

**MODIFIED ATMOSPHERE PACKAGING OF
GREEN-SHELLED COMMON BEANS (*Phaseolus Vulgaris* L)**

by

Nalini Pandya

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Approved by:

Dr. Carol Harper, Ph. D.
Chairman, Graduate Committee

Date

Dr. James Beaver, Ph. D.
Member, Graduate Committee

Date

Dr. Annette Wszelaki, Ph. D.
Member Graduate Committee

Date

Dr. Tim Porch, Ph. D.
Graduate Studies Representative

Date

Dr. Edna Negrón, Ph. D.
Director, CITA

Date

Abstract

The objective of this research was to develop a modified atmosphere packaging (MAP) system for green-shelled common beans (*Phaseolus vulgaris* L., cv. *Morales*), which are locally grown in Puerto Rico, in order to increase their shelf-life. The green-shelled common beans were packed in 3 different gas mixtures, 1) 4% O₂, 10% CO₂, and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂, and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂, and 78% N₂ control (AIR) using Cryovac PD-961EZ plastic bags and stored at 5 °C for 26.5 days. Quality analysis were done on each treatment after every 4 days on three replicates and a temperature abuse of 2 days at 20 °C was simulated on each day of analysis and they were also analyzed for quality changes. Quality analyses included evaluations of physiological changes, color, water activity, pH, titratable acidity and texture of the beans. The green-shelled common beans stored in AIR, maintained their overall quality at 5 °C for 10 days, while beans in MAP I were able to maintain their fresh-like quality up to 18 days at 5 °C. Both AIR and MAP I maintained the color, texture, titratable acidity and pH and remained free of off-odors during their shelf-life. The tenderness of the beans increased in both treatments, without any stickiness or off-odor, which could be beneficial in terms of less cooking time required to cook the beans. Further more, a computer program was developed to predict time evolutions of concentrations of O₂, CO₂ and N₂ inside the flexible package. This program is not limited to beans and can be used for any other food materials. The present study provides some crucial information for the Puerto Rican food industry, as green-shelled beans are a legume preferred by local consumers.

Resumen

El objetivo de este estudio fue desarrollar un empaque en atmósfera modificada (MAP) para verde desgranada (*Phaseolus vulgaris*) con la finalidad de incrementar su vida útil. La habichuela verde desgranada fue empacado en dos diferentes mezclas de gases 4% O₂, 10% CO₂, 86% N₂ (MAP I), 2% O₂, 5% CO₂, 93% N₂ (MAP II), y un control (aire), almacenados a 5 °C por 26.5 días. El análisis de calidad fue realizado en cada tratamiento y sus replicas después de 4 días y después de 2 días a temperatura de abuso a 20 °C. Medidas de color, actividad de agua, pH, acidez titulable, textura y de cambios fisiológicos fueron utilizados como indicadores de calidad del producto. Los datos fueron analizados utilizando el software Infostat ($p \leq 0.05$). La habichuela verde desgranada almacenado en AIRE, mantuvo su calidad a 5 °C por 10 días mientras que la mezcla de gases 4% O₂, 10% CO₂, 86% N₂ mantuvo una calidad similar al del fréjol fresco desvainado por 18 días a 5 °C. Tanto el tratamiento con AIRE y MAP I preservaron el color, textura acidez titulable y pH del La habichuela verde desgranada, además de no presentar olor a fermentado durante su tiempo de vida útil. Así mismo, un programa de computadora fue desarrollado para predecir la evolución en el tiempo de la concentración de O₂, CO₂ y N₂ dentro del empaque flexible. Este programa no esta limitado solo a habichuelas y puede ser aplicado en otros vegetales. El presente estudio provee información crucial para la industria de alimentos de Puerto Rico como para los consumidores locales.

I would like to dedicate this work to.....

...God for giving me the strength and patience in completing my work, as without his guidance nothing is possible in life.

...My daughter, who has filled my life with joy.

...My parents, who gave me good values, built my strong character. Thank you for all the support, encouragement and love.

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Introduction

The new trend of this era is eating fresh, as people have become more aware of the health benefits of eating fresh fruits and vegetables. An inexpensive bowl of common beans (*Phaseolus vulgaris* L.) is the centerpiece of the daily diet for over 300 million of the world's population. This staple is the most important food legume in the both North and South America and Africa, far outdistancing chick-peas (*Cicer arietinum*), lentils (*Lens esculenta*; *Ervum lens*), and cowpeas (*Vigna sinensis*) (Agricultural Statistics, 1997). The global bean harvest of 18 million tons (annual) has an estimated value of US \$11 billion (CIAT, 2001a).

Common beans are characterized as a nearly perfect food by nutritionists, due to their high content of protein, fiber, complex carbohydrates and other important dietary necessities. Hence, the common bean is also known as the "poor man's meat." A single serving (1 cup) of beans provides at least half the US Department of Agriculture's recommended daily allowance of folic acid—vitamin B, that is especially important for pregnant women. Beans are the fourth most important source of protein in tropical America and surpass two popular regional root crops—potato and cassava—as a source of calories (CIAT, 2001a).

The common bean was first cultivated more than 7000 years ago originally in two centers—Mesoamerica (Mexico and Central America) and the Andean region. French bean, snap bean, common bean and string bean all belong to the species *Phaseolus vulgaris* L. (CSIRO, 1998). Spanish-speaking countries have many different names for the common bean, like: *frijol*, *fríjol*, *frisol*, *fréjol*, *frejol*, *poroto*, *habichuela*, *habilla*,

caraota, judía, alubia, and chuwi. In the Dominican Republic and Puerto Rico, the common bean is called "habichuela" (CIAT, 2001b).

Rice, beans and plantains are staple foods of Puerto Rico (World Infozone Ltd, 1997-2006). Rice and beans are found in every house and at every occasion in daily life of Puerto Ricans. They prefer to eat fresh beans compared to canned, dried or frozen beans. The favorite type of common beans in Puerto Rico are white beans, which are actually a bit off-white in color (Beaver and Miklas, 1999). Green-shelled white common beans are grown locally in Puerto Rico by the farmers and are sold in their local vegetable markets as whole pods (Fig. 1), which the consumers shell at home (Fig. 2). The green-shelled beans are cooked with rice or included in soups.

The small white common beans are short bushy plants that can be harvested 60-65 days after the planting. Common beans are grown all year round in Puerto Rico, but the best season for the crop is between November and May, as during the rest of the months it is the hurricane season, so if there is too much rain, the crop will not survive. The beans are harvested manually, that is, the pods of the beans are picked by hands. The beans after harvesting are stored in shade or a cool room, as vegetables and fruits respire even after they are harvested (postharvest) and heat increases the respiration rate of the vegetables and fruits (Salunkhe *et al.*, 1990).

As fresh vegetables and fruits stay metabolically active postharvest, the shelf-life of fresh produce is shorter compared to the processed products. For the last decade, modified atmosphere packaging (MAP), a suitable packaging system, using a semi-permeable packaging material, composed of a gas atmosphere other than air that slows the basic level of metabolism, has been used to extend the shelf-life of respiring products.

MAP also inhibits spoilage agents, extending the shelf-life of the food (Church and Parsons, 1995). Martinez-Ferrer *et al.* (2002) reported that MAP of fresh mangos and pineapple, consisting a gas mixture of 4% O₂, 10% CO₂ and 86% N₂, extended the shelf-life of these tropical fruits by slowing down their metabolic activity and delaying the rate of spoilage. Cano *et al.* (1998) reported that a controlled atmosphere storage of green beans, with 1% O₂ and 3% CO₂ extended the shelf-life of the beans to 22 days.

However, MAP is complicated, since both the respiration rate of the respiring plant product and the permeability of the packaging material are variable (Church and Parsons, 1995). Many researchers have published mathematical models in order to predict the change in the gas atmospheres within the package during their storage period, considering the respiration rate of the respective plant product and the permeability of the packaging material used. Talasila *et al.* (1995) have developed a model to design rigid modified atmosphere packages for fresh fruits and vegetables taking into account the change in total pressure of gases inside the package. Lee *et al.* (1991) published a model, for predicting respiration rates of fresh produce within MAP. Their model was able to predict the respiration rates of fresh plant produce at various oxygen and carbon dioxide concentrations, as well as transient and equilibrium gas concentrations within permeable packages.

Green-shelled common beans are perishable fresh produce and their shelf-life could be extended by packaging them in MAP with appropriate storage temperature, thereby, delaying physiological deterioration. Therefore, the objectives of our research were:

- To develop a modified atmosphere packaging system for green-shelled common beans, in order to increase shelf-life with minimal physiological changes.
- To develop a computational program that can predict the behavior of the gases used in modified atmosphere packaging of fruits and vegetables during storage, when provided with accurate input parameters, like the respiration rate of the packaged fruit or vegetable and the permeability of the film for oxygen, carbon dioxide, nitrogen, and water vapor.



(a)



(b)

Figure 1. (a & b) Pods of small white common beans (*Phaseolus vulgaris* L. cv. Morales)



Figure 2. Shelled small white common beans, known as “green-shelled common beans” (*Phaseolus vulgaris* L).

Literature Review

Common Beans

The scientific name of common beans is "*Phaseolus vulgaris* L.", which comes from the family Fabaceae/Leguminosae (CSIRO, 1998). Many different cultivars of common beans are found in the market (CIAT, 2001c). Common beans are given their common names, such as "dark red kidney beans" for their color and shape, while "Wax beans" are named for the color of their pod which resembles the color of the bee's wax.

The common beans can be eaten at different maturity levels, depending on the cultivar that is consumed. For example, snap, string and green beans are harvested at the immature pod fill stage, as they are eaten in the pod, while dark red kidney beans are harvested when they are dry, as they are eaten as dried seeds (Floridata, 1996-2006). The green-shelled common beans are harvested when the beans within the pod are still tender and are shelled at home and are cooked with rice and in soups.

Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) is a technique, where in fresh food products are enclosed in gas-barrier materials using different gas combinations as per the requirement of the respective food product, to prolong its shelf-life (Young *et al.*, 1988). Instead of air, a gas combination of reduced O₂, elevated CO₂, and a balance of N₂ is used in MAP. MAP is used to suppress the spoilage agents like bacteria, fungi and yeasts thereby, maintain the quality of a perishable food during its natural life or extend its shelf-life (Church and Parsons, 1995).

Most of the scientific literature has concentrated on modified atmosphere packaging (MAP) of green beans. Much of this research deals with quality changes in

frozen green beans (Martins and Silva, 2003) or effects of oxygen levels on color of cold stored beans in controlled atmospheres (Cano *et al.*, 1998). HPLC methods to determine the sugar and starch in green beans (Lopez-Hernandez *et al.*, 1994), effects of blanching on chemistry, quality and structure of green beans (Canet *et al.*, 2005), and texture and sensory evaluation of green bean cultivars (Baron and Penfield, 1993) have also been studied. Most of this knowledge can be applied in the canning industry. No reports have been published on modified atmosphere packaging (MAP) of green-shelled common beans. MAP of green-shelled common beans is a challenge because the beans are living, respiring products.

Respiration in Fruits and Vegetables

Respiration is a process that continues in plants even after harvest (postharvest). Respiration in fruits and vegetables serves as an indicator of their physiological activity and potential storage life (Salunkhe *et al.*, 1990). During respiration in living plant parts, like fresh fruits and vegetables, complex carbohydrates, polysaccharides and other energy sources are metabolized into simpler molecules with the production of carbon dioxide, water and energy in the form of heat (Salunkhe *et al.*, 1990).



Knowledge of the amount of energy released in the form of heat by the product, in the respiratory equation, plays an important role in maintaining the quality of the product during storage, as it helps in determining the correct amount of cooling needed for the product. It also influences the amount of air movement required around the product in storage and consequently, the package design.

Factors Affecting the Respiration Rate of Fruits and Vegetables

The respiration rate depends on several factors, like the temperature, quantity of available substrate, wounding, amount of oxygen available in the atmosphere (gas combination), moisture content, type of plant and plant part, surface area to volume ratio, and nature of the surface of the harvested product (Stanely, 1991).

Temperature is an important factor that influences the respiration rate, which in turn affects the quality of vegetables and fruits. Increases in temperature lead to increases in respiration rates (Lopez Osornio and Chaves, 1998; Stanely, 1991; Tano *et al.*, 1999). Deterioration in the quality of fresh produce in MAP, due to temperature abuse, has been reported by Tano *et al.*, (1999). Salunkhe *et al.* (1990) reported respiration rates of various fruits and vegetables at different temperatures, from which it is evident that, the respiration rate of fruits and vegetables increases with the increase in temperature. For example, it has been reported that, respiration rate of peas (unshelled) at 5 °C is 55-76 mg CO₂/kg*hr while at 10 °C is 68-117 mg CO₂/kg*hr (Salunkhe *et al.*, 1990). High temperatures in the humid tropics, such as Puerto Rico, can be an especially difficult problem for the preservation of fresh fruits and vegetables.

Severity of preparation also affect the respiration rate of fresh produce (McLachlan and Stark, 1985). Barry-Ryan and O'Beirne (1998) conducted a study on the effects of different slicing methods of carrot, and confirmed the importance of gentle processing and the use of sharp blades in order to increase the shelf-life of carrot slices. It is known that shelling of peas and beans causes increases in the respiration rate. For example, it has been reported that the respiration rate of shelled peas (349-556 mg CO₂/kg*hr) is more than the unshelled peas (245-361 mg CO₂/kg*hr) at 20 °C (Salunkhe

et al., 1990). Thus, the respiration rate of the green-shelled common beans will likely increase with shelling. The increase in respiration rate will also depend on the method of shelling (manual or mechanical).

The gas combinations in which fruits and vegetables are stored also play an important role, as a supplement to temperature, in influencing the respiration rate and, thereby, affecting product quality. Groeschel *et al.* (1966) reported that the reduction in oxygen concentration to 2% decreased the respiration rate of stored green beans to 60% of that stored in ambient air, while carbon dioxide had little or no effect on the respiration rate of the stored green beans. Cano *et al.* (1998) reported that green bean pods stored at 8 °C in a controlled atmosphere of 1% O₂ and 3% CO₂ extended the storage life to 22 days. Hong and Kim (2001) reported that the respiration rate of the fresh cut green onions depends on the O₂ concentration and temperature. They also mentioned that the presence of CO₂ had little effect on O₂ uptake of cut green onion at relatively high O₂ concentrations (less than or equal to 20%).

O'Beirne (1990) established that in lettuce, the respiration rate depends on product type and within a product type it also can vary among cultivars. The respiration rate also varies between vegetables and fruits (Stanely, 1991) and depends on the maturity of the product (Wills *et al.*, 1989).

Packaging Material and Modified Atmosphere Packaging

As discussed earlier, fresh products respire, hence, they will use up O₂ and produce CO₂. Therefore, the initial gas concentrations inside the MAP change during storage. O₂ concentration decreases with an increase in CO₂ concentration. This can result in anaerobic respiration, causing off-flavors and odors (Tano *et al.*, 1999). The off-

flavors and odors caused by anaerobic respiration can make the product unacceptable for consumption. Therefore, choosing the proper packaging film, with a suitable permeability, is necessary to prevent fermentation.

Modified atmosphere equilibrium within the package is established when the rate of O₂ and CO₂ transmission through the package equals the product's respiration rate (Day, 1992a; Day, 1992b). To attain an exact equilibrium of the modified atmosphere within the package, one should consider the intrinsic and extrinsic characteristics (Fig. 3). Intrinsic characteristics encompass the physiological characters of the food product like size, variety, maturity, tissue type, respiration rate and severity of preparation. While extrinsic characteristics include the components of the external environment around the food product that affects quality of the food product during storage. Extrinsic characteristics include temperature, relative humidity, microbial load on the product before packing, type of film used to pack the food product, surface area of the packing film, volume of the package used, weight of the product filled in the that volume of the package and equipment used to prepare the product. The most important factor in intrinsic and extrinsic characteristic of the fresh product is its respiration rate and temperature of the storage, respectively.

