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RESEARCH ARTICLE

Enhancing shelf-life of minimally processed cut carrots: A comparative study of physical, thermal and chemical approaches

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Abstract

Minimal processing is the fastest-growing avenue of the vegetable processing industry, driven by consumers seeking convenience and freshness. Such products have huge demands in hotels, restaurant and cafes (HoReCa) and supermarkets as they enable quick accessibility and availability of fresh-like and convenience-added safe vegetable produce that may also lead to a reduction in food wastage. Minimally processed carrot is a popular segment; under this study, the cut carrots of different genotypes were subjected to different interventions, *viz*., physical, chemical, thermal and a combination treatment for minimal processing to enhance the shelf life while ensuring safety and quality of cut carrots stored at refrigerated conditions. Physico-chemical, textural and microbiological analyses were done, which indicated that the combined treatment, consisting of thermal treatment, chitosan coating and UV treatment, proved to be effective interventions in maintaining the safe shelf life of VRCAR-134 and Kashi Krisna cut carrots for four days at 10°C storage.

Keywords: Minimal processing, Cut-carrot, Approaches, Shelf-life.

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Introduction

Carrot (*Daucus carota* L.) is amongst the widely grown and consumed vegetable crops across the globe on account of its superior nutritional and distinct flavour profiles (Kalia et al., 2023). Though the fresh-cut carrots add convenience to the consumer, at the same time, the cutting process inevitably affects the quality of the carrots by exposing them to the external environment (Ma et al., 2024). Minimal processing as an approach has emerged as one of the fastest-growing avenues of the food industry owing to the rise of a specific segment of consumers recognised as 'rich in cash, poor in time' (De Corato et al., 2020). The minimal processing involves washing, cutting and packaging of fruits and vegetables, rendering them into ready-to-cook products. These products have quick accessibility and availability in restaurant chains and supermarkets, which also enables a reduction in food wastage (Chen et al., 2024). Changing purchasing power and modern lifestyle have demanded practical solutions like minimal processing for healthy and convenient food options, which not only saves time but also offers fresh-food-like benefits (Denoya et al., 2017). However, minimally processed vegetables (MPV) pose their challenge of expedited spoilage due to exposure to the external environment, which increases the chances of microbial contamination, metabolic activity, biochemical changes and spoilage (Bansal et al., 2017). Owing to these problems, it has been observed that the MPVs are often associated with shorter shelf-life than their intact forms. The microbial stability of MPV is equally important as completion of the viability of the product is aligned with a microbial load of 10^7cfu g^{-1} (Alegria et al., 2010). However, FSSAI standards for microbial stability of the MPV are m=10^6 cfu/g, M =10^7 cfu/g, n=5 and c=2 (FSSAI, 2025). Conventionally, the preservation of vegetables was done aiming a singular objective, either to satisfy the quality attributes or to maintain the microbial load with the length of time that evolved into hurdle technology, which encompasses multiple techniques to provide a synergistic method to enhance the effect of preservation treatment (Khan et al., 2017). The thermal approaches for minimal processing are classical, and they function on the principle that inactivation of microorganisms depends on the temperature and the duration of the heat treatment (Ohlsson & Bengtsson, 2002). Chitosan coating is another innovative approach, which is chemically n (poly b-(1–4) N acetyl-d-glucosamine) and has a 'Generally Recognised as Safe' GRAS status from the USFDA. The principle by which the chitosan coating acts is the induction of the defence response of the tissue to which it is applied due to its antimicrobial nature (Singh et al., 2024). However, non-residual physical approaches have gained popularity due to their user-friendly and environmentally friendly nature. Among the physical methods, ultraviolet light is an effective technique that works on the principle that short-wavelength light gets absorbed effectively by the microorganisms, which disrupts the process of DNA replication by the formation of some photoproducts, resulting in the death of microbes (Jadhav & Choudhary, 2024). This study entails the usage of three types of approaches, that is, thermal (heat treatment), chemical (chitosan coating), physical (UV radiation) and their combination, to explore their feasibility as an intervention to enhance the quality and the consumer acceptability of cut carrots using minimal processing technology.

