzymes and microorganisms. Hence, this process maintains quality while extending the shelf life of food (Anthon and Barrett, 2002; Begum and Brewer, 2001; Tunde-Akintunde, 2010). Some researchers have reported on the effects of blanching in various food products. Others have reported on the preferred influence of microwave blanching compared to other blanching methods (Bhattacharya *et al.*, 2017; Bingol *et al.*, 2014; Quarcoo and Manu, 2016; Ruiz-Ojeda and Peñas, 2013; Severini *et al.*, 2016). Moreover, it reduces microbial load and does not affect sensory quality.

The application of various aspects of modified atmosphere packaging (MAP) on different fresh produce has been examined by many researchers. This technique involves the use of gas mixtures to preserve food according to a particular food requirement. Many researchers have also reported on advancements in the use of MAP and its potential to extend shelf-life and preserve the quality of fresh food products (Aindongo *et al*., 2014; Oms-Oliu *et al.*, 2008; Qu *et al.*, 2020; Sandhya *et al*., 2010; Soliva-Fortuny and Martin-Belloso, 2003). Others have examined the influence of MAP on subsequent outbreaks of foodborne diseases and the growth of resistant foodborne pathogens (Aindongo *et al*., 2014; Harris *et al*., 2003). Additionally, MAP is known to be comparatively cheap and easier to use as it does not involve any protocols which have a long duration.

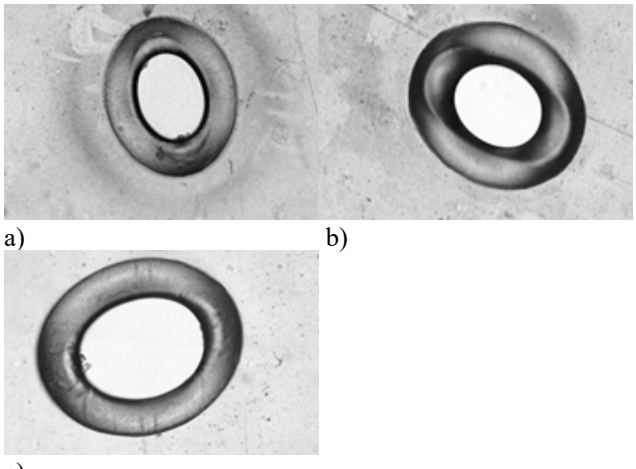
Permeability is one of the factors to be considered when using MAP, which is particularly the case for produce with a high rate of respiration. In some cases, the levels of the components of the packaging atmosphere attained using traditional MAP are not sufficient to maintain quality of produce for a sufficient length of time (Jarvis *et al*., 2017; Mangaraj *et al.*, 2009; Sandhya *et al*., 2010). Also, moisture condensation can occur as a result of fluctuating temperatures (Linke and Geyer, 2013). This may lead to the development of undesirable properties such as off-odours and anaerobiosis and can severely modify the volatile profile of packaged food product (Aindongo *et al*., 2014, Martín-Belloso *et al.*, 2013). Alternatively, the use of a perforated MAP has been proposed as a technique to overcome these limitations (Hussein *et al.*, 2015; Rodriguez-Aguilera and Oliveira, 2009). It is important to note that several

authors have reported on the use of blanching as a viable pretreatment of fresh food products and also highlighted the use of MAP for extending shelf life. However, as yet, no research has been conducted on the combined effect of blanching and micro-perforated-MAP on carrot storage quality. This research aims to evaluate the synergetic effect of microwave blanching and micro-perforated MAP on carrot quality during storage.

MATERIALS AND METHODS

Fresh carrots (Daucus carota) were purchased from Auchan supermarket (Wuxi, China), at the full ripeness stage. The carrots were refrigerated at 4°C, less than 24 hours prior to processing.