The overall quality of a fresh fruit or vegetable can be maintained using a combination of the appropriate storage temperature and packaging film (depending on its permeability) that has the capability to maintain the proper gas combination inside the package (Artes *et al.*, 2000; Lopez Osornio and Chaves, 1998; Tano, 1999).

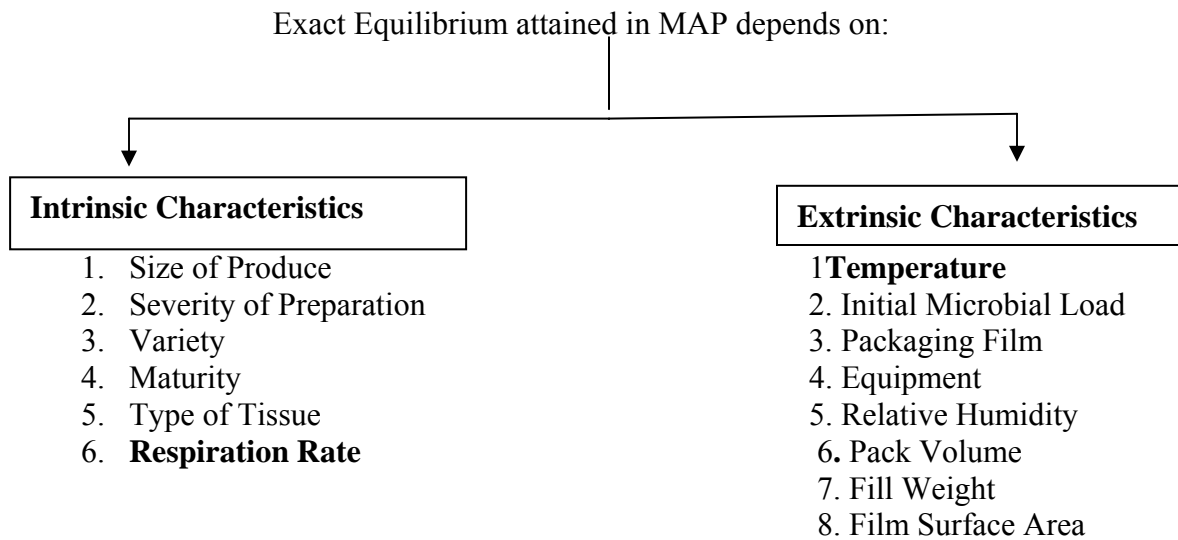


Figure 3. Intrinsic and extrinsic characteristics required to attain equilibrium in MAP.

The permeability of the packaging films is directly proportional to temperature (Church and Parsons, 1995; Oraikul, 1991), hence, a film that has capability to attain and maintain a desired atmosphere inside the package at a particular temperature, loses its capability to do so with the change in temperature, which can lead to a suboptimal atmosphere in the package (Church and Parsons, 1995).

Mathematical Models and Modified Atmosphere Packaging

In order to aid in the optimization of MAP, many mathematical models have been developed to predict the behavior of different fruits and vegetables, considering their respective respiration rates and permeabilities of the packaging film. Salvador *et al.* (2002) developed a mathematical model that describes the exchange of gases through the flexible packages for MAP of Burlat cherries, taking into account the respiration rate of the fruit and the transmission rate of the packaging film. The model was verified experimentally, and the results are reported to be satisfactory with predicted values of the model, if the O₂ concentrations are higher than 2%. Wade and Graham (1987) formulated

a model to describe the modified atmospheres developed during the storage of fruits in plastic films, where they described the steady-state composition of the gases within the package, by assuming constant temperature, which conform with the ideal gas laws. Talasila *et al.* (1995) developed a model to design rigid MAPs for fresh fruits and vegetables taking into account the change in total pressure of gases inside the package.

Quality Analysis of Fruits and Vegetables Packed in Modified Atmosphere Packaging

Researchers studying the MAP of fruits and vegetables, measure the quality of the fresh produce by recording and analyzing pH, titratable acidity, firmness (or texture), microbial count, water activity, physiological changes and sensory properties of the product (Artes *et al.*, 2000; Lopez Osornio and Chaves, 1998; Salvador *et al.*, 2002; Tano *et al.*, 1999). Changes in pH, titratable acidity, and water activity can indicate physiological changes and changes in the texture and microbial count.

All foods contain an acid or mixture of acids. The flavor, brightness of color, and quality of the food is influenced by these acids in fruits and vegetables (Wilbur and Ronald, 1988). Titratable acidity and pH are the two interrelated concepts that deal with acidity in food analysis. Titratable acidity is a measure of the total acid concentration contained in a food and pH is mathematical shorthand for expressing the free H_3O^+ concentration in a concise and convenient notation. Titratable acidity is a better predictor of an acid's impact on flavor than pH. However, titratable acidity alone cannot tell the full story (Nielsen, 1998). Hence, it is the combination of titratable acidity and pH that allows us to understand changes in the typical flavor, color and quality of fruits and vegetables. Lopez Osornio and Chaves (1998) have shown that the pH and titratable

acidity of raw grated beetroots (*Beta vulgaris* L.) remain almost unchanged or very close to the original pH and titratable acidity of the raw grated beetroots when the temperatures are lower. Increase in temperature leads to an increase in pH and titratable acidity.

Szczesniak (1962) reviewed and compiled the definitions of texture used by workers in the field, the dictionary definition and the rheological definition, and classified texture into 3 main groups:

- 1) Mechanical characteristics measured organoleptically by pressures exerted on the teeth, tongue and roof of the mouth during eating. It can be further divided into hardness, cohesiveness, viscosity, elasticity, and adhesiveness.
- 2) Geometrical characteristics, which refer to the arrangement of the constituents of the food and are reflected mainly in the appearance of the food product. It can be divided into 2 general groups of qualities: those related to size and shape of the particles and those related to shape and orientation.
- 3) Other characteristics comprise mouth feel qualities related to the perception of the moisture and fat content like oiliness and greasiness of the food.

The tenderness of the green-shelled common beans, is the preferred characteristics by the local Puerto Rican consumers (personal communication with Dr. James Beaver, University of Puerto Rico at Mayaguez).

Potential Unfavorable Effects of Modified Atmosphere Packaging

Depletion of oxygen in MAP of fresh fruit and vegetables leads to anaerobic respiration, which can accelerate senescence and spoilage (Church and Parsons, 1995). Tano *et al.* (1999) reported that anaerobic respiration of mushrooms leads to fermentation of mushrooms, indicated by the production of fermentative metabolites, such as

acetaldehyde and ethanol. Soliva-Fortuny *et al.* (2005) reported that fresh cut pieces of Golden Delicious apples packed in modified atmosphere limited the appearance of fermentative metabolites during their storage of 3 weeks, because of reduced carbon dioxide production.

From a food safety point of view, the microbiological decay of a modified atmosphere packed food is the biggest concern to the manufacturers, as well as consumers. In MAP, different concentrations of O₂, CO₂ and N₂ are used, compared to those found in the ambient environment. O₂ will generally stimulate the growth of aerobic bacteria and can inhibit the growth of strictly anaerobic bacteria, although there is a wide variation in the sensitivity of anaerobes to oxygen (Farber, 1991). CO₂ is both water and lipid soluble and is mainly responsible for the bacteriostatic effect, by extending the lag phase of growth and decreasing the growth rate during the logarithmic phase (Farber, 1991). N₂ is an inert tasteless gas that displays little or no antimicrobial activity on its own (Farber, 1991).

Fruits present comparatively less public health risks due to their relatively low pH (Church and Parsons, 1995), but in case of vegetables the pH level is quite high and, hence, vegetables are prone to bacterial and fungal decay. Church and Parsons (1995) stated that vegetables are at risk from mesophilic pathogens, like *E.coli* and *Salmonella* spp. in ambient storage (Brocklehurst *et al.*, 1987; Saddik *et al.*, 1985) and from psychrotrophic pathogens, like *Listeria monocytogenes*, in both ambient and cooler temperatures (Berrang *et al.*, 1989; Brocklehurst *et al.*, 1987; Sizmur and Walker, 1988).

Objective

Thus, it is known that, MAP in conjunction with proper storage temperature, correct gas combination within the package, suitable permeability of the packaging film in respect to the respiration rate of the packed vegetable or fruit, increases the shelf-life of that particular plant product. Along with the increase in shelf-life, MAP also is known to maintain the freshly harvested characteristics, in terms of color, texture, pH and titratable acidity in many vegetables and fruits like carrots, peas, mushrooms, beetroot and pomegranate. Green-shelled common beans being the most preferred beans by the local people of Puerto Rico, our objective was to develop a modified atmosphere packaging of green-shelled common beans, thereby making these beans, with the freshly harvested characteristics, available to the local consumers. As success of MAP depends on 2 essential variables, respiration rate of the plant product and the permeability of the packaging films, many mathematical models have been published by researchers, in order to predict the evolution of gases within MAP considering those 2 variables. Based on these available information, our second goal was to develop a computer program, based on published mathematical models, which can predict the evolution of the gases in modified atmosphere packaging of fruits and vegetables during their storage period.

Methods and Materials

Experimental study on respiration of the green-shelled common beans

The green-shelled common beans were harvested at the Isabela Substation of the University of Puerto Rico, Agricultural Experimental Station, approximately after 60 days of planting and were transported shortly after the harvest to the food packaging lab in a cool container, maintaining the temperature of the beans at 4 - 6 °C during the transport. Then, the uninfected, fresh beans were sorted from the harvested lot for shelling. The common beans were mechanically shelled (Taylor Pea Sheller, aka. the “Little Sheller”, Atlanta, Georgia) between 18 and 20 °C. Random samples of 250 g of green-shelled beans were placed in glass jars of 950 ml. The head space volume of the glass jar was calculated. The jars filled with the beans were placed at 5, 10, 15 and 24 °C. Three replicates were used for each temperature treatment. A thermometer was placed in the cool chamber corresponding to each temperature in order to monitor the temperature. The respiration rate was measured each day from all the jars kept at each temperature until physiological changes or microbiological deterioration began to appear. The gas sample was measured for percentage of CO₂, 4 hours after the jars had been sealed. The gas sample was extracted from the jars using a 10 ml syringe and analyzed in a gas analyzer (Servomex Food Package Analyzer Series 1400, Norwood, MA), which measured the percentage of CO₂. Using this percentage of CO₂, the respiration rate was calculated as milliliters of CO₂/kg*hr on a fresh weight basis. This was calculated using the following equation:

$$R_{CO_2} = CO_2/kg*hr$$

$$CO_2 = \text{Head space volume (ml)} * \text{Change in } CO_2 \% \text{ in the jar}$$

Final rate of CO₂ (R_{CO₂}) is expressed in mg CO₂/kg*hr, as ml of CO₂ was converted into mg of CO₂ using the appropriate conversion factor, which was 1.93, 1.89, 1.86 and 1.80 mg/ml for 5, 10, 15 and 24 °C, respectively.

Experimental Study of MAP on green-shelled common beans

The beans were harvested, handled and sorted, as described in the respiration study. Color, pH, titratable acidity, texture and water activity analyses were performed on the fresh beans before packaging them under different modified atmospheres (Fig. 4). Three replicates of 225 g each of shelled beans per treatment were packed in Cryovac PD-961EZ plastic bags (18 cm width and 16.5 cm length). The gas combinations used to pack the beans were: 1) 4% O₂, 10% CO₂, and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂, and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂, and 78% N₂ control (AIR). All the packages were stored at 5 °C for 26.5 days. Changes in CO₂ within the packages were analyzed from 3 replicates of each gas treatment, along with the above mentioned different quality analyses (last step of Fig. 4), on an interval of every 4 days. In order to identify changes in the beans, at the time of occurrence, this interval of 4 days for different analyses was selected. On each day of analysis, 6 replicates were taken out of the 5 °C storage, and the gas and quality analyses were performed on 3 replicates, while the other 3 replicates were stored at 20 °C for 2 days, for temperature abuse simulation. The gas and quality analyses on the 3 replicates of temperature abused packages were performed after 2 days.

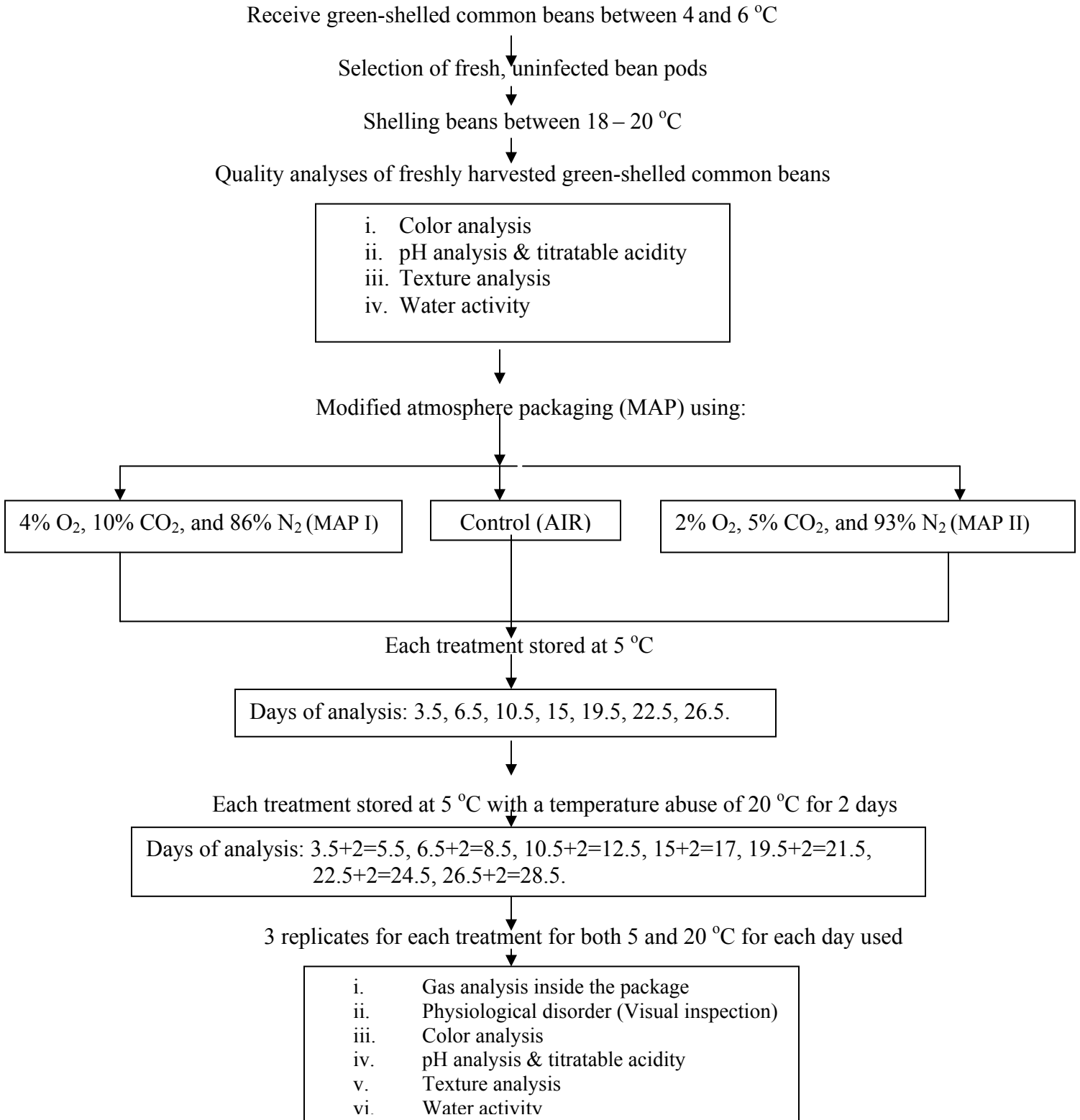


Figure 4. Flow chart of the experimental process for MAP.