Materials and Methods

Six varieties/genotypes of tropical carrot, *viz*., VRCAR-134 (Orange root), VRCAR-44 (Orange root), VRCAR-206 (Red root), Kashi Arun (Red root), VRCAR-125 (Black root) and Kashi Krishna (Black root) developed at ICAR-IIVR, Varanasi, UP were used for the study (Singh et al., 2025). The fresh roots of carrots at marketable maturity were subjected to peeling and cutting. The 0.25 cm thick size cut carrots were treated to physical, chemical and thermal techniques *viz*., UV, ascorbic acid, citric acid, sodium bisulfite, chitosan, 85° C/ 1 min and 100°C/ 2 min as preliminary screening techniques for minimal processing. Out of 42 resultant combinations (genotype x treatments), two carrot genotypes, VRCAR-134 (orange) and Kashi Krishna (black) and four treatments were selected on the basis of overall acceptability for further analysis. Thermal treatment included heat treatment at 85°C for 1 minute (T), while chemical treatment encompassed 1% (w/v) chitosan coating application (C), the physical treatment was done using Ultraviolet-C radiation exposure (P) for 1 minute, and the combined treatment was a combination of the thermal + chemical + physical interventions (TCP). Cut carrots were treated with the treatments mentioned and stored in 200g batches in the LDPE punnets in triplicate at 10°C and were assessed for various physico-chemical analyses, and comparisons in the quality were drawn with the control samples (K) of both genotypes.

Physico-chemical characteristics

The pH of samples was determined (in triplicate) at 25°C by the potentiometric method using a Helix HBPH-12 digital pH meter. The β-carotene and anthocyanin content were determined using a Shimadzu UV-VIS Spectrophotometer 1900 using the method outlined in Ranganna (1986) and expressed as mg/100 g. The firmness of the cut carrots was determined using a TA-XT2i texture analyser (M/s stable Micro System, UK) fitted with a 25-Kg load cell and expressed in Newton. The antioxidant activity was determined using the DPPH method of Acharya (2017) with slight modifications and results were expressed in percentage inhibition.

$$\beta\text{-Carotene (mg/100g)} = \frac{\text{O.D of the sample X Volume made up X 100}}{\text{0.2592 X weight of sample X 1000}}$$

Microbiological assay

The number of viable microorganisms was counted by using the pour plate method. One gram of the cut carrot sample was masticated in nine ml of saline, and further serial dilutions were made. One ml of extract was poured and uniformly mixed into the molten agar medium before solidification. Petri plates were incubated at 37°C for 24 hours. The count was reported in CFU/g.

Sensory characteristics

A panel of nine semi-trained assessors evaluated the cut-carrot samples using Descriptive Sensory Analysis (DSA) with a proforma. The test samples, identified by three-digit codes, were presented to the panellists in a randomised order. The panellists were informed about the parameters used to evaluate the attributes before the sensory assessment.

Statistical analysis

All the experiments were independently carried out in triplicate and expressed as mean ± standard deviation, and the significance was analysed using one-way ANOVA followed by Tukey multiple comparison test using GraphPad Prism version 8.4.3 (GraphPad Software, La Jolla, CA, USA).

Results and Discussion

pH of the minimally processed carrots

Minimal processing involves exposure to the air, microbes and other external factors that might alter the pH. The physically UV-treated cut carrots did not exhibit any significant (p <0.05) change in the pH, while the control, chemically treatment and combination treatment of VRCAR-134 genotypes exhibited a significant increase (p <0.05) in pH on the 4th day of storage to 6.47 and 6.60 and 6.46 from 6.41, 6.43 and 6.42 on the 0th day, respectively (Figure 1). However, VRCAR-134 thermally treated carrots showed a significant (p <0.05) surge in pH on the 2nd day of storage as well. Similarly, a significant (p <0.05) surge in pH was observed in the chemically treated, physically treated and combined treated cut carrots of Kashi Krishna genotype on the 4th day of storage, while the control and thermally treated cut carrots exhibited a significant (p <0.05) surge in pH on the 2nd day of storage as well. Among all the treatments, the physical (P) and thermal-chemical-physical (TCP) combined treatment in both the carrot genotypes maintained stability in the pH, which is crucial to maintain the quality of cut carrots. On the contrary, the control (K) and the thermally treated samples (T) showed the maximum degradation, particularly evident on the 4th day of storage. An increase in pH of the minimally processed cut carrots was also observed in the study by Kashinath (2008), wherein pH increased from 4.3 in fresh samples to 4.9 to 5.9 in different treated samples at 21 days of refrigerated storage (Figure 2). Pilon et al. (2006) studied the minimal processing of carrots and pepper under refrigerated conditions and noted a similar trend in pH, which can be associated with the loss of organic acids during metabolism and storage.