The carrots were first washed, peeled and finally sliced into 8-mm pieces before being blanched in water at 360 W for 300 secs using a microwave oven (Panasonic Co., Ltd, China) with a maximum rated power of 800 W at 2450 MHz. The internal dimensions of the microwave oven were approximately 302×509×348 mm (Başkaya *et al.*, 2015). The actual microwave power level was 669 W using the IMPI-2L method (Saifullah *et al.*, 2019). For the experiment, 100 g of carrot slices was blanched and cooled immediately in ice. Afterwards, the surface water was removed using a water removal machine (Shandong Duckling Group Home Appliance Co. LTD China, Model T 68-188 dehydrator) at 50 W for 2 min.



a) b)

c)

Fig. 1. Microscopic view laser micro-perforation (a) 0.05 μm, (b) 0.10 μm, (c) 0.15 μm.

The samples were placed in high density polyethylene (HDPE) 16×23×8 cm packaging film, and then sealed in an atmosphere of 5% O_2, 10% CO_2, 85% N_2 using a modified atmosphere multifunctional machine (Hengzhong Machinery Co., Zhangjiagang, China). Perforation was accomplished using a laser machine (Wuxi Yiwang Laser device, China) producing holes of various sizes, 0.05 μm, 0.10 μm, and 0.15 μm. The number of perforations were maintained within the range of 4 to 8 for each perforation size. The samples were identified according to their perforation sizes, 0.05 μm (B8), 0.10 μm (C4 and C8) and 0.15 μm (D4 and D8), making up 5 samples altogether. A light microscope was used to measure the perforation sizes at 100 times magnification as shown in Fig. 1. The carrot were stored at 4°C for 30 days. The samples were analysed at 5-day time intervals (0, 5, 10, 15, 20, 25, and 30 days). All the analyses were carried out in triplicate.

The firmness of the sliced carrots was measured using a texture analyser (TA-XT2i, UK) according to the method of (Fan *et al*, 2019). The measurement was carried out at a pretest speed of 2.00 mm s^{-1}, and the test speed and post-test speed were determined at a penetration distance of 10 mm to determine the maximum force (N).

The carotene content was determined as described (Başkaya Sezer and Demirdöven, 2015). The samples were extracted using a mixture of (acetone: hexane: ethanol, 25: 50: 25, v/v/v). 2 g of carrot samples were homogenized with 38 ml of the mixture using a lab blender for 20 secs, which was then centrifuged at 5320 rcf for 12 min at 5°C. The absorbance was determined using a spectrophotometer (Kyoto Shimadzu Co., Ltd, Japan) at 450 nm. The β-carotene content was determined in terms of milligram per kilogram.

The moisture content of the carrot samples was evaluated at a constant temperature of 105°C using a hot air oven. The sample was oven-dried until a constant weight was achieved according to the method of (AOAC 2000).

The water activity of the carrot samples was determined using a laboratory water activity analyser (Lab Master, S/N: 1612o16) at 25°C. The carrot samples were placed in a sample chamber after calibration until equilibrium was reached.

Low field nuclear magnetic resonance (LF-NMR) was used to analyse the transverse relaxation time (T_2) of carrot as presented by (Fan *et al*., 2019) using an analyser (MiceoMR20-030V-1, Numag Electric Co., Suzhou, China) with a resonance frequency of 23.2 MHz and a 0.5 T magnetic field intensity. The operating temperature of the magnet was 32°C. First, the oil sample was calibrated and free induction decay (FID) was used to adjust the centre frequency. Next, the T_2 relaxation time and pulse parameters: NECH (number of echoes) = 15,000, NS (number of scans) = 4, TD (sampling points) =750,002, TW (time waiting) = 6000 ms, P2 (pulse time of 180°) = 11 μs, P1(pulse time of 90°) = 6 μs, TE (time echo) = 0.5 ms, O (Offset frequency) = 494824.07 kHz, SW (sampling frequency) = 100 kHz, were evaluated automatically using the Carr-Purcell-Meiboom-Gill pulse sequence (CPMG).

Crude enzyme extract was prepared according to a method described by previous researchers (Morales-Blancas *et al.*, 2002). One hundred ml of potassium phosphate buffer (0.1 mol L^{-1}, pH 6.5) was used to homogenize 40 g of carrot sample and then centrifuged for 40 min at 9,000 rpm at 4°C. The POD was determined using the collected enzyme extract. The POD substrate solution was prepared using a mixture of 99.8 mL potassium phosphate buffer, 0.1 mL hydrogen peroxide (30%), and 0.1 mL of guaiacol. After

a few minutes of shaking, the POD was assayed using a mixture of 3.48 mL of substrate and 0.12 mL of enzyme extract. Measurements were carried out at 470 nm based on the increase in absorbance. One unit of enzyme activity was assumed to occur with a change of 0.01 absorbance units per min for POD.

