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Storage logistics of fruits and vegetables: effect of temperature

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The main objective of this study is to minimize the losses of fruits and vegetables that happen during its storage, using mathematical models to optimize the products distribution in deposit and to minimize costs referring to the storage of these products. The mathematical model for optimization used a mixed integer linear programming (MILP) formulation. It was implemented in the software GAMS® and the solver used was CPLEX®. Simulations were conducted considering various temperatures of storage and the same cost of U$ 1.00 for every analyzed product, aiming to minimize the costs relating to its storage. Starting from values of keeping quality of the products and considering two storage zones (refrigerating chamber and external deposit) it was possible to proceed an analysis in relation to keeping quality of each product in function of the temperature. The results showed that the more distant the real storage temperature of a product is of its ideal temperature, the greater the costs with the loss of quality of this product. It was verified that the cost relating to the loss of quality of products has great influence on the total storage cost. It shows the importance of optimizing the storage logistics of these products, so that these costs are not still more expressive, what certainly occur without a tool for that. It was also verified the order of products priority to occupy the chamber. The results showed that it depends on the temperature, but fruits as grape and plum have larger priority in majority combinations of temperatures, followed by peach and strawberry. Papaya, bell pepper, tomato and cucumber have great variation in its priority and for smaller chamber temperatures (T_c), the products with smaller priorities were cucumber and tomato, but for larger T_c were cauliflower and celery. In that way, the proposed model comes as a tool that can help distribution centers managers in taking decisions referring to the logistics of storage of fruits and vegetables in order to minimize total costs and losses of the sector.

1. Introduction

The Brazilian horticulture has a production value of approximately 6.5 billion dollars, higher than the value of agriculture of grains and oilseeds in the country. This is the agriculture sector that has the higher growth in the world (Gutierrez, 2001).

The Brazilian production of vegetables in 1998, reached about 11 million tons, occupying an area of more than 778 thousand hectares. In order of economic

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importance, highlighted in the Brazilian production of vegetables: tomatoes (23%), potatoes (23%), onion (8%) and carrot (6%) (Vilela and Henz, 2000).

Despite this great importance in the country's economy, the production line do not go through controls that would be essential to maintain the quality of products, such as maintaining the cold chain during transportation and storage. According to Gutierrez (2001), in Brazil, the cooling, as a method of keeping the quality of fresh fruits and vegetables during transport, storage and exposure to the consumer, is rarely adopted and misused. This contributes to the high post-harvest losses of vegetables in the country, which, for some products reach 50% of what is produced (Chitarra and Chitarra, 2005).

To get an idea of the size of this problem in the country, in 2001, were harvested 15 million tons of vegetables, and more than 5 million tons were lost, enough to supply 53 million people and generate a loss more than US$ 1 million (Vilela et al., 2003).

According to Vilela and Henz (2000), the participation of supermarkets in vegetables sale in the country that year, represented approximately 30%, with an average annual growth of 3%, which shows the importance of this segment in these products trade.

It is known that the management of a deposit of fruits and vegetables is more complex than a deposit of processed products as the first ones need rapid commercialization and special conditions of storage to reduce its loss of quality, because it reflects in reduction of its commercial value. Furthermore, the deposit of a supermarket has restrictions, such as its physical space, and it is impossible and impracticable to create an environment with specific conditions to store each variety of a product.

The aim of this study, therefore, was to develop a mathematical model capable of optimizing the distribution of products in supermarkets deposit such that the sum of the costs involved is minimal, respecting the restrictions of storage, to try to improve the current situation of storage of fruits and vegetables in Brazil.

2. Mathematical Description of the Model

To develop the mathematical model were needed some data describing the physical space available, the volume of product to be stored, the conditions under which products must be kept and the location of these within the deposit. Knowing this information, it was possible to determine which is the area in the accommodation of the deposit, with specific conditions of storage that a product should take. This area was called the "zone" by Broekmeulen (1998). In a supermarket deposit there are basically two areas, the external deposit, subject to room temperature, and the refrigeration chamber, maintained at a pre-established temperature.

Three assumptions were considered. The first one is that the storage time and temperature are the only storage conditions that influence the reduction of keeping quality of products. The second is that the storage temperature depends on the zone. And the last one is that the stock levels and the models of keeping quality change are known for all products.