Quality Analyses:

a. Gas Analysis:

The concentrations of CO₂ from each treatment were analyzed using a 10 ml sample, following the procedure described in the respiration study of the beans and on the days of analyses as described in the experimental plan.

b. Color Analysis:

Before packaging the freshly harvested common beans for each treatment, the color of the beans was measured using a Hunter Lab Colorimeter (Miniscan XE, Reston, Virginia) with “*L*”, “*a*”, “*b*” parameters. Color of the beans was measured on each day of analysis from each of the 3 replicates of each treatment stored at 5 °C and after a 2 d temperature abuse at 20 °C. The beans were placed in a black Petri-dish with an aperture big enough to allow only the light from the colorimeter to pass, in order to take the color reading of the samples. Color of 3 samples from each replicate were taken. Each parameter is read according to Fig. 5.

<i>L</i>	0 → 100
	<i>Black</i> → <i>White</i>
<i>a</i>	+100 → -80
	<i>Red</i> → <i>Green</i>
<i>b</i>	+70 → -80
	<i>Yellow</i> → <i>Blue</i>

Figure 5. Parameters used to measure color of common beans with Hunter Miniscan Colorimeter.

c. Physiological disorders:

Visual inspection for any type of physiological disorder of the green-shelled common beans on each day of analysis from each of the 3 replicates of each treatment

was performed. During visual inspection the factors considered were: shriveling, browning, presence of molds, germination and off-odors of the beans. The rating scale of 1 to 5 was used to rate visual inspection. These scales of each factor mentioned above are described in Tables 1, 2, 3, 4 and 5, respectively. The scales were modified from Kader *et al.* (1973). The percentage refers to total number of the all the beans in each package.

Table 1. Rating scale for shriveling.

Rating scale	Visual shriveling description	Defects
1	None	None
2	Slight (< 25%)	Recognition of shriveling, not objectionable
3	Moderate (25-50%)	Slight shriveling, becoming objectionable
4	Severe (50-75%)	Obvious shriveling, definitely objectionable
5	Extremely severe (75-100%)	Complete shriveling, not acceptable

Table 2. Rating scale for browning.

Rating scale	Visual browning description	Defects
1	None	None
2	Slight (< 25%)	Slightly objectionable, can impair sale of the beans
3	Moderate (25-50%)	Will definitely impair sale of beans
4	Severe (50-75%)	Not acceptable by the customers, not at all salable
5	Extremely severe (75-100%)	Rejected

Table 3. Rating scale for of molds.

Rating scale	Visual mold description	Defects
1	None	None
2	Slight (< 25%)	Slightly objectionable, can impair sale of the beans
3	Moderate (25-50%)	Will definitely impair sale of beans
4	Severe (50-75%)	Not acceptable by the customers, not at all salable
5	Extremely severe (75-100%)	Rejected

Table 4. Rating scale for inspection of germination.

Rating Scale	Visual germination	Defects
1	None	None
2	Slight (< 25%)	Recognition of germination/visual defect, not objectionable
3	Moderate (25-50%)	Slight germination/visual defect, becoming objectionable
4	Severe (50-75%)	Obvious germination/visual defect, definitely objectionable
5	Extremely severe (75-100%)	Complete germination/visual defect, not acceptable

Table 5. Rating scale for off-odors.

Rating Scale	Description of the off-odors.	Defects
1	None	None
2	Slight (< 25%)	Slightly objectionable, can impair sale of the beans
3	Moderate (25-50%)	Will definitely impair sale of beans
4	Severe (50-75%)	Not acceptable by the customers, not at all salable
5	Extremely severe (75-100%)	Rejected

d. pH & Titratable Acidity:

The bean mixture to measure pH was prepared as described by Barry-Ryan and Beirne (1998) and Barry-Ryan *et al.* (2000) using 1:1 of product and distilled water. Thirty grams of beans were blended for 2 mins with 30 ml of distilled water (pH 7). pH was then taken of the prepared mixture using a portable pH meter, which was antecedently calibrated using buffer solutions of pH 4 and 7. The pH of the freshly harvested green-shelled common beans was measured before packaging and later on each day of analysis from each of the 3 replicates of each treatment stored at 5 °C and those temperature abused at 20 °C. Three samples per replicate were taken to measure pH and titratable acidity.

In order to measure titratable acidity, 10 ml of aliquot was taken from the beans and distilled water mixture prepared for pH measurement. This 10 ml aliquot was titrated against 0.1N NaOH to a phenolphthalein endpoint, from colorless to light pink (Nielsen, 1998). This procedure was repeated thrice, as 3 samples were analyzed per bag. Titratable acidity was taken for the freshly harvested beans before packing and on each day of analysis from each of the 3 replicates of each treatment stored at 5 °C and those temperature abused at 20 °C. Titratable acidity was calculated as percentage of acid in a sample aliquot (Wilbur and Ronald, 1988), using the malic acid equivalent factor (67.05), as this is the acid present in green-shelled common beans, and has been used previously to calculate the titratable acidity of green beans by Cano *et al.* (1998):

$$Z = \frac{VxNxEq.Wt}{Y} x100 \quad (2)$$

Where, Z = % of acid in sample

V= volume in L of NaOH titrated

N = normality of NaOH (0.1N)

Eq. Wt = Equivalents of acid

Y = weight of aliquot in g of sample

Texture Analysis:

Texture was determined as tenderness. The freshly harvested beans are tender and, as they dry, out they become hard. As we were doing modified atmosphere packaging of the beans, we expected the beans to maintain the fresh, tenderness characteristic. Twenty beans were randomly picked from each of the three replicate packages for texture analysis. Texture analysis was done on 20 beans fresh and treated from each of the 3 replicates of each treatment stored at 5 °C and after the temperature abuse of 20 °C. The force necessary to penetrate the bean was measured using Texture Analyzer-Stable Micro System Model TA-XT2 (Hamilton, MA). The accessory used to penetrate the bean was a 2-mm cylinder probe. The instrument was calibrated using the protocol provided by the manufacturer before starting with the analysis.

f. Water Activity:

Water activity was measured by placing the sample in the plates of the Water Activity Meter, Aqualab CX2. Water activity of the freshly harvested beans was measured before packing (day 0) and on each day of analysis from each of the 3 replicates of each treatment for both 5 °C and the temperature abuse of 2 days at 20 °C.

Statistical Analysis

The experimental setting was based on completely randomized design. An ANOVA was performed for each treatment and a statistical analysis between the treatments using Fisher's LSD test ($p \leq 0.05$) for each quality analysis using Infostat Software.

Computational Model for Prediction of Time Evolution of Gases Within MAP.

The situation of MAP involves various parameters, namely respiration rate of the product, weight of product, initial composition and volume of gases inside the package, surface area of the package, packaging material thickness and its permeability to different gases, temperature and pressure inside and outside the package. Based on the conservation of mass of each gas inside the package, mathematical models describing time evolution of composition of gases inside the package have been suggested in the literature. One such typical model by Salvador *et al.* (2002) for prediction of temporal evolution of the composition is considered here. The model described below is similar to their model but without considering any water transpiration.

Based on this model and for the situation under consideration, the model can be written,

$$\frac{dn_{O_2}}{dt} = -P_{O_2} \frac{A}{x} (p_{O_2,in} - p_{O_2,out}) - R_{O_2} W, \quad (3)$$

$$\frac{dn_{CO_2}}{dt} = -P_{CO_2} \frac{A}{x} (p_{CO_2,in} - p_{CO_2,out}) + R_{CO_2} W, \quad (4)$$

$$\frac{dn_{N_2}}{dt} = -P_{N_2} \frac{A}{x} (p_{N_2,in} - p_{N_2,out}). \quad (5)$$

In these equations, n_{O_2} , n_{CO_2} and n_{N_2} are the number of moles of oxygen, carbon dioxide and nitrogen gases, respectively, inside the package at any time t . P_{O_2} , P_{CO_2} and P_{N_2}

are film permeabilities of the package for oxygen, carbon dioxide and nitrogen gases, respectively. p_{O_2} , p_{CO_2} and p_{N_2} represent partial pressures of oxygen, carbon dioxide and nitrogen gases, respectively, with subscripts *in* and *out* suggesting partial pressures inside and outside the package. W is weight of product (eg. beans) in the package, A is surface area of the package through which different gases penetrate into and out of the package. R_{O_2} and R_{CO_2} are respiration rates for beans and x is film thickness of the package. The respiration rate can be represented by (Salvador *et al.*, 2002):

$$R_{O_2} = \frac{V_m p_{O_2}}{K_m + p_{O_2}} \quad (6)$$

Where V_m is maximum respiration rate and K_m is Michaelis-Menten constant.

For further analysis, all gases are considered to behave as an ideal gas. Therefore

$$P_{total} V = (n_{O_2} + n_{CO_2} + n_{N_2}) RT \quad (7)$$

where R is the universal gas constant and T is the temperature of gases inside the package and the presence of water molecules are neglected. In the case of flexible or collapsible packaging material (e.g., thin plastic film bag) with finite permeability, the pressure inside the package adjusts so as to become equal to the outside environmental pressure. For such a flexible package, the pressure is considered equal to the outside pressure, which can be considered constant in time if the outside pressure, remains constant. In the present case the outside pressure value used in the computation is equal to 1 atm and therefore, $P_{total} = 1$ atm. Also,

$$\frac{P_{O_2,in}}{P_{total}} = \frac{n_{O_2}}{n_{O_2} + n_{CO_2} + n_{N_2}}, \quad \frac{P_{CO_2,in}}{P_{total}} = \frac{n_{CO_2}}{n_{O_2} + n_{CO_2} + n_{N_2}}, \quad \frac{P_{N_2,in}}{P_{total}} = \frac{n_{N_2}}{n_{O_2} + n_{CO_2} + n_{N_2}} \quad (8)$$

$$\text{and } P_{total} = P_{O_2,in} + P_{CO_2,in} + P_{N_2,in} \quad (9)$$

The above equations can be solved using the fourth order Runge-Kutta numerical method (Burden and Faires, 1997) for combinations of values for the initial concentration of gases inside the package and other parameters. The numerical solutions of the above model equations are presented in the Results and Discussion section.

Results and Discussion

Experimental study on respiration of the green-shelled common beans

Experimental study on respiration rate of the green-shelled common beans at different temperatures was conducted, as no data is available on the respiration rate of green-shelled common beans. The respiration rate depends on product type, within a product type it also can vary among different crop cultivars (O'Beirne, 1990). Figure 6 represents the respiration rate of green-shelled common beans at temperatures 5, 10, 15 and 24 °C. At 24 °C the beans showed the highest respiration rate of 123.92 mg CO₂/kg*hr on the first day dropping to 95.26 mg CO₂/kg*hr showing browning, germination and off-odors on the second day, ending its shelf-life. At 15 °C it was evident that the respiration rate of the beans was less than 24 °C varying between 83.56 to 61.53 mg CO₂/kg*hr from the first and the fourth day, which was its end of shelf-life. Though the beans showed initiation of browning on the second day, on the fourth day the browning was intense and off-odors were severe. At 10 °C the beans respired much less than 24 and 15 °C varying between 61.62 to 28.09 mg CO₂/kg*hr from the first and the sixth day, which was the end of its shelf-life. The respiration rate of the beans at 10 °C gradually decreased during the storage period. While at 5 °C the beans showed an almost constant respiration rate and was much less than at 24, 15 and 10 °C. The average respiration rate at 5 °C was 15.94 mg CO₂/kg*hr with a standard deviation of 2.46 mg CO₂/kg*hr from the first and the tenth day, which was the end of its shelf-life. There was a slight increase in respiration on the 3rd and 5th day, but overall the respiration rate of the beans remained low and constant at this temperature. While at 24, 15 and 10 °C the green-shelled beans showed a drop in respiration rate for the first 2-3 days, then an

increase and then finally dropping back. A statistical analysis also showed a significant difference ($p \leq 0.05$) between the means of the respiration rates for all four temperatures (Table 6). This confirms the fact that an increase in temperature increases the respiration rate in vegetables and fruits, as young growing tissues of the vegetables respire faster at higher temperatures. Our findings also agree with the Q_{10} factor, which signifies, that with every 10 °C rise in temperature, the respiration rate of fruits and vegetables doubles (Salunkhe *et al.*, 1990).

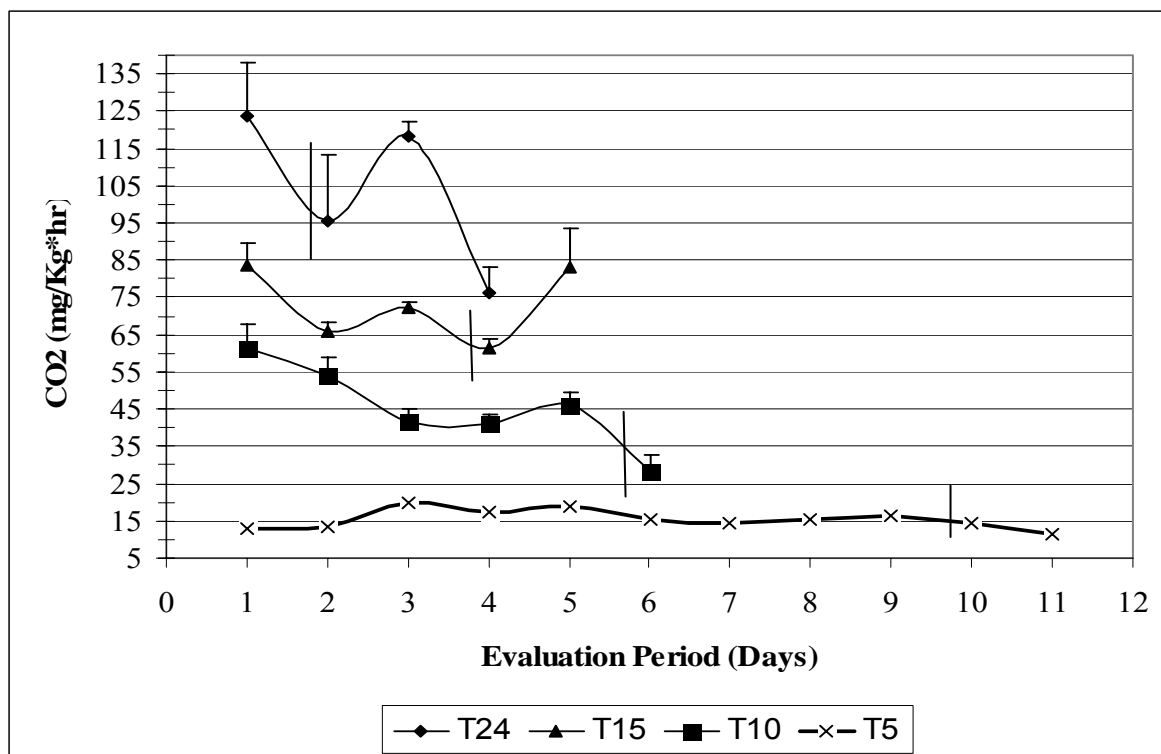


Figure 6. Respiration rate of green-shelled common beans in the form of mg CO₂/kg*hr at four different temperatures (5, 10, 15 and 24 °C). The vertical line | signifies end of shelf-life. The vertical bars represents standard error of the mean.

Table 6. Mean respiration rate of green-shelled common beans at different temperatures in terms of CO₂ mg/kg*hr.

Temperature	Respiration rate (CO ₂ mg/kg*hr)
5 °C	15.94a
10 °C	48.88b
15 °C	73.95c
24 °C	123.92d

Means within a column followed by same letter are not significantly different ($p \leq 0.05$).

