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Optimization of radiation dose and quality parameters for development of ready-to-cook (RTC) pumpkin cubes using a statistical approach

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ABSTRACT

Full factorial design was employed to study the effect of gamma irradiation (0–2.5 kGy) and storage (up to 28 d) at 10 °C on quality of RTC pumpkin. Data obtained from microbial, color, texture and sensory analysis were fitted into a cubic model. Resulting equations were solved to assess radiation dose and maximum storage period for acceptable microbial quality ($<10^5$ CFU g^{-1}) and sensory scores (overall acceptability > 5). Radiation dose of 1 kGy resulted in a product with desired microbial and sensory quality up to storage period of 21 d. The processed product (1 kGy) had significantly ($p < 0.05$) higher total antioxidant and vitamin C content as compared to non-irradiated control after storage of 21 d. HPLC analysis demonstrated that there were no qualitative changes in phenolic and carotenoid constituents due to radiation processing. Thus radiation processing was successfully employed to develop RTC pumpkin with improved shelf-life.

Industrial relevance: The present study demonstrates the efficacy of the statistical approach of the experimental design for optimization of radiation dose and storage time for ready-to-cook (RTC) pumpkin cubes with acceptable microbial and sensory quality. Complex interactions among radiation dose, storage duration and quality attributes of RTC pumpkin were successfully mathematically modeled. The mathematical modeling can be useful for commercial production as the required processing conditions can be suitably obtained based on the desired quality characteristics of the final product.

1. Introduction

There is a growing demand for fresh-cut fruits and vegetables due to their associated convenience, fresh characteristics, and human health benefits (Ragaert, Verbeke, Devlieghere, & Debevere, 2004). The International Fresh-Cut Produce Association defined fresh-cut produce as trimmed, peeled, washed, and cut into 100% usable product that is subsequently bagged or prepackaged to offer consumers high nutrition, convenience, and value while still maintaining freshness (Beaulieu & Gorny, 2001). However, it is well-known that processing of vegetables promotes a faster physiological deterioration, biochemical changes and microbial degradation of the product, which may result in degradation of the color, texture and flavor (Kabir, 1994). Several preservation methods, including antioxidant treatment, modified atmospheric packaging (MAP), refrigeration and chlorine wash are currently employed for commercial preparation of fresh-cut vegetables (Ahn et al., 2005).

Consumption of fresh-cut vegetables has been implicated in outbreaks of foodborne illnesses (Beuchat, 1996; Wachtel & Charkowski, 2002). Psychotropic bacteria, such as *Listeria monocytogenes*, are known to grow at low temperature even under modified atmosphere packaging (Beuchat & Brackett, 1990). Various disinfectants used in commercial processing lines, such as chlorine, have only limited effect (approx. 1 log cycle reduction) on microbial populations (Zhang & Farber, 1996). Therefore, there is an increasing concern for microbial quality of such produce.

Gamma irradiation is a non-thermal technology that effectively eliminates foodborne pathogens in various foods, including fresh vegetables without compromising nutritional properties or sensory qualities of food. Gamma irradiation in combination with low temperature storage is known to prolong the shelf-life of various fresh-cut produce (Ajlouni, Beelman, & Thompson, 1993). However, very few reports exist on radiation preservation of RTC Indian vegetables using these combination treatments (Tripathi, Chatterjee, Vaishnav, Variyar, & Sharma, 2013).

The shelf-life of fresh-cut fruits and vegetables depends on various factors such as processing conditions, treatment, storage temperature, packaging conditions, and microbial and physiological spoilage, thereby, affecting visual appearance, firmness and consumer acceptance. Understanding the response of a food system to qualitative or quantitative experimental variables is a complex task. Efficiency of mathematical modeling to optimize the processing conditions based on various experimental designs has been widely demonstrated (Iborra-Bernad, Philippon, García-Segovia, & Martínez-Monzó, 2013). Such mathematical

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equations can be utilized in the food industry for deciding the process parameters required for obtaining the desired shelf-life of fresh-cut produce.

Pumpkin (*Cucurbita pepo*) belongs to the Cucurbitaceae family, which includes melons, squashes, cucumbers and gourds. The pumpkin varies greatly in shape, ranging from oblate to oblong, with smooth, slightly ribbed skin and deep yellow to orange coloration. It is widely consumed in Indian households, and is a rich source of nutrients, especially natural antioxidants such as beta carotene, folic acid, and vitamin E. The intact vegetable can be stored for several days; however, once cut, it is highly perishable and deteriorates within 1–2 d. The high moisture content and the presence of macronutrients such as sugars make it vulnerable to spoilage by microorganisms limiting its marketability. Recently, the shelf-life of cut pumpkin under modified atmospheric packaging (30 % CO_2/70 % N_2; 100 % CO_2 and vacuum) while stored under refrigeration temperature has been examined (Stefanov, Hristov, Stoeva, Denkova, & Nikolova, 2012). 100 % CO_2 was inferred to be the best by these workers for a storage period of 5 d, with total microbial counts 7.7×10^3 CFU g^{-1} and yeast and mold counts of approx 10 CFU g^{-1} after 5 d. However, efficacy of radiation processing in enhancing the shelf-life and quality of fresh-cut pumpkin has not been investigated so far.