Define the decision variable x_{ij} (binary variable) for all $i \in P$ and $j \in Z$:

$$\begin{cases} x_{ij} = 1 \text{ if the product } i \text{ is designed to zone } j \\ x_{ij} = 0 \text{ in any other case} \end{cases}$$

Thus, the problem may be placed in the form of a mixed integer linear programming (MILP). Then, the problem is to find a plan for distribution of fruits and vegetables that minimizes the cost function (*C*) given by:

$$C = \sum_{i \in P} \sum_{j \in Z} \frac{c_i . s_i}{d_{ij}} x_{ij} + \sum_{i \in P} \sum_{j \in Z} \frac{b_{ij} . c_i . s_i}{d_{ij}} x_{ij} + \sum_{i \in P} \sum_{j \in Z} \frac{q_{ij} . c_i . s_i}{d_{ij}} . x_{ij} + \sum_{j \in Z} a_j . S_j \tag{1}$$

and fulfilling the following restrictions:

1. Each product can be assigned to only one specific zone.
2. The storage capacity of the zone can not be exceeded.
3. The time that the product *i* stays in zone *j* can not exceed the keeping quality of this product.

2.1 Discussion of the Model Parameters

The cost function (*C*) depends on several factors, the parameters of the model. The set *P* includes all fruits and vegetables studied and each receives an index *i*. The set of zones (*Z*) encompasses all zones *j*, each with specific conditions and a physical capacity of storage (S_j).

The parameter a_j is the storage cost of zones. Keep a cold chamber required to spend extra energy. For this reason, the costs to the storage the deposit and the cold chamber is different. The percentage of products loss (b_{ij}) depends on many factors such as transport, handling of the products and inadequate storage, which added, lead to loss of the products. The acquisition cost of the products (c_i) is the price paid per kilo or unit of the product. The parameter d_{ij} is the time that the product is stored, which was considered equal to a day for all products.

Another parameter of the model is q_{ij} (fraction of the original quality that is lost when compared with the storage in ideal conditions for a product). This parameter is obtained through the following relationship:

$$q_{ij} = 1 - \frac{KQ_{ij(real)}}{KQ_{i(ideal)}} \tag{2}$$

where $KQ_{ij(real)}$ and $KQ_{i(ideal)}$ is the keeping quality of product *i* in the real storage temperature and the keeping quality of product *i* in its ideal temperature, respectively.

Tijskens and Polderdijk (1996) developed a useful formulation for calculating the keeping quality of fruits and vegetables. They showed that the keeping quality is proportional to the inverse of reaction rate *k*, independent of the kinetic mechanism of the loss of product quality. Thus, it is possible to describe the behavior of keeping quality as a function of temperature. To Labuza (1984), the reactions of loss of quality of food can be described by the Arrhenius Law, where specific reaction rates depend on temperature. The reaction rate *k* can be approximated by this Law:

$$k = k_{ref} e^{\frac{E_A}{R}\left(\frac{1}{T_{ref}} - \frac{1}{T_{abs}}\right)} \tag{3}$$

In many fruits and vegetables, the quality attribute, which limits consumers acceptance, changes of an attribute in one temperature to some other attribute in other temperature. This can be seen, for example, in cold sensitive products. In tomatoes, for example, kept at constant temperatures below 8 °C, the limiting factor is usually color, but when the temperature is above 13 °C, the limiting factor is firmness.

The keeping quality proposed by Tijskens and Polderdijk (1996) under constant conditions, may be represented by:

$$KQ = \frac{KQ_{ref}}{\sum_{n=1}^{N} k_{ref(n)} e^{\frac{E_{A(n)}}{R}\left(\frac{1}{T_{ref}} - \frac{1}{T_{abs}}\right)}} \tag{4}$$

where N is the process number that contribute to the keeping quality, which normally is not greater than two. The value of $k_{ref(1)}$ (reaction rate of the first component in the reference temperature) is equal to one.

Assuming $k_{ref(1)}$ equal to one, statistical analysis was made possible without the need for information on the type of quality function. Moreover, the expression for the keeping quality becomes almost independent of the type of kinetic mechanism involved.

The loss of product quality is usually measured by analysis of one or more parameters which may be physical, chemical, microbiological or sensorial (Taoukis and Labuza, 1989). It is possible to determine the keeping quality of a product at a reference temperature (KQ_{ref}) using methods for assessing quality, which may be measurement of color and firmness, for example (Mitcham et al., 1996).

This method is generic and applicable to products of moderate and tropical areas. This model can be used, therefore, to predict the keeping quality of fruits and vegetables stored in a supermarket. The proposed equation was implemented in the software GAMS® and many optimizations were made leading into account different temperatures to the cold chamber and for the deposit and different quantities of products purchased by the supermarket, using the CPLEX® solver.