Quality Analysis:

a. Gas Analysis:

It was evident that all three treatments stored at 5 °C showed an increase in %CO₂ on the first day of analysis (3.5 days), it then stabilized close to their increased percentage during the rest of their storage period (Fig 7). It was observed that MAP II and AIR packages showed an increase of around 10% of CO₂ after 3.5 days, while MAP I showed an increase in around 0.6% of CO₂ after 3.5 days. The initial increase in %CO₂ can be attributed to the fact that the beans might have undergone a respiration shock. Hence, in order to acclimatize with the environment inside the package, they respired more (higher %CO₂). The %CO₂ in AIR packages varied between 9.3 to 11% between 3.5 to 26.5 days. The possible reason for the 10% increase in CO₂% in AIR packages could be, greater availability of %O₂ compared to the other two treatments, allowing the beans to respire more, thereby, producing more %CO₂. While the %CO₂ in MAP I remained between 9 to 10%, only dropping to 8.4% after 22.5 days. The statistical analysis, showed that there was no significant difference ($p \leq 0.05$) between the means of MAP I and AIR treatments stored at 5 °C (Table 7). The %CO₂ in MAP II packages, after the initial increase of 10% at 3.5 days, showed a gradual decrease from 15.3 to 9.3% between 3.5 to 26.5 days. The mean of MAP II was significantly different ($p \leq 0.05$) from the means of MAP I and AIR treatments stored at 5 °C (Table 7).

All the three treatments showed an increase in %CO₂ between 7 to 10% during the temperature abuse period of 3.5 + 2 to 26.5 + 2 days at 20 °C (Fig. 8). The statistical analysis of all three treatments (2 MAPs and AIR) stored at 5 °C with a temperature abuse of 2 days at 20 °C showed that there was no significant difference ($p \leq 0.05$)

between the means of MAP I and AIR, while it showed the mean of MAP II was significantly different ($p \leq 0.05$) from the means of MAP I and AIR (Table 7). The statistical analysis showed that there was a significant difference ($p \leq 0.05$) between the means of all the three treatments (2 MAPs and AIR) with the means of their respective temperature abuses (Table 7).

Table 7. Changes in CO₂% for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] stored at 5 °C for 26.5 days and with a temperature abuse for 2 days at 20 °C.

Treatments	Mean %CO₂ of treatments stored at 5 °C	Mean %CO₂ of treatments for temperature abuse at 20 °C
MAP I	9.55a(a)	17.00a(b)
MAP II	12.32b(a)	21.81b(b)
AIR	10.57 a(a)	18.94a(b)

Means within a column followed by same letter are not significantly different ($p \leq 0.05$). Means within a row followed by same letter within parentheses are not significantly different ($p \leq 0.05$).

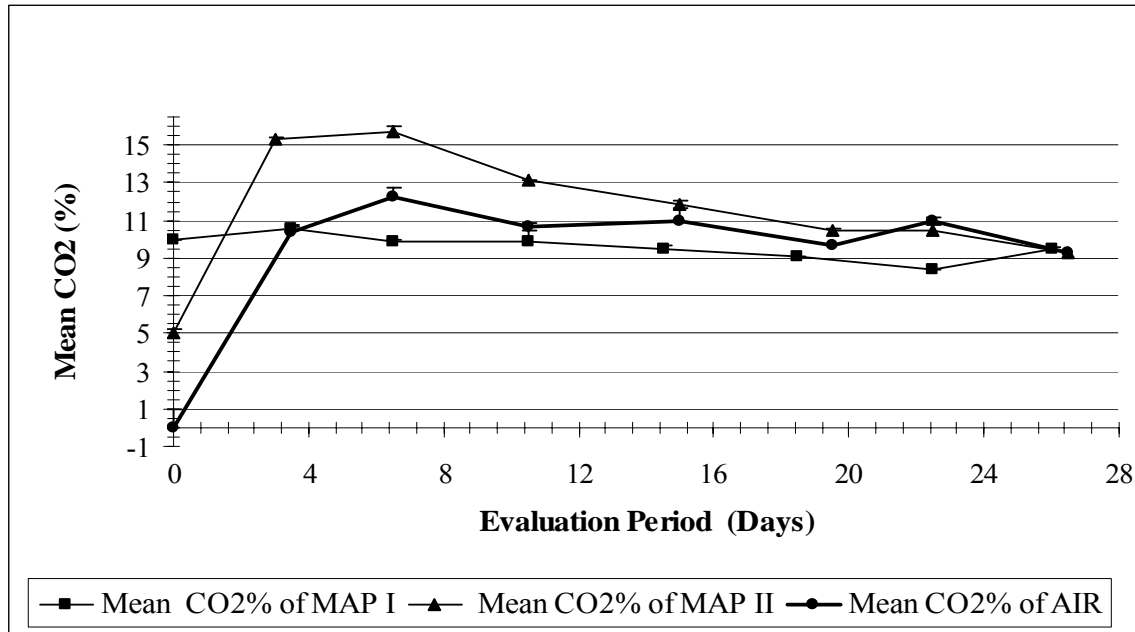


Figure 7. Change in %CO₂ for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C. The vertical bars represents standard error of the mean.

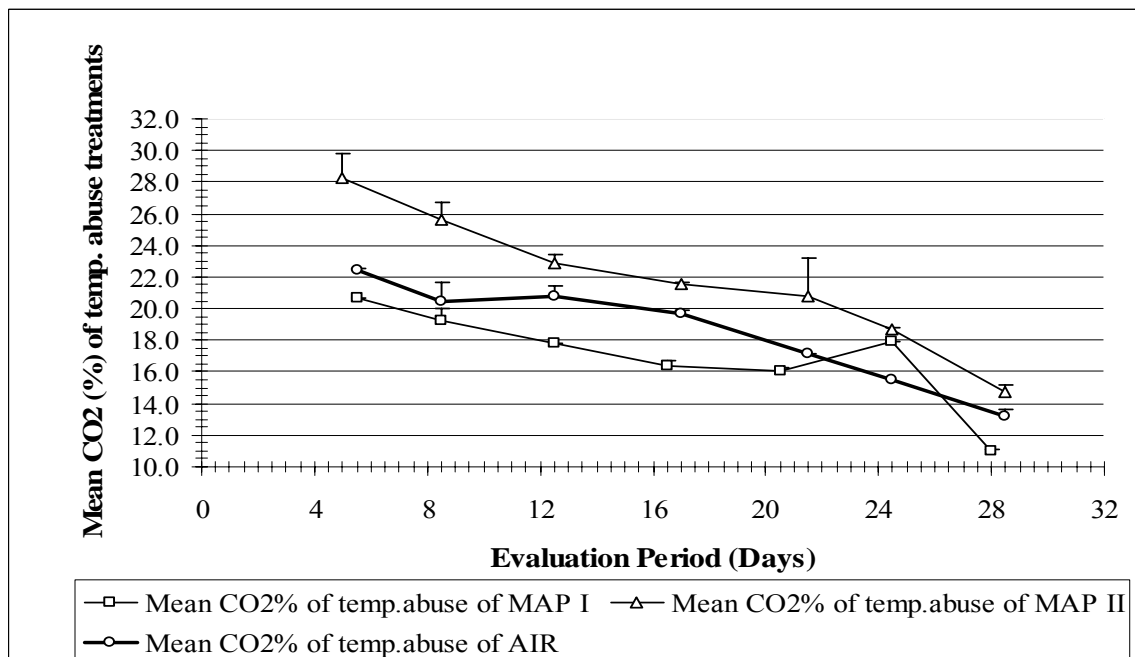


Figure 8. Change in %CO₂ for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C with a temperature abuse of 2 days at 20 °C. The vertical bars represents standard error of the mean.

b. Color Analysis:

Color of the green-shelled common beans plays a major role in predicting the quality of the beans during storage, as consumers first look for the appropriate color before making a purchase. The factors considered in order to decide the right packaging, for this particular cultivar of common beans was based on consumer preference. As Shewfelt (2003) has noted, there is no ideal standard color for most vegetables, therefore, a rational starting point in deciding the appropriate color for a vegetable should be determination of consumer preference. Common beans come to the market with a mixed maturity, that is mixture of green and yellow, but the consumers in Puerto Rico prefer the yellow or rather off-white color when buying.

Our observation with the color was that at 5 °C, all treatments showed an increase in yellow color with storage, dropping off the initial green color of the beans. The color of all treatments was within the acceptable range of color. L value of MAP I and MAP II increased by an average of 1.2, while with the AIR treatment, the beans showed an increase in L value of 3, becoming whiter compared to other two treatments over the storage period (Fig. 9). From the statistical analysis, it was determined that the mean L value of MAP I was significantly different ($p \leq 0.05$) from the mean L values of MAP II and AIR, while no significant difference ($p \leq 0.05$) was found between means of MAP II and AIR (Table 8), but the difference was not significant enough to reject package, as mentioned above all the three treatments were in acceptable range of whiteness.

The a value of all three treatments, when compared with the average a value of the fresh beans, increased by an average of 1.82, indicating that the beans became less green, but MAP I and MAP II showed a greater loss of green color than the AIR treated

beans (Fig 11), as -a value (-80) indicates green color, while +a value (+100) indicates red color. There was a significant difference ($p \leq 0.05$) between the mean a values of AIR and MAP II, while the mean a value of MAP I showed no significant difference ($p \leq 0.05$) with the mean a values of the AIR and MAP II (Table 9). However, from the practical point of view there was no significant difference between any of the three treatments, as all 3 treatments had lost their green color becoming more yellow in almost the same proportion.

When the b value was considered, the MAP I and AIR treatments showed a b value very close to the b value of freshly harvested green-shelled common beans until 18.5 days, while after 22.5 days there was an increase in b value by only 1.5. While MAP II showed an average increase of 1.5 in the b value during its storage period right from the beginning. Hence, overall observations of the b value were similar to the a value indicating that the common beans turned slightly more yellow (Fig. 13), as +70 of the b value indicates yellow color while -80 of the b value indicates blue color. Yellow color of the common beans was due to degradation of chlorophyll, as expected with senescence during its storage period (Shewfelt, 2003). The mean b value of MAP II was significantly different ($p \leq 0.05$) from the mean b values of MAP I and AIR (Table 10). However, the difference was not perceptible to the eye.

The temperature abuse of all three treatments showed more yellowing of the beans, when compared to their analysis before temperature abuse, but were still in the acceptable range from the consumer's point of view (Figs. 10, 12 and 14). A significant difference ($p \leq 0.05$) between the mean L values of MAP I and MAP II and their respective temperature abuse treatment was found (Table 8). Whereas no significant

difference ($p \leq 0.05$) between the mean L values of AIR and its temperature abuse treatment was observed (Table 8). There was no significant difference ($p \leq 0.05$) between the a value of the MAP I, MAP II and AIR with their respective temperature abuse treatments (Table 9). Also, the statistical analysis showed that there was a significant difference ($p \leq 0.05$) between the mean b values of all three treatments (2 MAPs & AIR) with the mean b value of their respective temperature abused treatments (Table 10).

Table 8. L value for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] stored at 5 °C for 26.5 days and with a temperature abuse for 2 days at 20 °C.

Treatments	Mean L value of treatments stored at 5 °C	Mean L value of treatments for temperature abuse at 20 °C
MAP I	65.94a(a)	66.76a(b)
MAP II	66.91b(a)	67.89b(b)
AIR	66.61b(a)	67.16a(a)

Means within a column followed by same letter are not significantly different ($p \leq 0.05$). Means within a row followed by same letter within parentheses are not significantly different ($p \leq 0.05$).

Table 9. a value for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] stored at 5 °C for 26.5 days and with a temperature abuse for 2 days at 20 °C.

Treatments	Mean a value of treatments stored at 5 °C	Mean a value of treatments for temperature abuse at 20 °C
MAP I	2.30ab(a)	2.30a(a)
MAP II	2.35b(a)	2.28a(a)
AIR	2.16a(a)	2.31a(a)

Means within a column followed by same letter are not significantly different ($p \leq 0.05$). Means within a row followed by same letter within parentheses are not significantly different ($p \leq 0.05$).

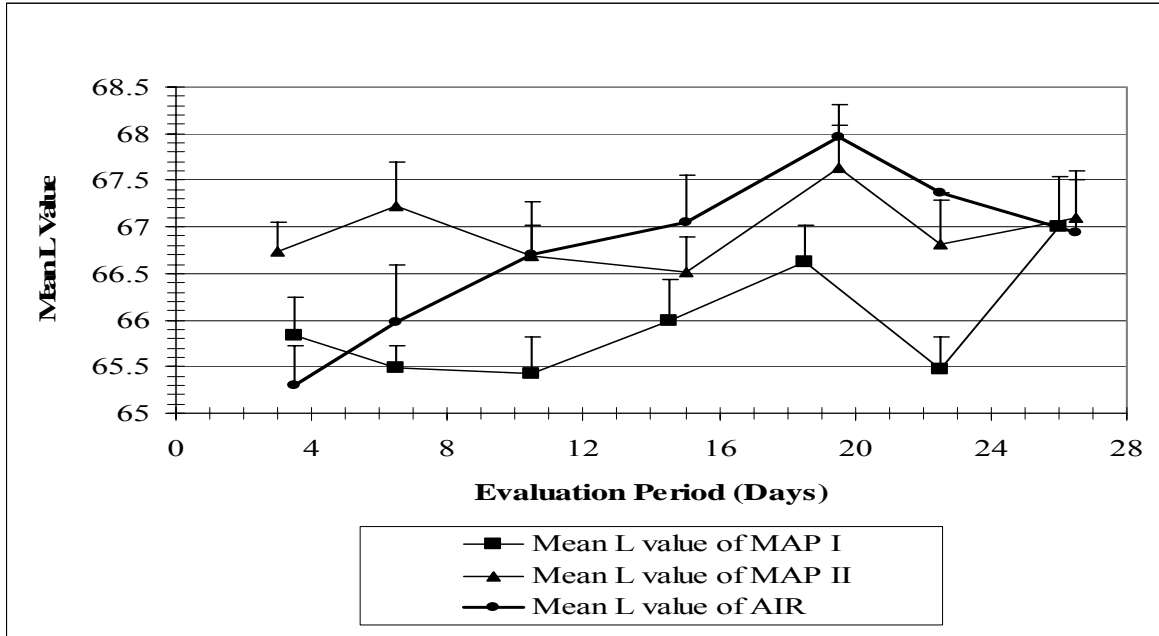


Figure 9. Color in terms of mean L value for 3 gas combinations [1] 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C. The vertical bars represents standard error of the mean.

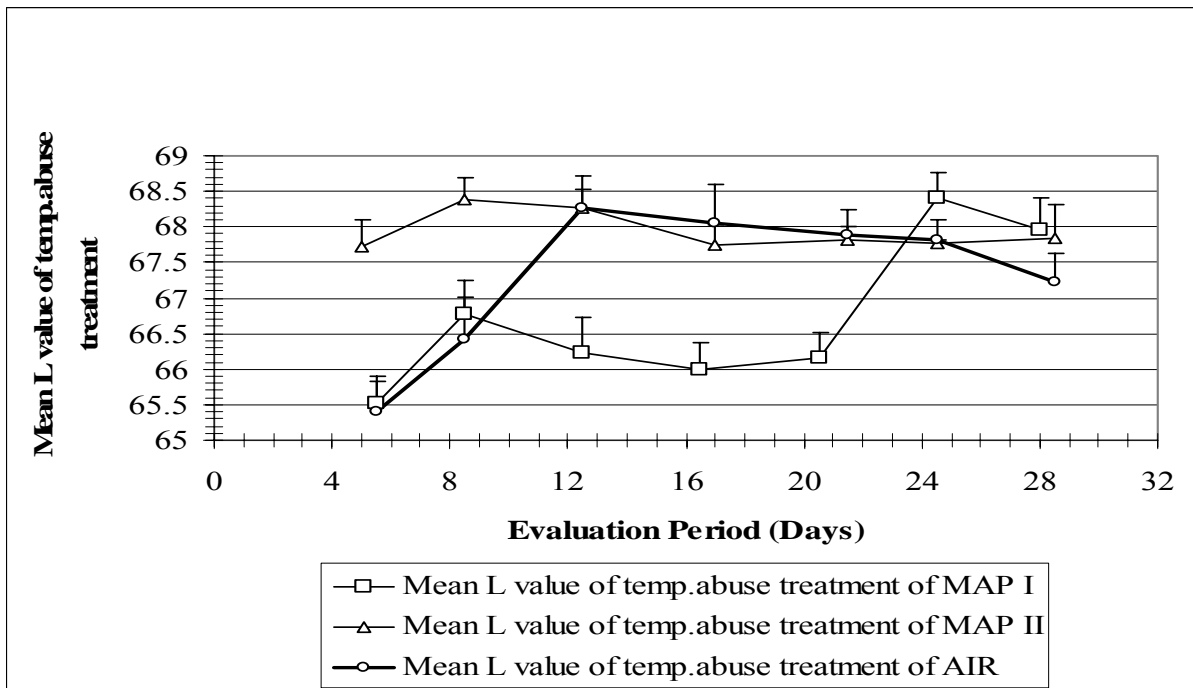


Figure 10. Color in terms of mean L value for 3 gas combinations [1] 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C with a temperature abuse of 2 days at 20 °C. The vertical bars represents standard error of the mean.