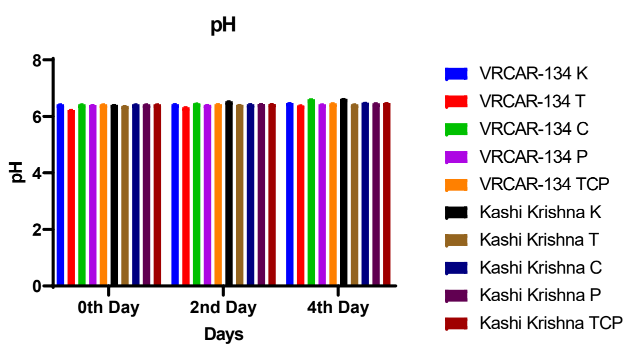

Figure 1: pH of minimally processed cut carrots obtained using various processing treatments over different storage days. T: thermal; C: chemical; P: physical; TCP: combination treatment of thermal, chemical and physical treatment; K: control

Texture as affected by minimal processing approaches

The chemical treatment, 1% (w/v) chitosan coating was ranked significantly (p <0.05) highest in terms of firmness that was determined as 4.885 N in VRCAR-134 with respect to 3.003 N in the control sample on 0th day while, firmness was reported as 3.590 N and 3.077 N in chitosan coated and control samples of Kashi Krishna, respectively on the 0th day. In both genotypes, there was a significant (p <0.05) improvement in the texture upon chitosan coating. The enhancement in firmness due to chitosan treatment can be attributed to its ability to form a protective coating that helps in reducing moisture loss and enzymatic degradation. Kaur & Nikhanj (2025) also observed lower weight loss, enhanced phenolics, carotenoid and ascorbic acid retention, indicating enhanced firmness and consumer acceptability of the fresh-cut carrots. On the contrary, treatments involving heat application (thermal treatment and combination treatment) significantly (p <0.05) reduced the firmness in comparison to the control samples (Figure 3). The thermal treatments often lead to softening due to the breakdown of cell wall components such as pectin and hemicellulose. However, the extent of softening was more pronounced in samples subjected to higher temperatures and prolonged heat exposure. Changes in texture upon thermal application are mainly due to beta-eliminative depolymerisation of the cell wall pectic polysaccharides, which leads to the enhanced solubilisation of pectin and reduced intercellular adhesion, which causes pronounced softening (De Roeck et al., 2010). Furthermore, combination treatments involving both heat and chemical applications exhibited intermediate firmness values, suggesting a partial mitigation of textural

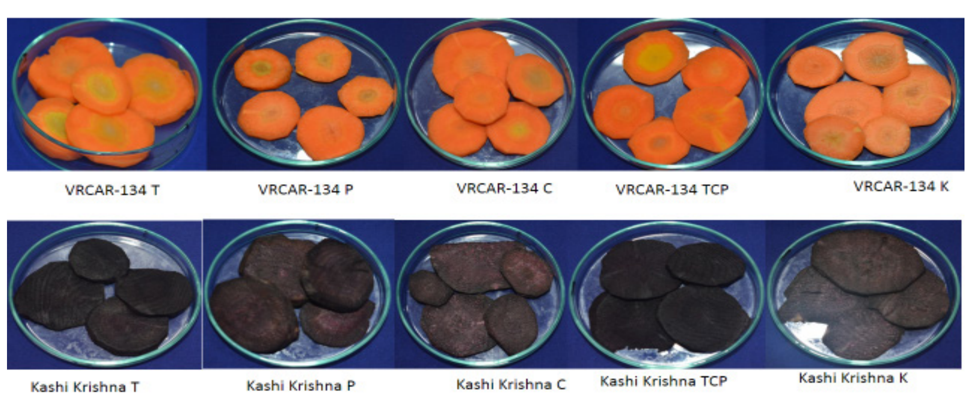

Figure 2: Minimally processed cut carrots obtained using various processing treatments. T: thermal; C: chemical; P: physical; TCP: combination treatment of thermal, chemical and physical treatment; K: control

degradation. These findings highlighted the importance of selecting appropriate processing methods based on the desired textural properties of minimally processed cut carrots, as maintaining firmness is crucial for the overall sensory perception and consumer acceptability of fresh-cut vegetables.