The colour properties of the stored carrot samples were analysed using a laboratory Colour Reader, more specifically the CR-400 Chroma Meter (Konica Minolta Sensing Inc., Osaka, Japan). Initially, before the colour analysis was performed, the instrument was calibrated using a standard white porcelain plate. The L*a*b* parameters were considered in order to evaluate the colour change in carrot. L* indicates the lightness value, a* indicates redness, while b* indicates the yellowness value. To determine the average of the L*a*b values, the carrot slices were scanned at three different places.

The total plate count of the carrot samples was determined according to the method (Fan *et al*., 2019). This was accomplished by homogenizing 1 g of carrot with 9 mL of saline solution. The solution was diluted, and then 1 mL was added to a petri dish with nutrient agar and incubated for 48 h at 37°C. The results were expressed in terms of the colony-forming unit per milligram (CFU ml^{-1}) of sample.

Analysis of data was carried out using a non-linear regression technique (Graph Pad PRISM® Version 8.0.2.263 software). A one-way ANOVA was performed and the multiple comparisons data were corrected using Tukey's statistical hypothesis testing.

RESULTS AND DISCUSSION

A loss of firmness was not observed within 10 days of the initiation of the storage period. Initially, the firmness of the carrot increased for up to 10 days and then decreased (Fig. 2).

The increase during the first 10 days of storage could be attributed to moisture migration from the product. (Dawange *et al.*, 2016) reported an increase in the firmness of the perforated carrot samples as a result of moisture loss causing dryness in the product. (Klaiber *et al.*, 2005) also reported an increase in the firmness of sliced carrot due to a loss of moisture. However, (Dawange *et al*., 2016) reported that carrot stored under perforated MAP decreased in firmness within 8 days of the initiation of storage due to the natural ageing of the vegetable. Therefore, the decrease in firmness after 10 days could be ascribed to the natural ageing of the carrot samples.

Based on the initial beta carotene content of carrot, (Kaack *et al.*, 2001) observed that seasonal variation can affect beta carotene content. The authors reported a higher beta carotene content in carrot for warm and sunny years. The authors also reported that the application of nitrogenous fertilizer at a rate of about 25 kg km^{-2} in the summer season can increase the beta carotene content of carrot. Blanching also increases the carotene content of carrot. This may occur as a result of the loss of moisture and soluble solids during the blanching process which includes the phenomenon of greater chemical extractability (Dutta *et al.*, 2005). Dutta *et al*. (2005) reported that after blanching carrot for 3 minutes, the carotene content increased by 65%. Also, the inactivation of certain oxidative enzymes during blanching may cause a further breakdown of some structures which leads to the higher bio-availability of beta carotene (Dutta *et al*., 2005; Guerra-Vargas *et al.*, 2001). During the 30-day storage period, the B-carotene content of the pretreated carrot samples decreased from an initial value of 8.484 mg kg^{-1} to 6.591 mg kg^{-1} (C8), 6.074 mg kg^{-1} (D8), 5.764 mg kg^{-1} (D4), 5.068 mg kg^{-1} (C4), 4.3884 mg kg^{-1}

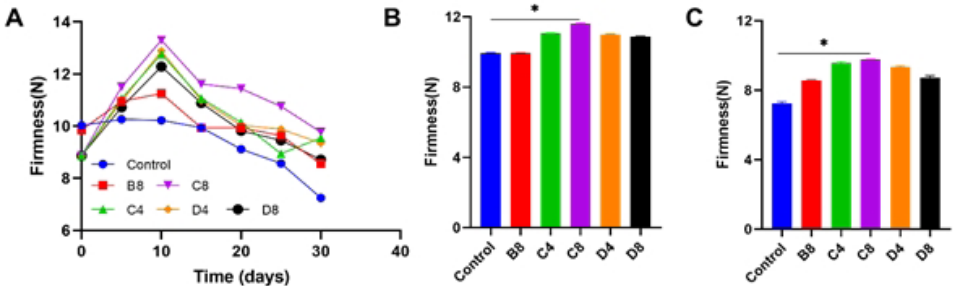


Fig. 2. Effect of blanching and micro-perforated MAP on the firmness of carrot (A) for 30 days of storage (B) comparative analysis at 15 days and (C) 30-days of storage.