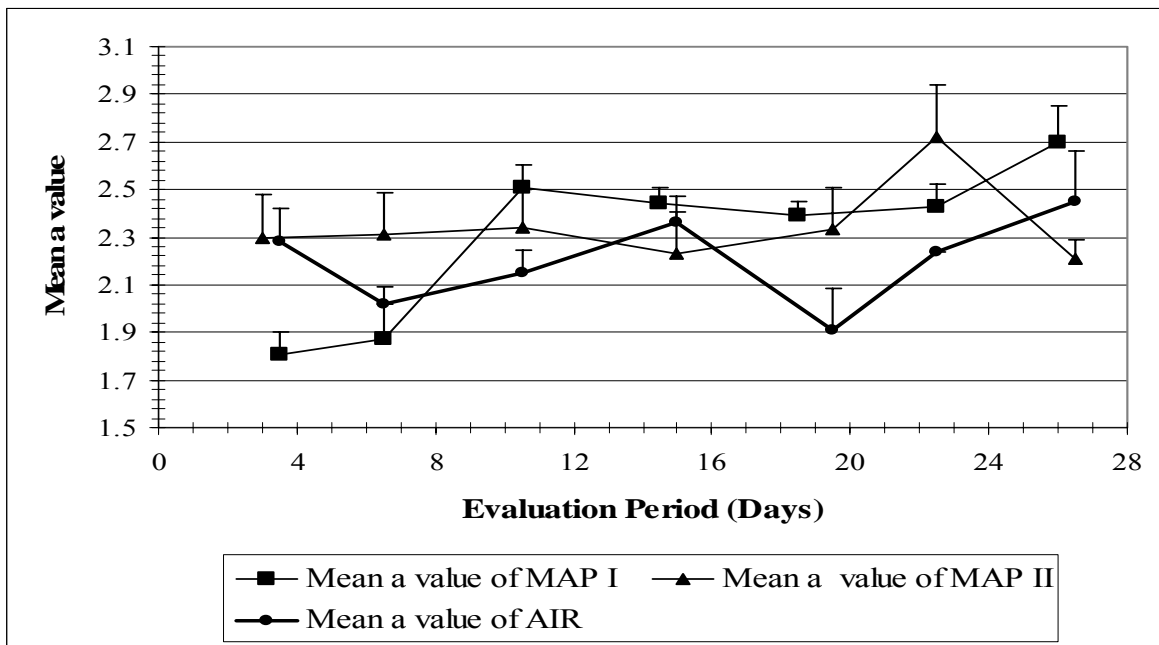


Figure 11. Color in terms of mean a value for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C. The vertical bars represents standard error of the mean.

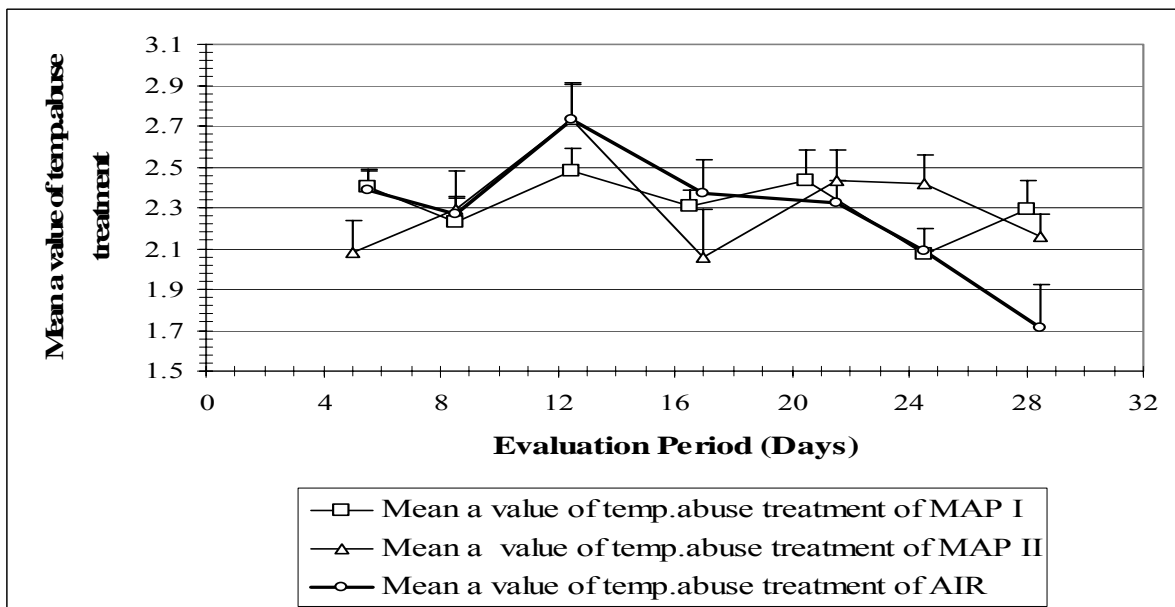


Figure 12. Color in terms of mean a value for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C with a temperature abuse of 2 days at 20 °C. The vertical bars represents standard error of the mean.

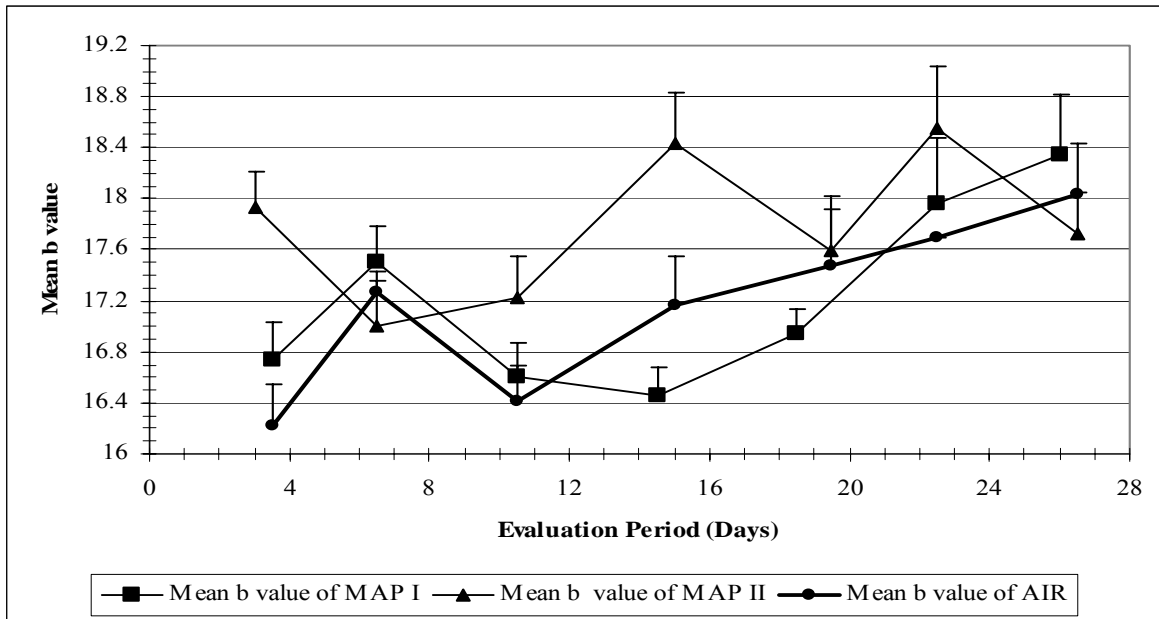


Figure 13. Color in terms of mean b value for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C. The vertical bars represents standard error of the mean.

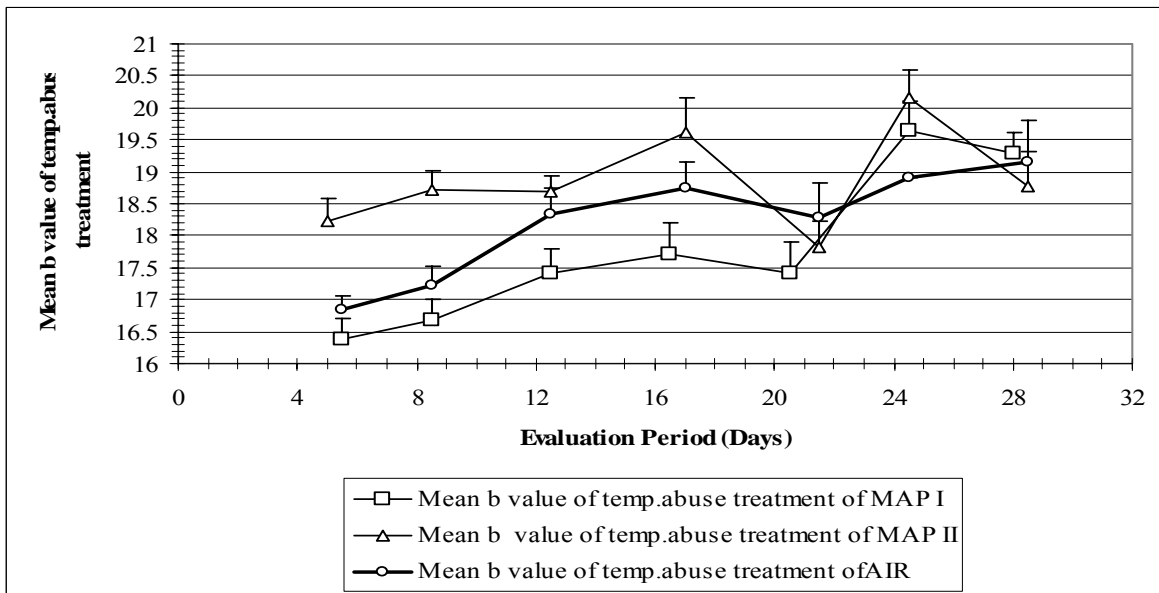


Figure 14. Color in terms of mean b value for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C with a temperature abuse of 2 days at 20 °C. The vertical bars represents standard error of the mean.

Table 10. b value for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] stored at 5 °C for 26.5 days and with a temperature abuse for 2 days at 20 °C.

Treatments	Mean b value of treatments stored at 5 °C	Mean b value of treatments for temperature abuse at 20 °C
MAP I	17.25a(a)	17.80a(b)
MAP II	17.85b(a)	18.85b(b)
AIR	17.18a(a)	18.11a(b)

Means within a column followed by same letter are not significantly different ($p \leq 0.05$). Means within a row followed by same letter within parentheses are not significantly different ($p \leq 0.05$).

c. Physiological disorders:

MAP I maintained a rating of no off-odors, until 6.5 days, while after 10.5 days it received a rating of slight, which means there was a very slight smell less than 25%, after 14.5 and 18.5 days the smell was rated around 2.3 (Fig. 15). The packages of all three treatments gave a fermented smell rather than a rotten smell. MAP II received a rating around 1.3 after 3 days of analysis, and varied between ratings of 1.7 to 3.7 from 6.5 to 26.5 days. The possible reason for a fermented odor in MAP II packages after 3 days could be correlated with an increase of 10% in %CO₂, observed on the same day may be as a result of anaerobic respiration of the beans that, might have led to formation of fermentative metabolites like ethanol or acetaldehyde. After 22.5 days a sharp fermented smell was experienced in MAP II packages compared to after 26.5 days which could also be related to the %CO₂ in the packages, as after 22.5 days the packages had more %CO₂ than after 26.5 days. While the AIR treatment received an odor rating between 1 and 2.7. Both MAP I and MAP II showed maximum fermented smell after 22.5 days, while AIR treatment showed a maximum fermented smell after 15 days and strangely, again gradually lowering down to the rating of around 1.7 and 2.08 for rest of the storage period. However, when compared with %CO₂ in the packages, it is evident that in all three treatments on the days where more %CO₂ was observed, it was accompanied by the fermented smell. It should be noted that, the packages that received an odor rating between 2 and 3 tended to lose the fermented odor after half an hour exposure of packages to atmospheric air or if the green-shelled common beans were washed immediately with cold water. In addition it was observed that, the common beans which had fermented odor ratings of 2 to 2.5, tasted a little bit fermented (i.e. had a very slight

irritation on the tongue) when tasted raw. However, the green-shelled common beans tasted fine when washed with cold water. Packages that had a fermented odor rating of more than 2.5, still tasted fermented after washing with cold water. The common beans packed in AIR, tasted very fermented and starchy on the 15th day, where the odor rating had reached 2.7 with highest %CO₂ inside the packages. In all three treatments the fermented odor and taste were associated with the increase in %CO₂. One of the presumed reasons for this is that increased %CO₂ might have led to initiation of non-hazardous *Lactobacillus* spp., or lactic acid bacteria, which are responsible for the fermentation. Farber (1991) has mentioned in his review paper that increased %CO₂ leads to initiation of facultative anaerobic micro-flora dominated by *Lactobacillus* spp. Another possible reason could be that as the %CO₂ increased in the packages, it might have dissolved on the surface of the common beans forming carbonic acid responsible for sour taste and fermented smell. Daniels *et al.* (1985), in their review paper, noted that in the presence of high concentrations of %CO₂ some of the gas exists as carbonic acid, which can cause unpleasant acidic souring. Formation of acetaldehyde and ethanol as a result of anaerobic respiration can also be considered as a responsible factor for fermented smell and taste. Tano *et al.* (1999) reported the presence of acetaldehyde and ethanol inside the modified atmosphere packages of mushrooms that were responsible for fermentation. However, the statistical analysis showed no significant difference ($p \leq 0.05$) between the mean rating of odor among all three treatments (Table 11).

From the visual inspection of the treatments (2 MAPs and AIR) for shriveling, germination, presence of molds, and presence of browning, it was observed that all of

them showed a rating of 1. In other words none of the treatments showed any of the above mentioned physiological disorders in their storage period of 26.5 days at 5 °C.

With temperature abuse, MAP I rated better compared to MAP II and AIR, because MAP I showed rating of 3.7 only after 10.5 + 2 days of temperature abuse (i.e., at 12.5 days), while MAP II and AIR showed a rating of 5 and 3, respectively, immediately after a temperature abuse of 3.5 + 2 days (i.e., at 5.5 day) (Fig. 16). Also, a rating scale close to 3.7 was given for a rotten odor, instead of a fermented odor that was observed in the regular treatments and did not dissipate when exposed to air. With the temperature abuse all three treatments had an increase in %CO₂ between 8 to 12%, which might have led to increase in many types of micro-flora, which would cause a rotten odor. The statistical analysis showed no significant difference ($p \leq 0.05$) between the means of the ratings of odor among all three treatments (Table 11). The statistical analysis of all three treatments with their respective temperature abuse treatments showed a significant difference ($p \leq 0.05$) (Table 11).