Effect of minimal processing approaches on colour pigments and antioxidant potential

The control sample had the highest β-carotene (4.51 mg/100g) in the VRCAR-134 genotype and anthocyanin content (140.11 mg/100 g) in the Kashi Krishna genotype, which decreased over time regardless of the treatment (Figure 4). The chemical treatment 1% (w/v) chitosan coated cut-carrots samples, exhibited 4.49 mg/100g β-carotene and the physical treatment, UV application, exhibited 133.41 mg/100 g anthocyanin content on the 0th day. Comparatively, a stable rate of deterioration of colour compounds in the orange and black genotypes was found by chemical and physical treatment, respectively. In contrast, the combination treatment thermal-chemical-physical exhibited a uniform rate of deterioration across the genotypes. The decline in concentration of colour compounds was relatively slower in 1% (w/v) chitosan-coated cut carrots of both genotypes, likely due to the protective effect against oxidative degradation. Viacava et al. (2022) studied the effect of chitosan coating and thyme essential oil on the quality of cut carrots and noted similar results, pointing out that chitosan could have acted as a moisturiser on account of its hydrophilic nature, rendering a significant reduction in the surface discolouration. Physical treatment (UV) could have contributed to colour retention by inactivating polyphenol oxidase and other degradative enzymes (Lei et al., 2018). However, prolonged exposure to processing conditions, particularly thermal treatment, accelerated pigment degradation, leading to a noticeable loss of vibrancy in the cut carrots. Singh et al. (2023) studied the thermal processing of acidified vegetables and observed reduced lightness in carrots post treatment. The reduction in redness values was also attributed to the thermal transition of carotenoid pigments present in carrots. The variation in colour retention among treatments suggested that a combination of mild processing techniques could help optimise the stability of bioactive pigments. Since β-carotene and anthocyanins are crucial for the nutritional and visual appeal of carrots, maintaining these pigments is particularly important for consumer preference and the functional benefits of minimally processed cut-carrots.

The variety Kashi Krishna (black) demonstrated a higher antioxidant potential, which remained substantially stable over time, irrespective of the treatment, as presented in Figure 5. This stability can be attributed to the presence of anthocyanins, which have strong free radical-scavenging properties that reduce oxidative stress (Gulcin, 2020). In contrast, the thermal treatment significantly reduced the antioxidant potential in the VRCAR-134 (orange) genotype, likely due to the degradation of heat-sensitive carotenoids and polyphenols, which are major contributors to antioxidant activity. The decline in antioxidant potential in thermally treated samples suggests that heat exposure may disrupt the structural integrity of bioactive compounds, leading to increased oxidation due to thermal degradation of bioactive compounds (ElGamal et al., 2023). However, the thermal-chemical-physical (TCP) treatment maintained a comparable

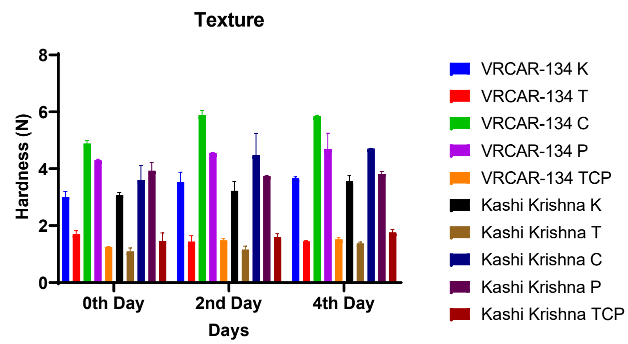

Figure 3: Texture of minimally processed cut-carrots on various days. T: thermal; C: chemical; P: physical; TCP: combination treatment of thermal, chemical and physical treatment; K: control