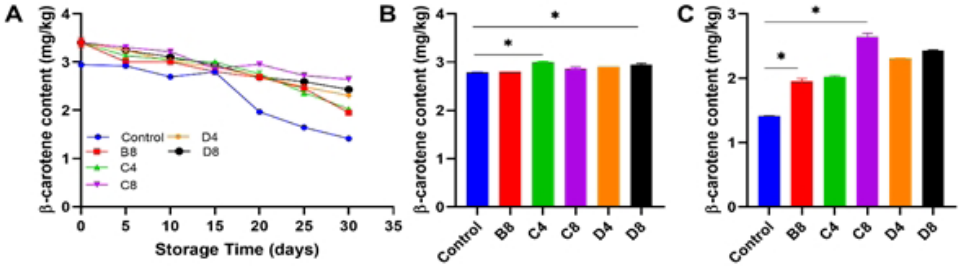


Fig. 3. Effect of blanching and micro-perforated MAP on the β-carotene of carrot (A) for 30 days of storage, (B) comparative analysis at 15 days and (C) 30-days of storage.

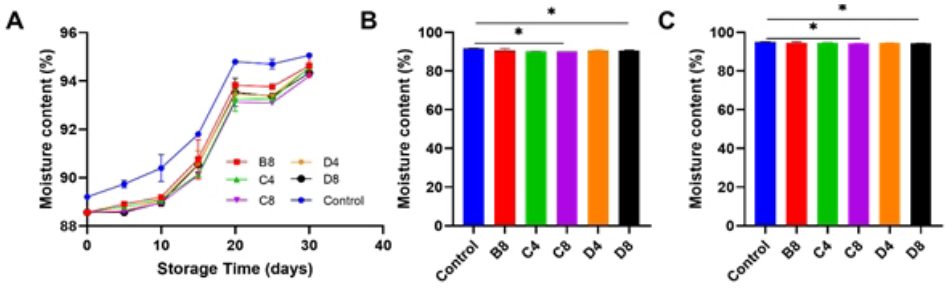


Fig. 4. Effect of blanching and micro-perforated MAP on the moisture content of carrot (A) for 30 days of storage, (B) comparative analysis at 15 days and (C) 30-days of storage.

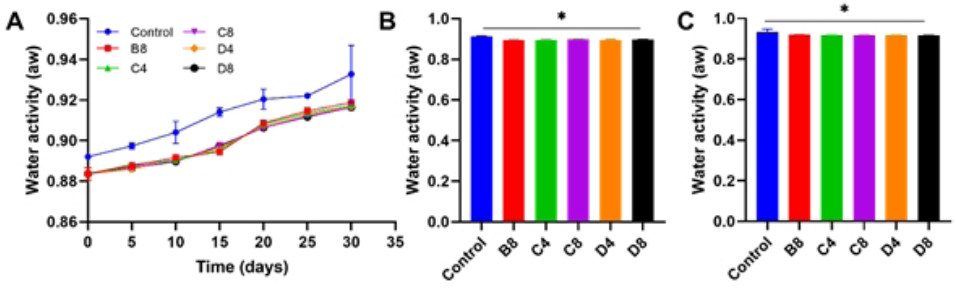


Fig. 5. Effect of blanching and micro-perforated MAP on the water activity of carrot (A) for 30 days of storage, (B) comparative analysis at 15 days and (C) 30-days of storage.