The objective of the present study was to determine the feasibility of using radiation processing in combination with low temperature storage for extending the shelf-life of fresh-cut RTC pumpkin cubes. The process parameters employed were optimized by full factorial experimental design using polynomial equations. Attempts were made to develop empirical equations that relate the process parameters with quality attributes and shelf-life of fresh-cut pumpkin. The effect of irradiation and storage on the nutritional quality of the product was also investigated.

2. Materials and methods

2.1. Plant material

Fresh pumpkin (*Cucurbita pepo*) of commercial maturity (average weight 8–10 kg) was procured from a local grower in the outskirts of Mumbai, India. The vegetable was brought to the laboratory within 12 h after harvesting and immediately stored at refrigerated temperatures (10 °C) till further processing.

2.2. Preparation of samples

The whole pumpkin was washed under running tap water to remove adhered dust. It was then hand-peeled and cut into small pieces of dimensions 2.5 cm × 2.5 cm × 0.5 cm with a sharp sterile knife. The cut pieces (80 g) were packed into polystyrene trays (inner dimensions: 9 cm × 9 cm × 2.5 cm). The trays were then wrapped around with cling film (Flexo Film Wraps Ltd., Aurangabad, Maharashtra, India) and sealed to avoid any leakage. Film used in the present study had a thickness of 8–10 μm and permeability to oxygen and carbon dioxide as 1.7 and 10.3 $cm^3\ m^{-2}\ s^{-1}\ Pa^{-1}$, respectively (data as provided by supplier).

Packaged pumpkin was subjected to various radiation doses up to 2.5 kGy in a cobalt-60 irradiator (GC-5000, BRIT, Mumbai, India) having a dose rate of 1.64 Gy/s. The irradiator was calibrated using a Fricke dosimeter before the start of the experiment and dose uniformity ratio was found to be 1.2. Irradiated samples were stored in the dark at 10 ± 1 °C. Preliminary studies demonstrated an optimal storage temperature of 10 °C. Storage at a lower temperature (4 °C) induced chilling injury resulting in low sensory scores, whereas at a higher temperature of 15 °C, physiological as well as microbial spoilage was very rapid resulting in shorter shelf-life.

2.3. Design of experiments

Experimental design and subsequent analysis of results were performed by a software Design Expert 8.0 (State-ease Inc., U.S.A.). Control and radiation-treated samples were analyzed on days 0, 7, 14, 21 and 28 after packaging. The full factorial experimental design was employed with gamma radiation dose and storage time as factors to be optimized (Perretti et al., 2013). Experiments were planned at different radiation doses (0, 0.5, 1.0, 1.5, 2.0 and 2.5 kGy) and five levels of storage duration (0, 7, 14, 21 and 28 d). Three replicates were prepared for each dose and storage day. Parameters studied for analyzing product quality were microbial load, color, texture and sensory acceptability.

Models for individual responses were generated by fitting experimental data into third order polynomial equations and then removing insignificant terms by backward regression method as reported earlier by Gupta et al., 2012. In this approach, model terms with the highest values of partial probability (p-value) are removed first and the process is stopped when the p-value of next term out satisfies the specified alpha out criterion. Value of alpha out was kept 0.1 which leads to an overall model with terms significant at 0.05 levels. The models were analyzed by analysis of variance (ANOVA) and the coefficient of determination (R^2) was used to quantify the predictive capability of the model. Fitted polynomial equations were then plotted in order to visualize the interrelationship of response and experimental levels of each factor. Optimal conditions were then derived using numerical optimization process. Criteria for desired microbial and sensory qualities were provided and model equations solved to obtain optimum processing conditions.

2.4. Sensory analysis

Cut pieces of pumpkin were cooked in boiling water for 5 min and presented to the assessors in white trays for sensory assessment. Hedonic testing was carried out by 15 panelists of trained sensory panel using a 9-point scale with 1, dislike extremely or not characteristic of the product and 9, like extremely or very characteristic of the product (Lopez-Rubira, Conesa, Allende, & Artes, 2005). Parameters evaluated were color, aroma, texture, taste, aftertaste and overall acceptability. Irradiated and stored samples were compared with fresh-cut control samples on each day of study to analyze all the parameters.

At optimized processing conditions, sensory evaluation was also performed by quantitative descriptive analysis (QDA) (Murray, Delahunty, & Baxter, 2001) along with hedonic analysis. A trained panel consisting of 10 members, 6 males and 4 females assessed the samples using unstructured 150-mm scale. The seven sensory attributes assessed were texture, color (yellow), aroma (pumpkin-like, irradiated and musty), and taste (pumpkin like and irradiated). Assessments were repeated twice and sensory data were collected by measuring distance (mm) from the origin.

2.5. Microbial analysis

Standard methods were used to enumerate total microbial load present in the RTC pumpkin at each sampling time and treatment for 28 d of storage (Lopez-Rubira et al., 2005). Enumeration of total aerobic mesophilic bacteria was carried out by pour-plate method on plate count agar (Himedia, Mumbai, India). Incubation was done at 37 °C for 24 h. Total yeast and mold count was performed by pour-plate method on potato dextrose agar (Himedia, Mumbai, India) supplemented with 0.01 g L^{-1} tartaric acid to lower pH of the medium to 3.5. Plates were incubated at 37 °C for 48 h. Microbial counts were expressed as $\log_{10}$ CFU g^{-1}. Each analysis was performed in triplicate.