Table 11. Rating of off-odor for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] stored at 5 °C for 26.5 days and with a temperature abuse for 2 days at 20 °C.

Treatments	Mean off-odor rating of treatments stored at 5 °C	Mean off-odor rating of treatments for temperature abuse at 20 °C
MAP I	2.19a(a)	3.86a(b)
MAP II	2.14a(a)	4.43a(b)
AIR	1.94a(a)	3.89a(b)

Means within a column followed by same letter are not significantly different ($p \leq 0.05$). Means within a row followed by same letter within parentheses are not significantly different ($p \leq 0.05$).

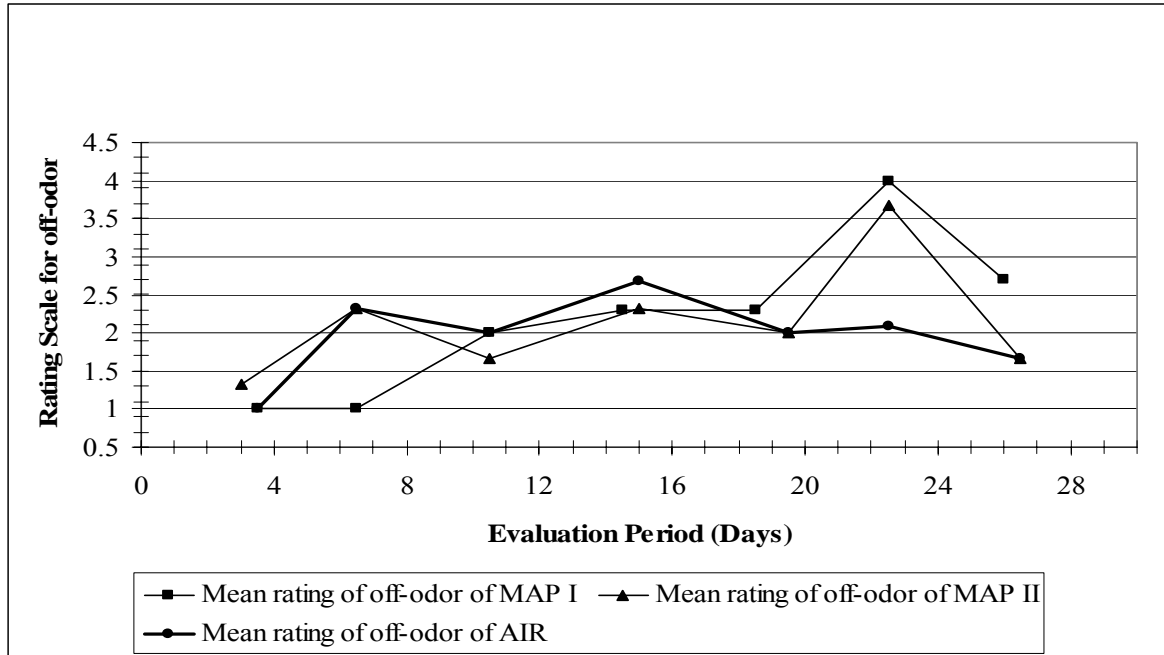


Figure 15. Mean rating scale of off-odor for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C.

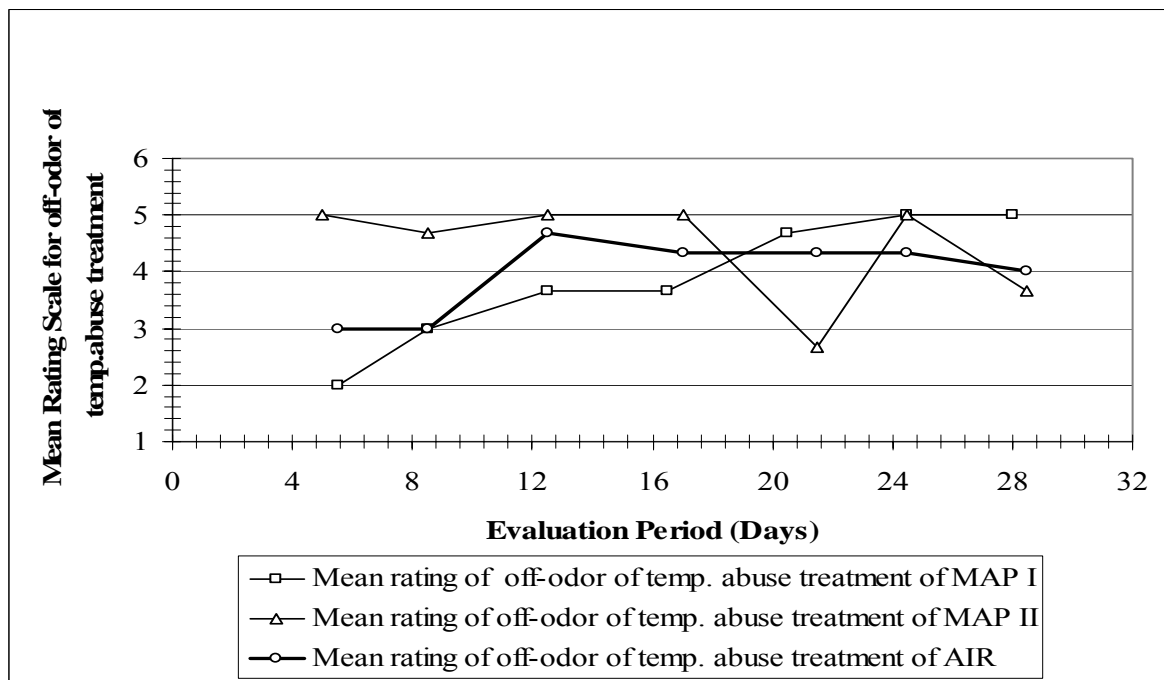


Figure 16. Mean rating scale of off-odor for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5°C with a temperature abuse of 2 days at 20 °C.

d. pH & Titratable Acidity:

The pH value of MAP I during the storage of 26.5 days at 5 °C varied between 6.29 on 6.5 day to 6.54 after 26 days. This sudden increase in pH after 26 days was unexpected and might have been caused by some experimental error. From 10.5 to 18.5 days pH was nearly constant around 6.36, while the pH of MAP II varied between 6.39 and 6.48 during its storage period. AIR treatment showed pH values between 6.3 to 6.4. It is evident that AIR showed a gradual increase in its pH value over its period of storage (Fig. 17). The statistical analysis showed a significant difference ($p \leq 0.05$) between the mean of the pH value of MAP II with the mean of the pH value of MAP I and AIR treatments, while there was no significant difference ($p \leq 0.05$) between the means of pH values of MAP I and AIR treatment (Table 12). The average pH value of freshly harvested green-shelled common beans was 6.45 and standard error of 0.023. Hence, the pH of all three treatments remained within the range of the pH of freshly harvested green-shelled common beans, suggesting none of the treatments had an adverse effect on the pH of the green-shelled common beans.

Figure 18 represents the mean pH values of all the three treatments stored at 5°C with a temperature abuse of two days. Between 3.5 + 2 days (i.e. 5.5 days) of temperature abuse to 10.5 + 2 days (i.e. 12.5 days) of temperature abuse, an increase in pH values was observed for all treatments and there-after, all three treatments showed a decreased in pH when compared with their respective treatment stored at 5 °C. However, the statistical analysis ($p \leq 0.05$) showed that the mean pH of all three treatments when compared with their respective treatments remained almost the same (Table 12). The statistical analysis of the temperature abuse treatments showed a significant difference ($p \leq 0.05$) between the

mean of the pH value of MAP II with the mean of the pH value of MAP I and AIR treatments, while there was no significant difference ($p \leq 0.05$) between the means of pH values of MAP I and AIR treatment (Table 12).

Table 12. pH values for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] stored at 5 °C for 26.5 days and with a temperature abuse for 2 days at 20 °C.

Treatments	Mean pH value of treatments stored at 5 °C	Mean pH value of treatments for temperature abuse at 20 °C
MAP I	6.36a(a)	6.35a(a)
MAP II	6.42b(a)	6.42b(a)
AIR	6.36a(a)	6.33a(b)

Means within a column followed by same letter are not significantly different ($p \leq 0.05$). Means within a row followed by same letter within parentheses are not significantly different ($p \leq 0.05$).

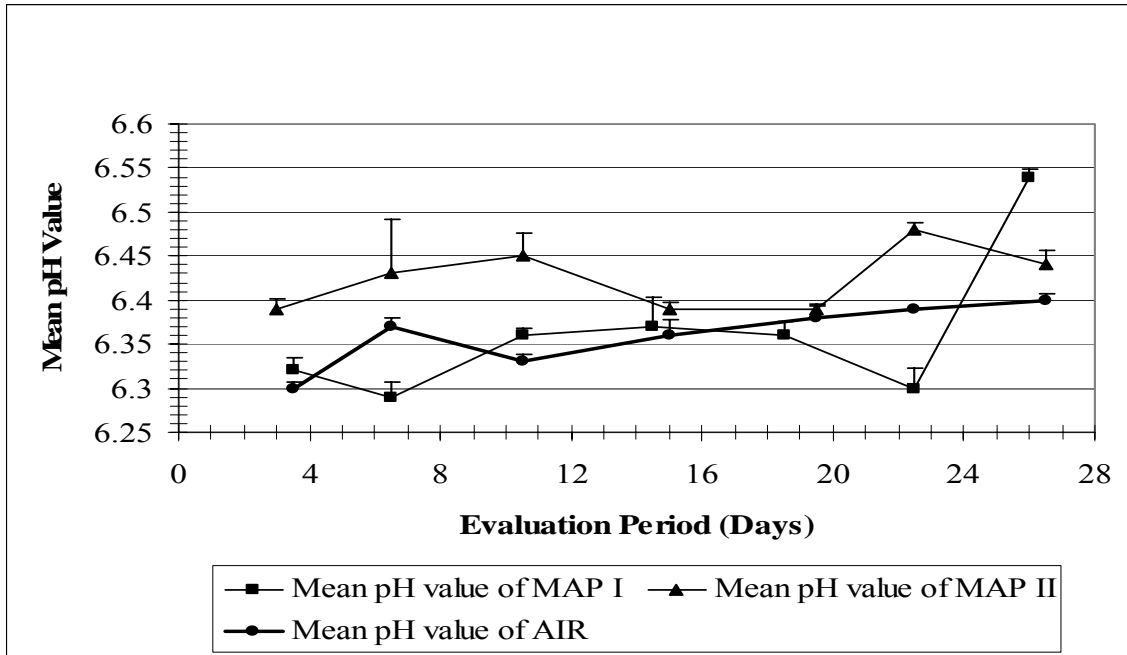


Figure 17. Mean pH values for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C. The vertical bars represents standard error of the mean.

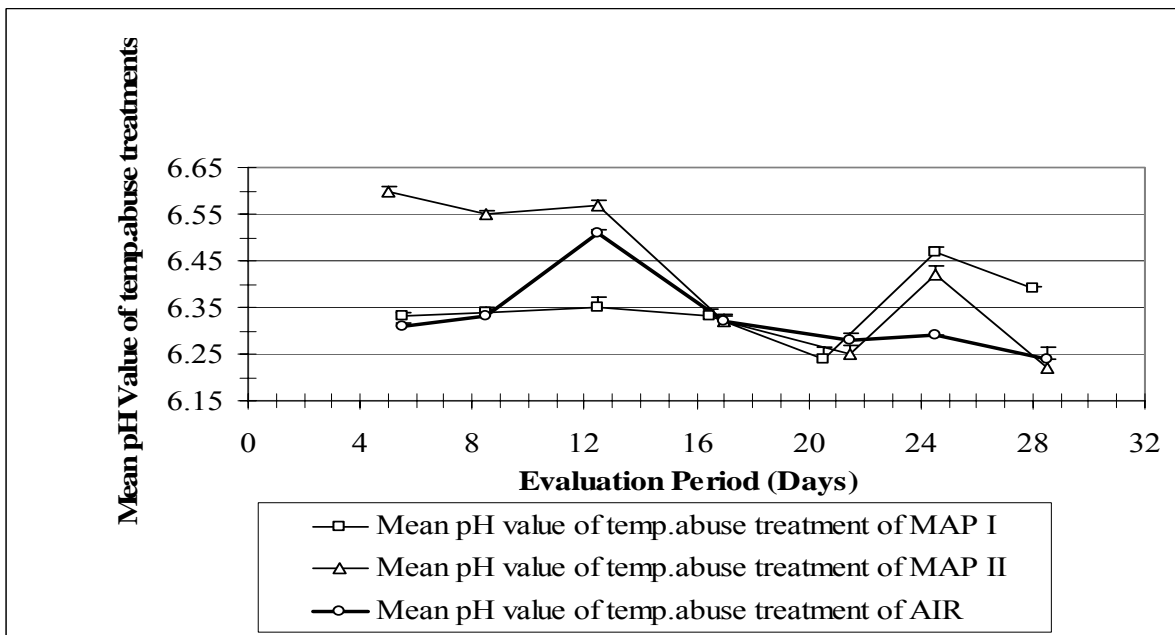


Figure 18. Mean pH value for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C with a temperature abuse of 2 days at 20 °C. The vertical bars represents standard error of the mean.

The titratable acidity of MAP I increased gradually during the storage period of 26 days (Fig. 19), from 6.5 days with a titratable acidity of 0.096% to 22.5 days with a titratable acidity of 0.148% while decreasing to 0.127% after 26 days. MAP I showed an initial titratable acidity of 0.109 after 3.5 days. The titratable acidity of the AIR treatment showed more or less the same trend as MAP I until 10.5 days, and maintained almost constant titratable acidity of 0.115% from 10.5 to 19.5 days, with a slight increase of 0.01% at 22.5 and 26.5 days. While the titratable acidity of MAP II increased from 0.118% after 3.5 days to 0.131% after 15 days. It demonstrated a sharp decline and increase between 19.5 to 26.5 days. The average titratable acidity of the freshly harvested green shelled common beans was 0.10 and a standard error of 0.004. Cano *et al.* (1998) reported the titratable acidity of fresh green beans to be 0.12% with a plus and minus of 0.01%, this study's findings of the titratable acidity of freshly harvested green-shelled common beans are similar. The mean titratable acidity of MAP I did not show any significant difference ($p \leq 0.05$) with the mean titratable acidity of MAP II and AIR, while there was a significant difference ($p \leq 0.05$) between the mean titratable acidity of MAP II and AIR treatments (Table 13).

The temperature abuse for two days of all three treatments showed consistent increase in the titratable acidity between 0.01 to 0.04% demonstrating the fact that a temperature abuse of fresh common beans increases its titratable acidity. It was evident from the statistical analysis of the temperature abuse treatments that there was no significant difference ($p \leq 0.05$) between the mean titratable acidity of MAP I and MAP II, while they were significantly different ($p \leq 0.05$) from the mean titratable acidity of AIR treatment (Table 13). But all three treatments did not show any significant difference

($p \leq 0.05$), with the mean titratable acidity of their respective temperature abuse treatment (Table 13).

Table 13. Percentage of titratable acidity for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] stored at 5 °C for 26.5 days and with a temperature abuse for 2 days at 20 °C.

Treatments	Mean % of titratable acidity of treatments stored at 5 °C	Mean % of titratable acidity of treatments for temperature abuse at 20 °C
MAP I	0.12ab(a)	0.13b(a)
MAP II	0.14b(a)	0.13b(a)
AIR	0.11a(a)	0.12a(a)

Means within a column followed by same letter are not significantly different ($p \leq 0.05$). Means within a row followed by same letter within parentheses are not significantly different ($p \leq 0.05$).