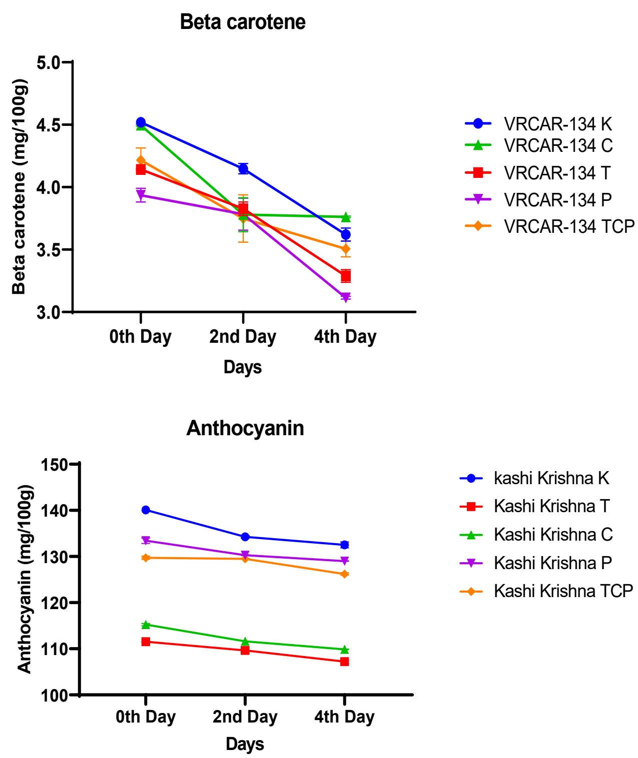

Figure 4: β-carotene content and Anthocyanin content of minimally processed cut carrots at different durations. T: thermal; C: chemical; P: physical; TCP: combination treatment of thermal, chemical and physical treatment; K: control

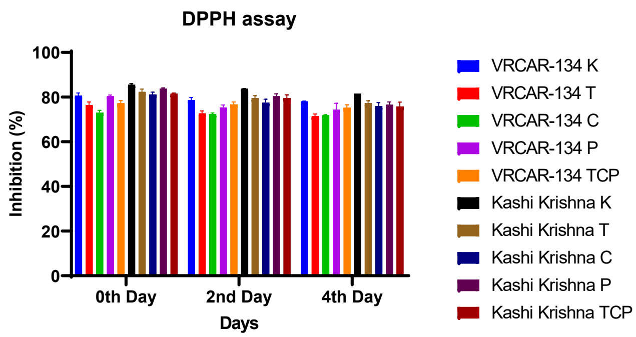

Figure 5: Antioxidant potential of minimally processed cut-carrots on various days. T: thermal; C: chemical; P: physical; TCP: combination treatment of thermal, chemical and physical treatment; K: control

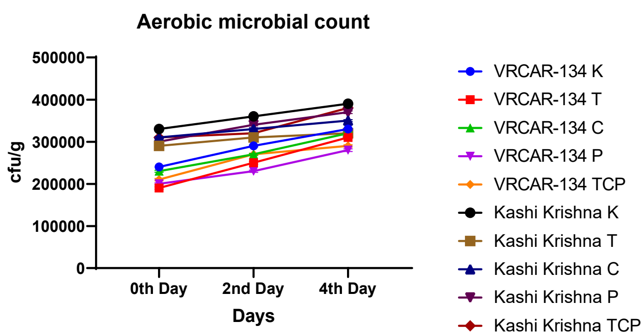

Figure 6: Aerobic microbial count of minimally processed cut-carrots on various days. T: thermal; C: chemical; P: physical; TCP: combination treatment of thermal, chemical and physical treatment; K: control

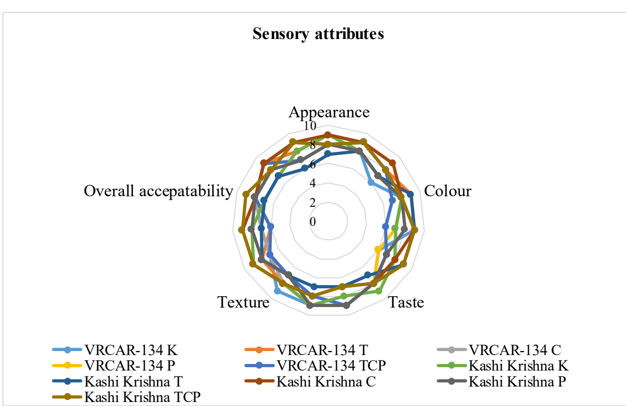

Figure 7: Sensory attributes of minimally processed cut carrots on various days. T: thermal; C: chemical; P: physical; TCP: combination treatment of thermal, chemical and physical treatment; K: control