(B8), and from 7.343 mg kg^{-1} to 3.555 mg kg^{-1} for the control sample respectively (Fig. 3). The results show that the decrease was greater for the control sample as compared to the pretreated samples stored in micro-perforated MAP. (Dawange *et al*., 2016) observed a decrease in β-carotene for all of the perforated packaged samples and control samples after the initiation of storage from the initial value of 9.512 (±0.9), and reported that the decrease was greater in the control samples by more than 4%. (Howard and Dewi, 1996) reported a decrease in the β-carotene concentration of processed carrots stored at 1°C and 2°C from 57.2 to 47.3 ppm after 17 days of storage. (Ilić *et al*., 2013) also observed similar results for carrot samples stored for 180 days at 0-2°C and < 90% RH.

Figs 4 and 5 show the moisture content and water activity of the carrot samples respectively. The results demonstrate that both the moisture content and water activity increased with duration of storage. This may be the result of the migration of water vapour from the storage environment into the packaging material. According to research carried out by (Wani and Kumar, 2018), there was an increase in the moisture content of oat and fenugreek during storage due to the migration of water vapour into the packaging material from the storage material and also HDPE permeability. (Hossain and Gottschalk, 2009) reported an increase in moisture content as a result of increases in the air permeability of the polyethylene bag. Initially the moisture content for the control and 360 W was 89.2% and 88.6% respectively, which increased to 94.2% for C8, 94.3% for D8, 94.5% for D4, 94.5% for C4, 94.6% for B8 and 95.1% for the control respectively. Similarly, the water activity of the control sample was greater than that of the pretreated sample throughout the storage period, with C8 having the lowest value. A similar result was observed by (Kumar *et al.*, 2012), who reported an increase in the water content of carrot, rice, and pulse flour due to water migration from the environment.

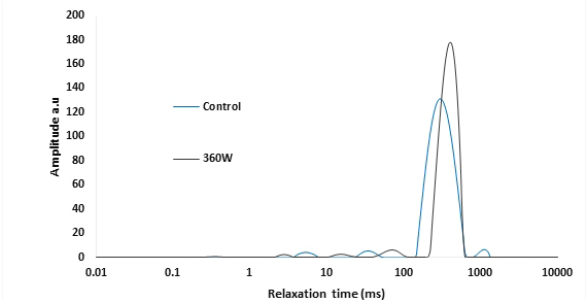


Fig. 6. Transverse relaxation times (T_2) in carrot for (a) control, (b) carrot pretreated at 360 W before storage in micro-perforated MAP

LF-NMR was used to monitor the water status of the carrot samples during storage. (Ezeanaka *et al.*, 2019) reported that LF-NMR may be applied to study the states and mobility of water in food products through the observed relaxation time by accurately measuring the radio resonance frequency absorption by non-zero nuclear spins (spin1/2) from protons in an external static magnetic field. According to (Zang *et al*., 2017), the T_2 relaxation time depends on water mobility. The varying binding ability of macromolecules and water molecules has a significant impact on the relaxation rate, showing various water binding states. The longer the relaxation time T_2, the greater the mobility of the water and vice versa. Fig. 6 shows the water status of