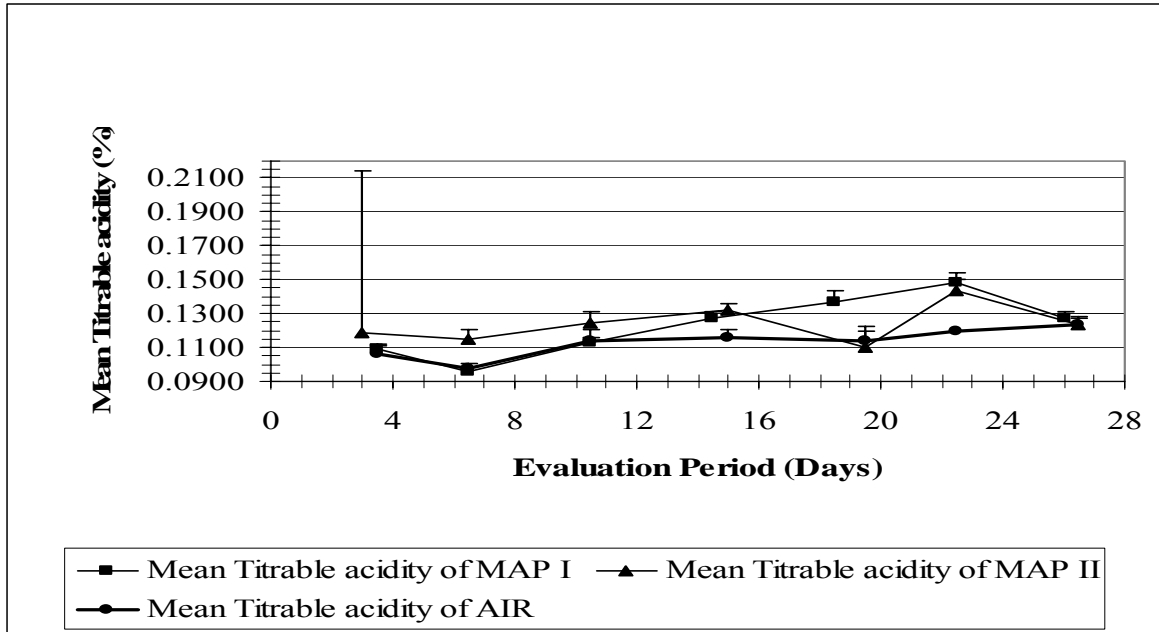


Figure 19. Mean percentage of titratable acidity value for 3 gas combinations [1] 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C. The vertical bars represents standard error of the mean.

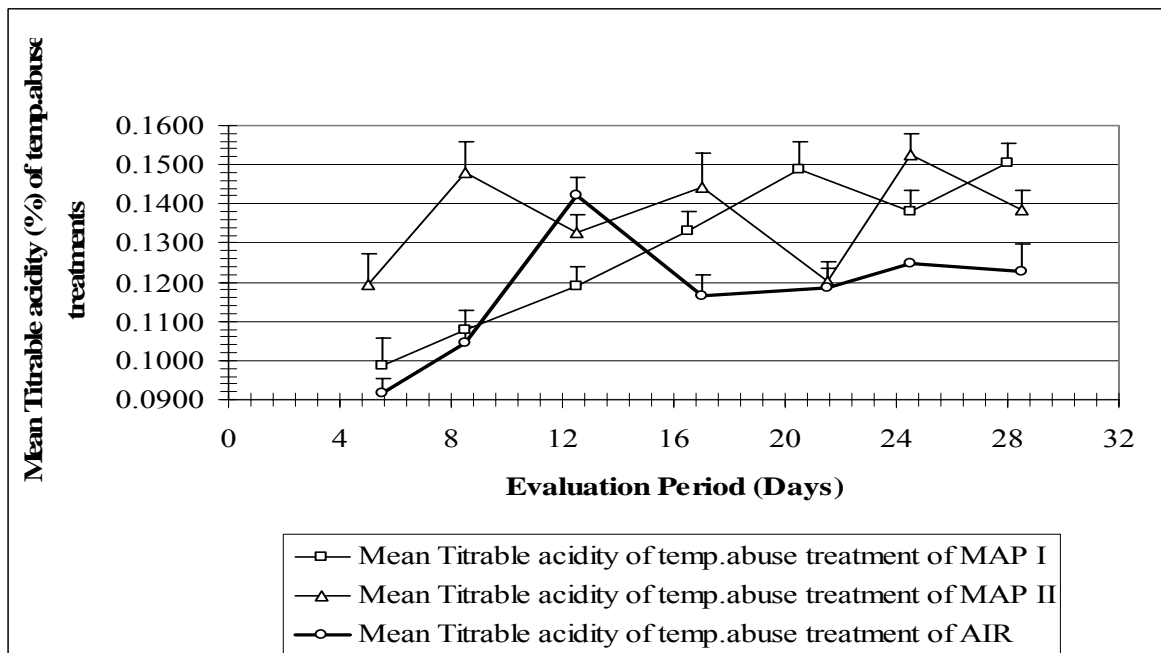


Figure 20. Mean percentage of titratable acidity for 3 gas combinations [1] 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C with a temperature abuse of 2 days at 20 °C. The vertical bars represents standard error of the mean.

e. Texture Analysis:

Texture was measured in terms of force (g) required to penetrate the green-shelled common beans, as it is the appropriate tenderness of these common beans that the consumer looks for when buying. All three treatments stored at 5 °C showed a negative slope during storage of 26.5 days, indicating that the green-shelled common beans became more tender during storage (Fig. 21). MAP I had the least negative slope and the average force it maintained over the storage period was 1026 g (Table 14). However, MAP I showed a sharp drop in the force required to penetrate the beans after 10.5 days to 934 g followed by a sharp increase after 14.5 days to 999 g. This sudden and unexpected drop may be due to the fact that the gases in the packages were filled manually. Differences in the gas volumes within the packages might have caused a variation in the texture. Alternatively, as the beans being of mixed maturity and randomly packed, after mixing properly, it could have happened that, the beans in the packages that were selected after 10.5 days might have been more tender compared to the beans in the packages that were selected after 14.5 days for the texture analysis. MAP II showed sharp drops and peaks in the force required to penetrate the core of the beans over the storage period, with the force varying between 930 g after 22.5 days to 1012 g after 6.5 days (Fig. 21). While the AIR treatment with the highest negative slope showed a gradual decrease in the force required to penetrate the beans, there was increase in force between 19.5 and 26.5 days (Fig. 21). Considering the fact that the average force required to penetrate the freshly harvested beans was 1030 g and a standard error of 7.29 g. The MAP I and AIR treatments maintained a good texture during their storage period. The statistical analysis showed that there was no significant difference ($p \leq 0.05$) between the

mean force of MAP I when compared with the mean force of MAP II and AIR but there was a significant difference ($p \leq 0.05$) between the mean force of MAP II and AIR treatments (Table 14). Identical trends in the graphs were observed when the area under the curves of the average force required to penetrate the beans, was plotted for each day of analysis for each treatment stored at 5 °C (not shown).

When MAP I was kept for two days at 20 °C temperature abuse, the beans showed more tenderness on almost each day of analysis on average decreasing by about 29 g of force (Fig. 22). MAP II showed a slight decrease in tenderness (that is, the force required to penetrate the core increased) at 3.5 + 2 days (i.e. 5.5 days), 15 + 2 days (17 days) and 19.5 + 2 days (21.5 days), with an increase of about 20 g of force, while other days showed an increase in tenderness with a decrease of about 28 g of force (Fig. 22). The AIR treatment showed a slight decrease in tenderness until 10.5 + 2 days (12.5 days), and an increase of about 16 g force required to penetrate the core, after 15 + 2 days (17 days) and 19.5 + 2 days (21.5 days), while on the remaining days it showed a decrease of about 38 g of force, thereby, more tender beans (Fig. 22). Tenderness of the green-shelled common beans remained good, as long as they did not get spoiled, in the sense that they were more easy to cook. Hardness increases cooking time of fresh beans. With the temperature abuse, all three treatments showed an increase in tenderness around 15 + 2 days (17 days) coupled with stickiness, indicating the presence of spoilage microflora. However, the statistical analysis of all three treatments, with their respective temperature abuse treatments showed no significant difference ($p \leq 0.05$) between their mean force (Table 14). The statistical analysis of the temperature abuse treatments showed that there was no significant difference ($p \leq 0.05$) between the mean force of MAP I when compared

with the mean force of MAP II and AIR, but there was a significant difference ($p \leq 0.05$) between the mean force of MAP II and AIR treatments (Table 14).

Table 14. Texture in terms of mean force (g) required to penetrate the core of the green-shelled common beans for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] stored at 5 °C for 26.5 days and with a temperature abuse for 2 days at 20 °C.

Treatments	Mean force (g) of treatments stored at 5 °C	Mean force (g) of treatments for temperature abuse at 20 °C
MAP I	1026.60ab(a)	1011.06ab(a)
MAP II	1008.20a(a)	1000.77a(a)
AIR	1033.97b(a)	1034.45b(a)

Means within a column followed by same letter are not significantly different ($p \leq 0.05$). Means within a row followed by same letter within parentheses are not significantly different ($p \leq 0.05$).

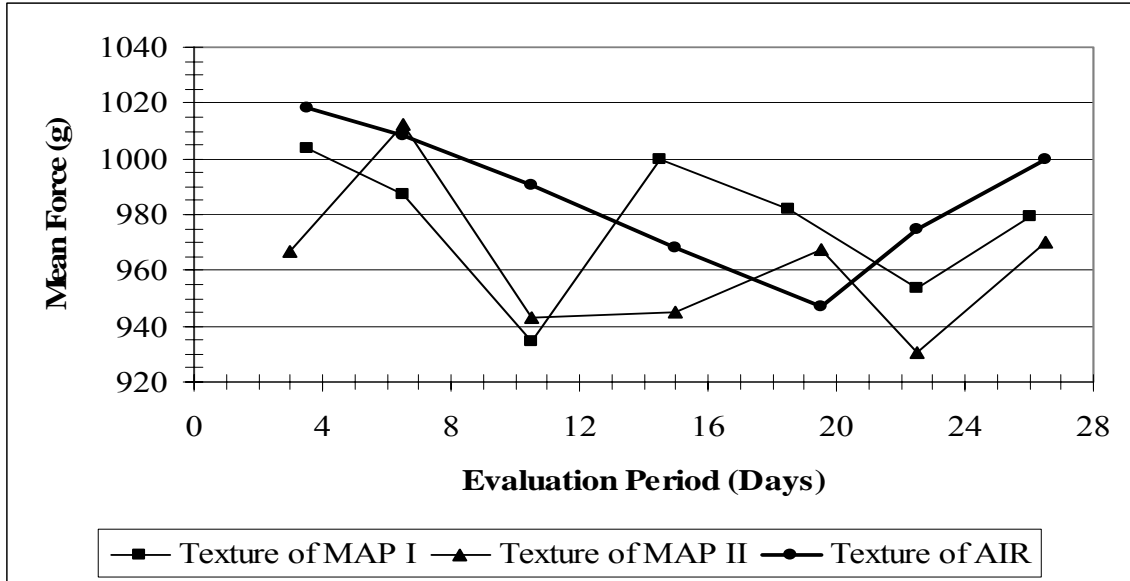


Figure 21. Texture in terms of mean force (g) required to penetrate the core of the green-shelled common beans for 3 gas combinations [1] 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C.

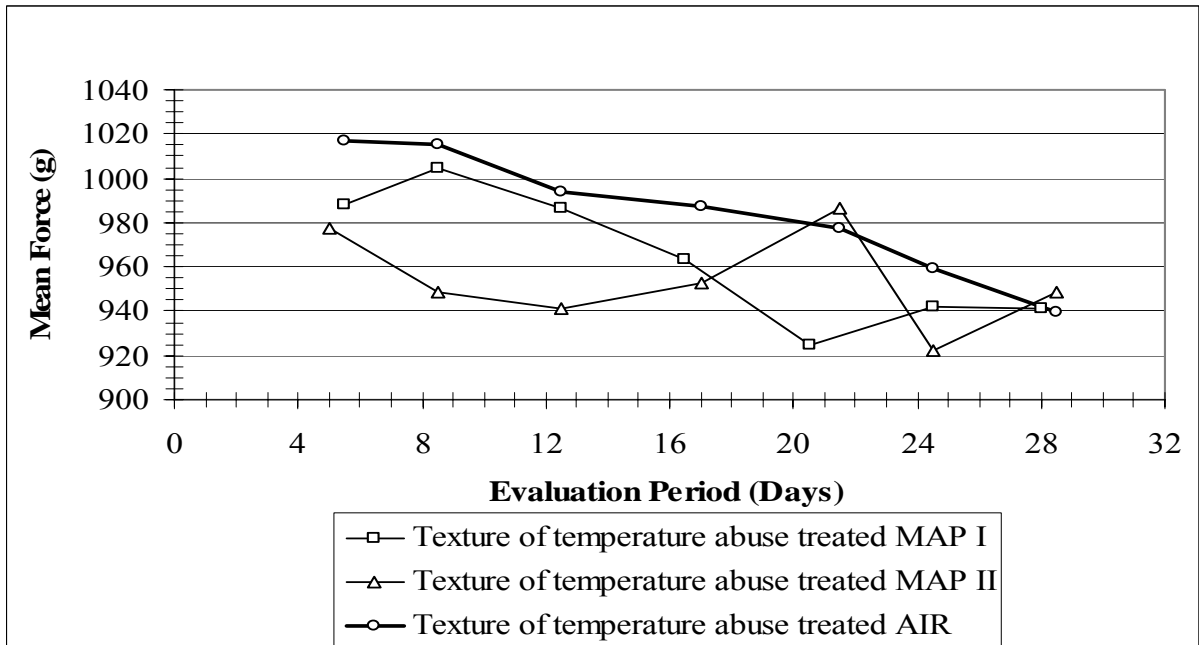


Figure 22. Texture in terms of mean force (g) required to penetrate the core of the green-shelled common beans for 3 gas combinations [1] 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] on each day of analysis stored at 5 °C with a temperature abuse of 2 days at 20 °C.

f. Water Activity:

The water activity in MAP I gradually decreased until the 14.5 day evaluation and increased back to the initial water activity that it had at 3.5 days (Table 15). MAP II showed an increase in water activity from 0.974 after 3 days to 0.984 after 26.5 days and the AIR treatment also showed an increase in the water activity from 0.973 after 3.5 days to 0.986 after 19.5 days and then decreasing back to around 0.98 after 26.5 days. However, the statistical analysis showed that there was no significant difference ($p \leq 0.05$) between the mean water activity which was 0.98, for all three treatments and did not change with their respective temperature abuses. Practically also it was observed that, the temperature abuse of all three treatments for 2 days at 20 °C did not show much of a change in the water activity, when compared with their respective treatments stored at 5 °C (Table 16).

Table 15. Mean water activity for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] stored at 5 °C on each day of analysis.

MAP I		MAP II		AIR	
Days	a _w	Days	a _w	Days	a _w
3.5	0.986	3	0.974	3.5	0.973
6.5	0.984	6.5	0.979	6.5	0.983
10.5	0.977	10.5	0.974	10.5	0.983
14.5	0.974	15	0.98	15	0.979
18.5	0.977	19.5	0.98	19.5	0.986
22.5	0.979	22.5	0.979	22.5	0.982
26	0.982	26.5	0.984	26.5	0.98

Table 16. Mean water activity for 3 gas combinations [1) 4% O₂, 10% CO₂ and 86% N₂ (MAP I), 2) 2% O₂, 5% CO₂ and 93% N₂ (MAP II) and 3) 21% O₂, 0.03% CO₂ and 78% N₂ control (AIR)] stored at 5 °C and with a temperature abuse for 2 days at 20 °C on each day of analysis.

MAP I		MAP II		AIR	
Days	a _w	Days	a _w	Days	a _w
5.5	0.983	5	0.977	5.5	0.984
8.5	0.982	8.5	0.979	8.5	0.975
12.5	0.978	12.5	0.97	12.5	0.977
16.5	0.976	17	0.978	17	0.982
20.5	0.97	21.5	0.982	21.5	0.983
24.5	0.979	24.5	0.979	24.5	0.981
28	0.98	28.5	0.98	28.5	0.98

Computational Model for Prediction of Time Evolution of Gases Within MAP.