antioxidant potential to the control over time, indicating that the synergistic effect of these processing techniques might help mitigate the degradation of antioxidant compounds. The retention of antioxidant potential in TCP-treated samples could be due to the protective role of chemical agents in preventing oxidation, along with the minimal impact of physical treatments on bioactive compounds. Additionally, controlled processing conditions might have contributed to reducing the enzymatic activity responsible for the breakdown of antioxidants. These findings highlight the importance of selecting suitable minimal processing techniques to preserve the antioxidant potential of different carrot genotypes, ensuring both nutritional quality and functional benefits for consumers.

Microbiology and sensory quality as affected by minimal processing

The aerobic microbial count remained within acceptable limits for four days, adhering to the FSSAI standards for minimally processed fruits and vegetables (m=1×10^6/g, M=1×10^7/g, n=5, c=2), as presented in Figure 6. The microbial load remained controlled due to the effectiveness of processing interventions in reducing initial contamination and preventing rapid microbial proliferation. The overall acceptability, assessed through sensory analysis (Figure 7), which encompassed taste, texture, colour and appearance, was highest for genotype VRCAR-134 under the combined treatment and Kashi Krishna under the chemical treatment. The superior acceptability of VRCAR-134 could be attributed to the enhanced textural integrity and colour stability offered by the combined treatment, while Kashi Krishna treated with chitosan exhibited the protective effect of chitosan in minimising moisture loss and oxidative changes.

Conclusion

The combined treatment, consisting of thermal treatment, chitosan coating and UV treatment, proved to be an effective and promising approach in maintaining the shelf life of cut carrots for four days at 10°C storage. Thermal treatment assisted in inactivating spoilage enzymes, while chitosan formed a semi-permeable coating that reduced dehydration and microbial contamination and improved texture. Additionally, UV treatment contributed to microbial reduction by targeting surface pathogens, thereby ensuring extended freshness and safety. The synergistic effect of these treatments not only helped in maintaining microbial safety but also preserved the sensory attributes, making it a viable approach for extending the post-processing shelf life of minimally processed carrots. These findings underscore the importance of integrating multiple preservation techniques to achieve optimal quality retention in fresh-cut carrots, enhancing both consumer appeal and marketability. Further, this work could evaluate the optimised physical, chemical, and thermal interventions across varied packaging systems to confirm consistency and commercial feasibility.

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सारांश

न्यूनतम प्रसंस्करण वाली सब्जियां, सुविधा और ताजगी चाहने वाले उपभोक्ताओं की बढ़ती मांग के कारण सब्जी प्रसंस्करण उद्योग का सबसे तेजी से बढ़ता हुआ क्षेत्र है। होटलों, रेस्तरां और कैफे (होरेका) और सुपरमार्केट में ऐसे उत्पादों की भारी मांग है क्योंकि ये ताजी दिखने वाली और सुविधा से भरपूर सुरक्षित सब्जियों की त्वरित उपलब्धता सुनिश्चित करते हैं, जिससे खाद्य अपशिष्ट में भी कमी आ सकती है। न्यूनतम संसाधित गाजर एक लोकप्रिय उत्पाद है; इस अध्ययन के अंतर्गत, विभिन्न जीनोटाइप की कटी हुई गाजरों पर भौतिक, रासायनिक, ऊष्मीय और मिश्रित उपचार जैसे विभिन्न उपचार किए गए ताकि रेफ्रिजरेटेड परिस्थितियों में रखी गई कटी हुई गाजरों की शेल्फ लाइफ को बढ़ाते हुए उनकी सुरक्षा और गुणवत्ता सुनिश्चित की जा सके। भौतिक-रासायनिक, बनावट और सूक्ष्मजैविक विश्लेषण किए गए, जिनसे पता चला कि ऊष्मीय उपचार, चिटोसन कोटिंग और यूवी उपचार से युक्त संयुक्त उपचार, 10°C तापमान पर भंडारण के दौरान VRCAR-134 और काशी कृष्णा गाजरों की शेल्फ लाइफ को चार दिनों तक सुरक्षित बनाए रखने में प्रभावी साबित हुआ।