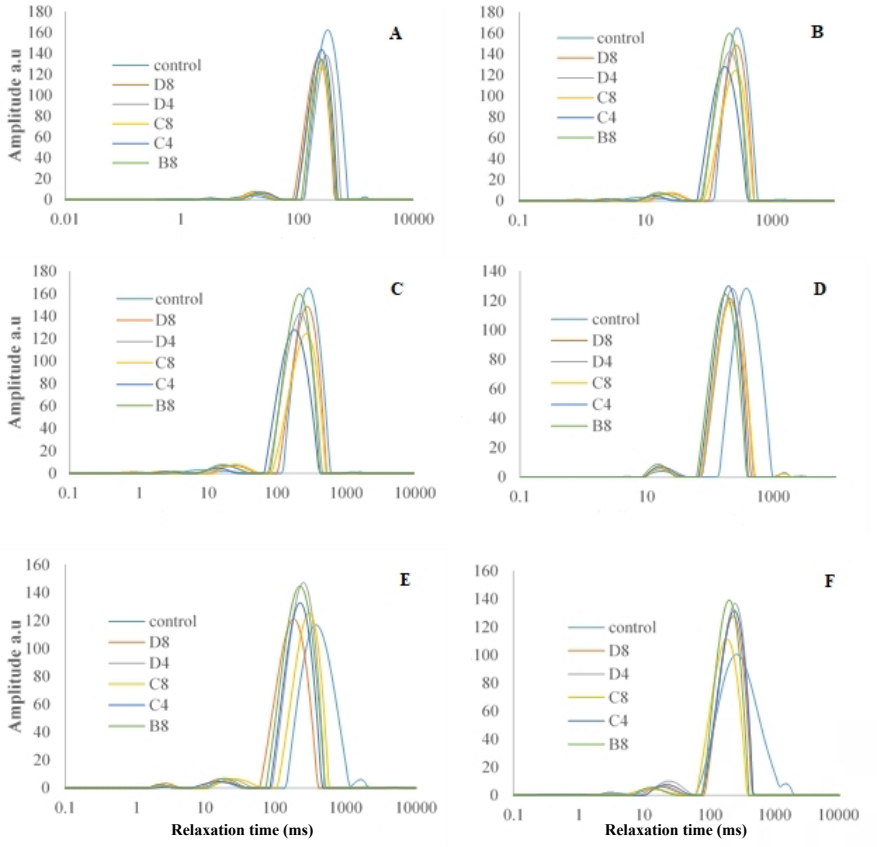


Fig. 7. Transverse relaxation times (T_2) in carrot for (A) 5 days, (B) 10 days, (C) 15 days, (D) 20 days, (E) 25 days, (F) 30 days of storage in micro-perforated MAP.

the carrot samples before storage while Fig. 7 portrays the water status of the carrot samples during 30 days storage. Initially, the relaxation times for three peaks were observed. The shortest relaxation time T_{21} with a range of 0.1-10 ms is considered to be caused by tightly bound water. T_{22}, with a range of 10-100 ms represents the lightly bound water, while T_{23} with a range of 10-100 ms is the most prominent portion and represents the immobilized water. With longer periods of storage time, the 4th peak of T_{24} was observed in the control sample at a range of 1000-10000 ms, which is thought to originate from free water. The result demonstrated that the T_{21} value did not change significantly ($p \leq 0.05$) throughout the storage period. This is probably due to the fact that it is closely related to internal structure and relatively stable (Aindongo *et al.*, 2014). At first, T_{22} and T_{23} increased, however, this was followed by a decrease as the storage duration lengthened. T_{23} of the C8 sample was lower compared to the other pretreated samples while that of the control presented the highest value. This is thought to be the result of a decrease in the metabolic rate. The appearance of T_{24} in the control samples which increased with the duration of storage shows relative increases in the metabolic rate and probably in membrane permeability as well.

Blanching is an effective pretreatment for inhibiting enzyme activity. Lamikanra (2002) reported that enzyme activity continues if they are not destroyed, which can lead to the formation of an off-colour and off-odour as well as colour changes. However, (Bedford and Joslyn, 1939) research has shown that completely inactivating peroxidase is not necessary to avoid off-flavours and off-colours in foods even

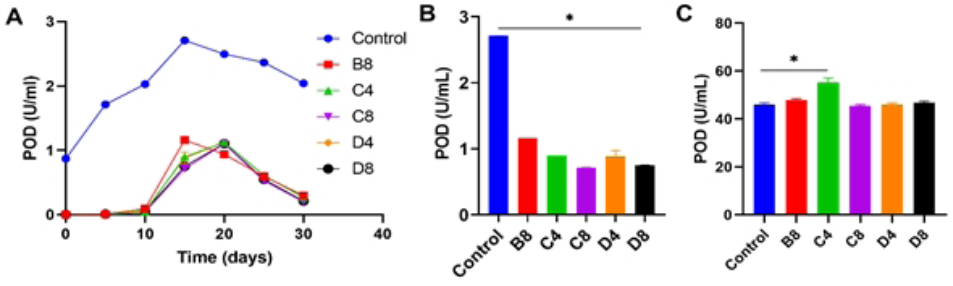


Fig. 8. Effect of blanching and micro-perforated MAP on the peroxidase (POD) of carrot (A) for 30 days of storage (B) comparative analysis at 15 days and (C) 30 days of storage.