The time evolution of the percentage of oxygen and carbon dioxide gases inside the package for three different cases of MAP of Burlat cherries were predicted by numerically solving the model equations presented earlier. The computer program to solve the equations was written in FORTRAN 90. The values for various parameters, as required by the computer program for three cases, are provided in Table 18. These cases were taken from the study by Salvador *et al.* (2002) and their results were used to assess the numerical results obtained here. The time evolutions of percentage of gases inside the package as obtained by present numerical work are presented in Figs. 23, 24 and 25. In these figures, experimental results of Salvador *et al.* are also presented.

In Case 1, the amount of oxygen that permeated through the film was not sufficient to balance the consumption of oxygen by the cherries and, consequently, the percentage of oxygen continued to decrease (Fig. 23). The carbon dioxide concentration reached a maximum from the initial increase and then started to decrease. The initial increase was due to the high rate of production of carbon dioxide, as more oxygen was available inside the package and the amount of carbon dioxide permeating out was not sufficient to balance this production. The present results compare fairly well with the numerical results of Salvador *et al.* (2002) and follow the same trend as they obtained. To assess the computer program further, two more cases were considered. Results obtained in Case 2 and Case 3 are shown in Figs. 24 and 25, respectively. These results properly captured the trend in evolution of concentrations of oxygen and carbon dioxide and were in fair agreement with numerical results of Salvador *et al.* (2002). To show an example of comparison for assessment purposes, values of the concentrations of oxygen and carbon

dioxide at time 200 h from the present work and numerical results of Salvador *et al.* (2002) are shown for all three cases in Table 18. The difference between the present results and those of Salvador *et al.* (2002) was due to the fact that in the present numerical work, water transpiration was not considered.

In view of the above, it was clear that the computer program predicted fairly acceptable results. The program can be further improved by including water transpiration. The same program can be used to predict evolution of concentrations of various gases in the MAP of green-shelled common beans. This would help in selecting suitable values for the parameters for MAP as listed in the first column of Table 17. Before using the computer program, one of the main requirements is to obtain the maximum respiration rate V_m and Michaelis-Menten constant.

Table 17. Input quantities for three cases of MAP of Burlat cherries.

Description	Values		
	Case 1	Case 2	Case 3
Universal gas constant (atm lit)/(mol K)	0.082050	0.082050	0.082050
Atmospheric pressure (atm)	1.0	1.0	1.0
Gas temperature (K)	278.15	278.15	278.15
Initial % of Oxygen inside the package	20.0	0.0	0.0
Initial % of Carbondioxide inside the package	10.0	20.0	20.0
Initial % of Nitrogen inside the package	70.0	80.0	80.0
Head space volume (lit)	0.3	1.5	1.5
Weight of cherries (kg)	0.3	0.3	0.3
($P_{O_2} \cdot A/x$) (mol/hr-atm)	0.00003278	0.00006184	0.00015019
($P_{CO_2} \cdot A/x$) (mol/hr-atm)	0.00015702	0.00029620	0.00071933
($P_{N_2} \cdot A/x$) (mol/hr-atm)	0.00003278	0.00006184	0.00015019
Maximum respiration rate O_2 mol/(kg-h)	0.001760	0.000409	0.000409
Michaelis-Menten Constant (atm)	0.710000	0.11	0.11
Partial pressure of Oxygen outside the package (atm)	0.2095	0.2095	0.2095
Partial pressure of CO_2 outside the package (atm)	0.0003	0.0003	0.0003
Partial pressure of Nitrogen outside the package (atm)	0.7902	0.7902	0.7902

Table 18. Comparison of values of the concentrations of oxygen and carbon dioxide in percentage at time 200 hrs by the computer program and numerical results of Salvador *et al.* (2002).

Description	Concentration determined by computer program		Concentration determined by numerical results of Salvador <i>et al.</i> (2002)	
	% O_2	% CO_2	% O_2	% CO_2
Case 1	1	7	3	7.9
Case 2	1.2	10.68	2.1	7
Case 3	3.04	5.22	5.8	3

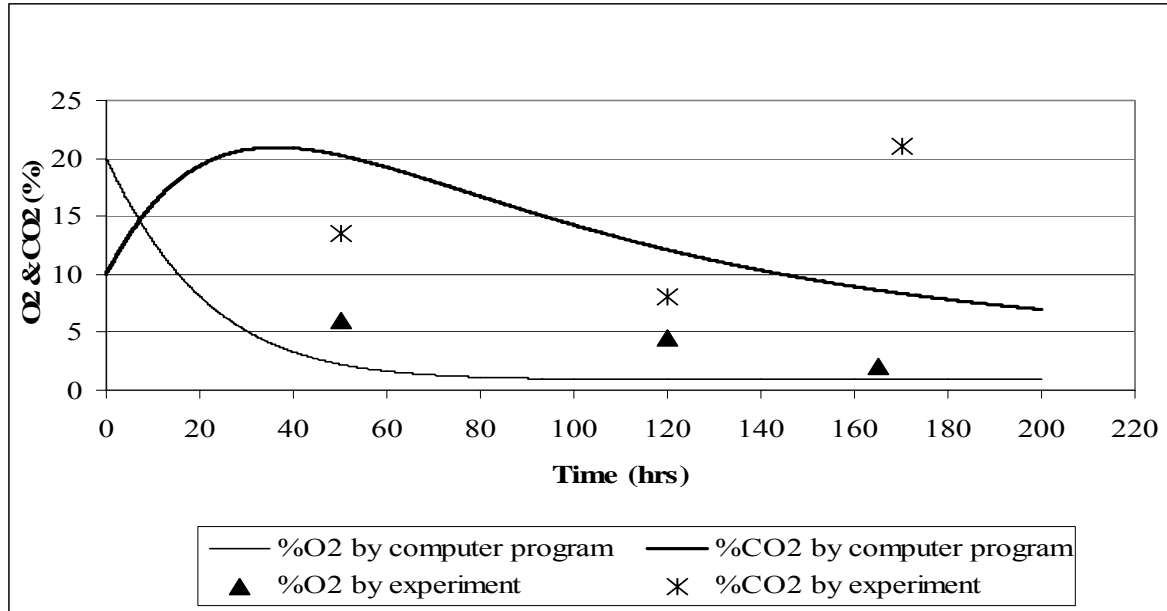


Figure 23. Change in the percentage of O₂ & CO₂ in the MAP of Burlat cherries using an initial gas mixture of 20% O₂, 10% CO₂ and 70% N₂ stored at 5 °C, plotted using the computer program and the experimental data of the research paper of Salvador *et al.* (2002) (Case 1).

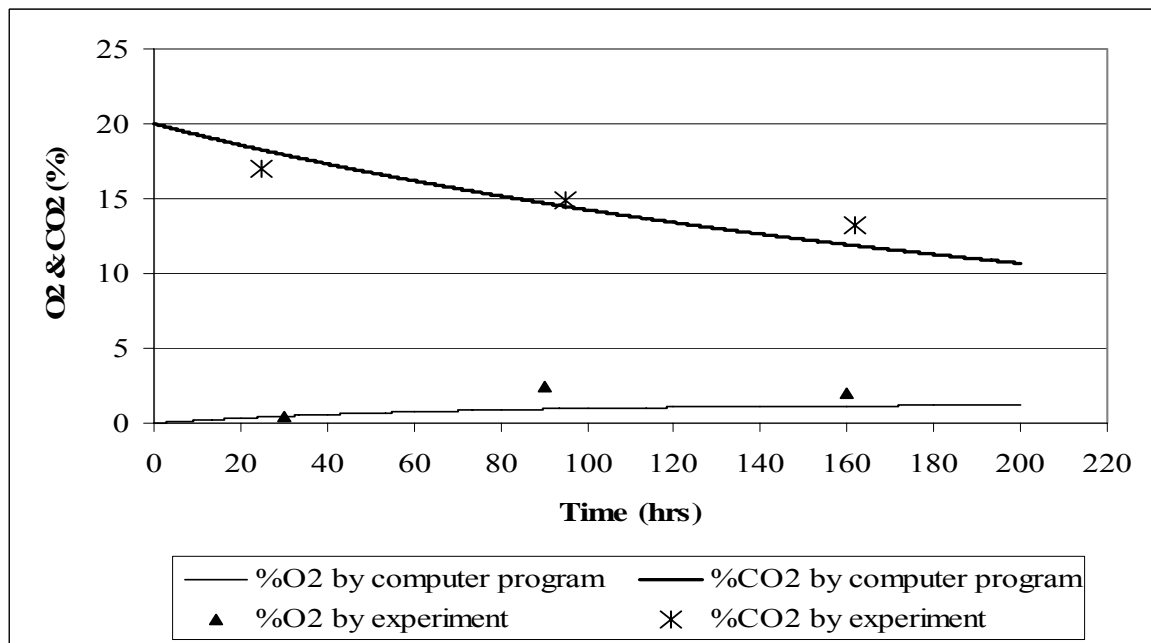


Figure 24. Change in the percentage of O₂ & CO₂ in the MAP of Burlat cherries packed in film A, using an initial gas mixture of 0% O₂, 20% CO₂ and 80% N₂ stored at 5 °C, plotted using the computer program and the experimental data of the research paper of Salvador *et al.* (2002) (Case 2).

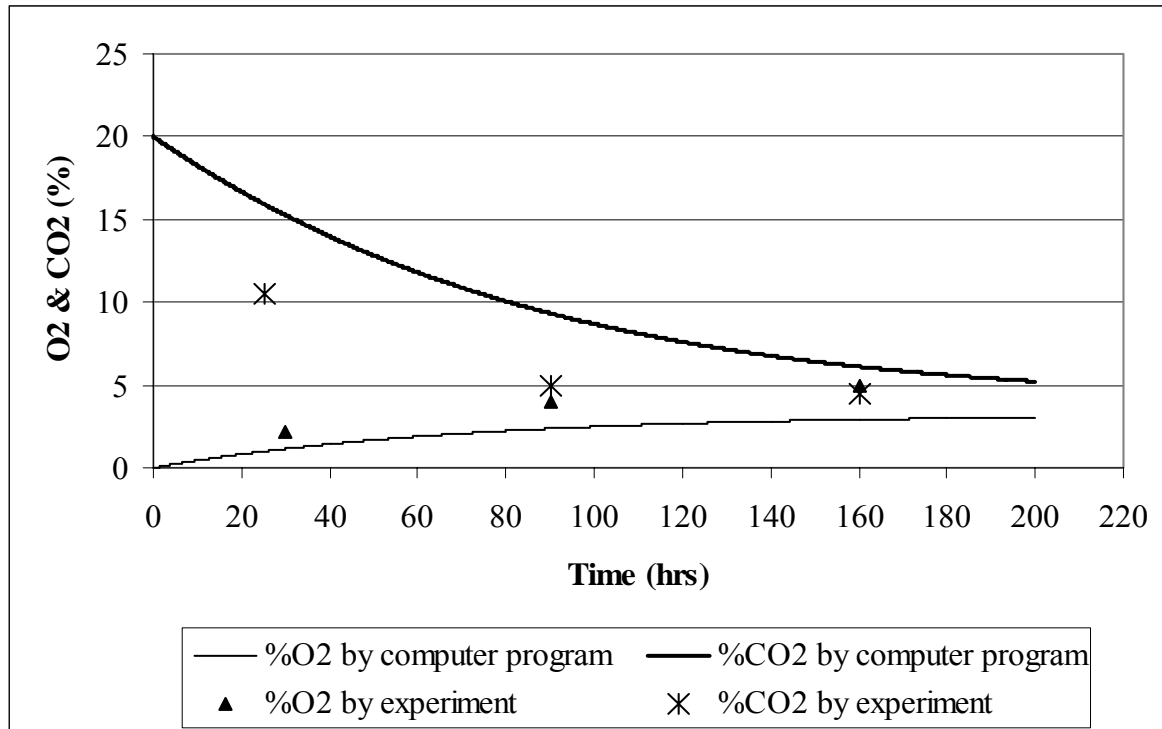


Figure 25. Change in the percentage of O₂ & CO₂ in the MAP of Burlat cherries packed in film B, using an initial gas mixture of 0% O₂, 20% CO₂ and 80% N₂ stored at 5 °C, plotted using the computer program and the experimental data of the research paper of Salvador *et al.* (2002) (Case 3).

Conclusion

The average respiration rates of green-shelled common beans were found to be 15.94, 48.88, 73.95, 123.92 mg CO₂/kg*hr at 5, 10, 15 and 24 °C, respectively. Both AIR and MAP I (4% O₂, 10% CO₂ and 86% N₂), proved to be good packaging atmospheres at a storage temperature of 5 °C for the common beans, maintaining their color, texture, desirable odors within the package, pH, titratable acidity and water activity, similar to freshly harvested green-shelled common beans. However, AIR had a shelf-life of about 10 days at 5 °C since the %CO₂ increased to 10% within the package by 3.5 days, after packing and thereafter, fluctuated between 9.5 to 12%, which led to the formation of a fermented off-odors and souring. The gas mixture of 4% O₂, 10% CO₂ and 86% N₂, maintained the original %CO₂ of 10%, thereby, delaying the fermented off-odors and sour taste. Hence, the shelf-life increased by 8 days more than the AIR package, having a total shelf-life of 18 days. It should be noted that there was not much change in color, texture, pH, titratable acidity or water activity during the storage period of 26.5 days at 5 °C. However, the off-odors and taste of the beans played a major role in determining the shelf-life of the green-shelled common beans. Temperature abuse of any of the treatments, whether AIR or the gas mixture of 4% O₂, 10% CO₂ and 86% N₂, is not recommended, as it shifted the fermented off-odors within the packages to a rotten odors, producing a softer texture and sticky to the touch. This was probably due to an increases in the spoilage microorganisms, which could have been from the increase of %CO₂ within the packages. However, the gas mixture of 4% O₂, 10% CO₂ and 86% N₂ showed more tolerance to temperature abuse, with 3.5 days of storage at 5 °C + 2 days of abuse at 20 °C, yet temperature abuse is never recommended. Thus, modified atmosphere

packaging, coupled with appropriate storage temperature, increased the shelf-life of the green-shelled common beans, maintaining their overall quality when compared to the AIR package. Modified atmosphere packaging (MAP) is tailor-made for every fruit and vegetable. However, for modified atmosphere packaging (MAP) to work properly, one should begin with high quality plant products, use the appropriate gas mixtures, choose packaging material with the proper packaging dimensions and an appropriate storage temperature. Modified atmosphere packaging (MAP) maintains the initial quality of the plant product and does not enhance the quality.

Further more, there is a need to develop better computational models of MAP situation for accurate prediction of the physiological changes taking place within the package. This would help prevent time consuming, large-scale experiments to obtain suitable values of the parameters involved in MAP. The computer program developed, based on the model equations of Salvador *et al.* (2002), can be used to narrow down the range of suitable values for the parameters involved. The predictions of the computer program for three different cases of MAP of Burlat cherries was in fair agreement with the experimental results of Salvador *et al.* (2002). The accuracy of the computer program depends on an accurate description of the respiration rate through the model equation (6). There is a need to further assess the program against reliable experimental data and to properly obtain model parameters V_m and K_m values as a function of temperature in the case of beans.

Suggestions for Future Work

- The changes in O₂ within the package should be monitored, as it would give a better picture of how the gas mixture within the package varies.
- A plastic film with higher CO₂ permeability and water transmission might give better results.
- Determination of acetaldehyde and ethanol concentrations should be conducted, as they can cause fermented off-odor within the packages.
- Microbiological analysis should be conducted, in order to determine if microorganisms contributed to the fermented odor within the package.
- Sensory analysis would provide a better perspective of the actual shelf-life of the green-shelled common beans.
- Further validation of the computational program should be done using reliable experimental data.

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