3. Results and Discussion

Optimizations were performed using Equation (1) and the restrictions, taking into account different temperatures for zones and different quantities of products purchased by the supermarket. Initially, the values of $KQ_{ij(real)}$ and $KQ_{i(ideal)}$ were obtained using Equation (4) and data estimated by Tijskens and Polderdijk (1996). It was found that for products with a number of process equal to one ($N = 1$) the keeping quality increases as temperature decreases. However, for products with number of process equal to two ($N = 2$), both in low as in high temperature, the keeping quality is small and increases as it approaches the ideal temperature of storage.

From these data was obtained the change of the quality factor, q_{ij}, with the temperature by Equation (2). The calculated results are shown in Figure 1, whereas the ideal temperature of storage of papaya is 12 °C, of tomato and cucumber is 14 °C, of pepper is 7.5 °C and of other products is 0 °C.

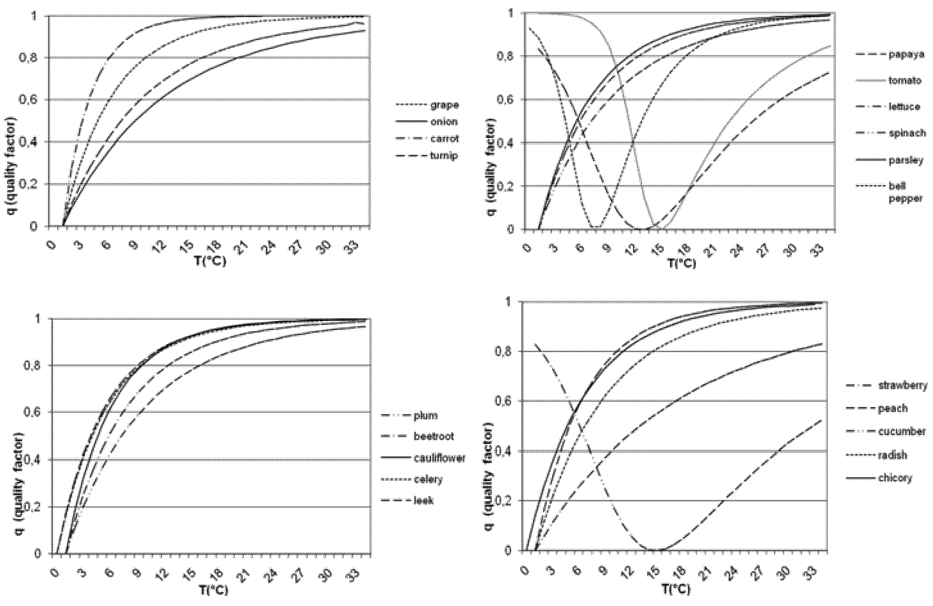

Figure 1. Change in quality factor of products with temperature.

The analysis of results shows that when the real storage temperature of each product is equal to its ideal temperature, $q_{ij} = 0$, there is no cost to the loss of quality of this product.

The maximum value of q_{ij} is 1 and the higher its value, more distant of ideality a product is stored and the greater the costs for its loss of quality.

The priority order of the studied products to stay in the cold chamber was also evaluated. For that, it was considered that the amount of each product was equal a box and the capacity of the chamber was increased one by one box to see what would the first product in the chamber. This procedure was performed for many combinations of chamber temperature (T_c) and stock temperature (T_e), with T_c of 5 °C to 15 °C and T_e of 10 °C to 33 °C, both ranging from one by one degree. The price paid for each product used in these optimizations was U$ 1.00 for all products.

Analyzing the results, it was observed that the grape, the first in order of priority in lower T_c, loses its place for the papaya, as T_c increases. The plum, peach and strawberry have its priority reduced because papaya and tomatoes pass to enter before in the chamber in higher T_c (T_c is approaching the T_{ideal} of these fruits).

The radish loses priority for the onion, bell pepper and cucumber, which pass to enter before in the chamber in higher T_c. The spinach lost its place to turnip and parsley to spinach, turnip and beetroot in higher T_c.

4. Conclusions

The proposed model is a tool that helps reduce the total cost of the establishment related to the storage of fruits and vegetables.

The equation proposed by Tijskens and Polderdijk (1996) was a useful tool to predict the keeping quality of the products in different storage temperatures.

It was found that the temperature in the chamber and the temperature of the stock significantly affect the order of priority to the products be in the cold chamber and that is very important to consider the keeping quality of each product in a certain temperature before deciding on the logistics of these products within the deposit.

The method is generic and therefore can be used as a tool to assist in decision making related to the logistics of storage of fruits and vegetables in supermarket.

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