Table 1. Colour analysis L* of blanched carrot in micro-perforated MAP for 30 days of storage

Days	Treatments					
	Control	B8	C4	C8	D4	D8
0	52.28±3.12a	45.05±2.61b	45.05±2.61b	45.05±2.61b	45.05±2.61b	45.05±2.61b
5	54.02±1.59a	46.96±1.15b	45.01±1.99b	46.29±2.39b	45.46±0.86b	47.08±0.76b
10	51.62±1.84a	44.90±0.365b	46.22±0.79b	45.90±1.30b	45.70±0.38b	44.66±0.46b
15	52.50±1.18a	46.82±2.855bc	46.37±0.19bc	47.56±1.45b	47.99±0.77b	48.86±0.86ab
20	54.48±1.44a	46.86±0.14b	46.76±0.25b	46.58±2.39b	45.66±0.63b	46.09±0.34b
25	54.22±2.31a	47.49±0.36b	45.59±1.86bc	46.32±2.18bc	45.29±1.07bc	45.35±0.25bc
30	55.23±2.61a	45.53±0.30b	45.99±0.35b	46.81±1.09b	47.95±0.41b	46.02±0.99b

Values represent "Mean ± SD" of triplicate readings. Values followed by different letters in the same column are significantly different at $p \leq 0.05$.

Table 2. Colour analysis a* of blanched carrot in micro-perforated MAP for 30 days of storage

Days	Treatments					
	Control	B8	C4	C8	D4	D8
0	19.44±1.17b	21.23±0.53ab	21.23±0.53ab	21.23±0.53ab	21.23±0.53ab	21.23±0.53ab
5	19.71±0.83c	21.44±1.60ab	21.07±0.25bc	21.14±0.28bc	21.78±0.83ab	22.42±1.03a
10	20.36±0.22c	21.00±0.42bc	24.14±1.45ab	24.52±1.91a	22.53±0.39b	24.97±0.75a
15	22.32±0.60c	21.93±0.47bc	24.85±2.41a	25.68±2.13a	24.83±0.27ab	25.15±1.23ab
20	24.21±2.19ab	25.18±0.14a	25.47±2.68a	26.59±0.76a	24.69±1.60a	26.33±0.89a
25	21.31±2.91c	24.47±0.65bc	24.89±0.93bc	26.42±2.59a	24.58±0.43bc	25.16±0.87ab
30	23.95±1.12c	26.01±1.19ab	25.42±0.05bc	27.37±0.62a	26.76±1.13a	25.92±1.11ab

Explanations as in Table 1.

Table 3. Colour analysis b* of blanched carrot in micro-perforated MAP for 30 days of storage

Days	Treatments					
	Control	B8	C4	C8	D4	D8
0	21.56±1.49a	21.28±0.58a	21.28±0.58ab	21.28±0.58a	21.28±0.58a	21.28±0.58a
5	23.39±0.12a	22.11±1.19b	20.41±0.57a	22.21±1.57bc	22.58±0.08b	22.17±1.47b
10	24.47±1.06a	23.14±0.19b	23.68±0.29a	22.69±0.46bc	22.92±0.28b	23.15±0.86b
15	25.41±0.05a	22.58±0.44c	23.29±0.90b	23.14±0.88b	24.30±1.07a	23.67±1.58a
20	24.71±0.51a	23.90±0.42a	23.98±0.53a	23.66±0.15a	23.50±0.42a	24.47±1.94a
25	26.17±0.04	25.12±1.04	24.81±0.69	24.29±1.87	23.72±0.35	24.93±1.39
30	26.54±0.195a	24.92±0.42a	24.12±0.18a	25.16±1.37b	25.03±1.39c	25.04±1.13a

Explanations as in Table 1.

during storage periods of 3-7 years provided that most of the initial activity is destroyed. The authors assert that a peroxidase value of about $1x10^{-2}$ units per gram of sample indicated an acceptable degree of quality. Fig. 8 shows the POD activity of all carrot samples. The POD activity increased until a maximum value of 2.71 U ml^{-1} was reached for the control and 1.16 U ml^{-1} for B8 on day 15. At day 20, the POD activity reached a maximum value of 1.10 U ml^{-1} for C8, 1.12 U ml^{-1} for D4, 1.11 U ml^{-1} for D8, and 1.13 U ml^{-1} for C4 respectively. The POD activity of C8 was lower compared to other pretreated micro-perforated packaged samples.

Colour parameters L*a*b were used to evaluate the effect of the pretreatment and packaging method on the colour of the carrot samples during storage (Tables 1-3). The lightness

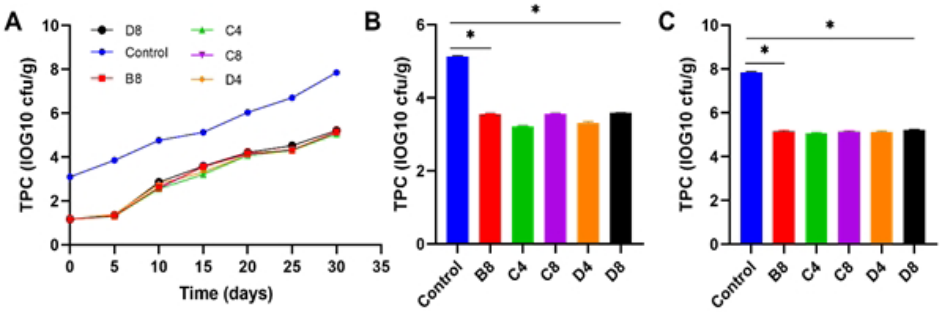


Fig. 9. Effect of blanching and micro-perforated MAP on the total plate count (TPC) of carrot (A) for 30 days of storage, (B) comparative analysis at 15 days and (C) 30 days of storage.

values (L*) of all of the pretreated micro-perforated packaged samples were found to be lower than that of the control sample. (Rawson *et al.*, 2011) reported an increase in the L*value of carrot as a result of the effect of leaching during hot water blanching, which contrasted with the expected result. In our study, the L* value of the control sample first increased then decreased with storage time, whereas there was no significant change in the micro-perforated packaged carrot samples. The decrease in L* value signifies darkening which may be attributed to lignification and surface desiccation. The a* (redness) and b* (yellowness) values for both the treated and untreated sample increased as the storage time was prolonged. It has been reported that blanching as a pretreatment prevents non-enzymatic browning, which results in a high value of β-carotene and total carotenoid content as well as redness and yellowness (Rawson *et al*., 2011). However, the a* values of the treated micro-perforated packaged samples were higher than those of the control samples, while by contrast, the b* values of the control samples were higher, as an indication of a more intense yellow colour. It may be deduced that colour loss is found to be more significant as the results showed a lower degree of redness and a higher degree of yellowness in the control samples during storage for 30 days. (Gill *et al.*, 2014) carried out research in order to compare the effect of quick freezing and conventional freezing combined with steam blanching and hot water blanching on the colour of carrot. The results showed that hot water blanching alone produced the best result for a* while hot water combined with quick freezing produced the best result for L*a*b.

Several published studies have investigated the effect of blanching in eliminating and reducing the microbial load in food products. Also, MAP has proven to be effective in inhibiting the growth of microorganisms. In our study, the microbial count consistently increased in all carrot samples as the storage duration increased. The changes in the total plate count (TPC) for the carrot samples over a 30-day period are shown in Fig. 9. The microbial load in the control samples was higher than those of the pretreated samples in the perforated packaging. This shows that blanching substantially affected the initial microbial load. (Gill *et al*., 2014) also reported that a lower microbial load in micro-perforated packaged carrot samples occurred as a result of lower oxygen levels and higher carbon dioxide concentrations in perforated packages.

CONCLUSIONS

1. In this study, it was found that blanching reduced the initial microbial load and improved quality in micro-modified atmosphere packaging.

2. Micro-perforated modified atmosphere packaging for the C8 samples substantially reduced the degradation of β-carotene, microbial load, and loss of firmness, decreased water mobility, while the water activity, moisture content and peroxidase increased in the carrot samples during storage as compared to other samples.

3. The results showed that moderate perforation for the duration of cold storage could preserve desirable carrot qualities. This may be a promising preservation technique for carrots and other fresh food products to ensure increased shelf life and retain the quality attributes of the products.

Conflict of interest: The authors declare no conflict of interest.

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