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Postharvest Management and Marketing of Apples in Mexico

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Abstract

México produced 745,820 tons of apple fruit in 2020 and does not supply the national demand, so imports must be made. Apple production is from July to October in the year, the highest production is in September and is destined for national consumption. In the fresh market, the highest sale price is in July and August, but as of November the price drops. For that reason, the business producers use refrigeration. The refrigerators can be 1500 cubic meters or higher, and cooled with harmless gases to avoid damage to the atmosphere, the refrigerator must have a temperature of 3.3 to 3.9° C, a CO₂ concentration of less than 10% and a concentration of oxygen from 2.0 to 2.5%. In the region the best refrigerators use liquid nitrogen and can take out their apple slowly each month to supply the market at a better price. To keep the fruit in CA until January of the following year, to have prices higher than \$50 Mexican pesos per kilo (2.45 US dollars).

Keywords: refrigerants, control atmosphere, marketing

1. Introduction

Mexico has an area of 57,186 ha of apple tree, of which 43,200 ha are irrigated (75.5%), the production in 2020, was 745,820 tons, if the average apple consumption per capita is 8.8 kg [1], for that reason only 84,753 inhabitants had access to the national apple, which represents less than 1% of the population in Mexico [2], therefore there are production deficit of apple in Mexico, and the rest of the population would not have access to the apple in their annual diet, to supply this demand with the apple production of Mexico, the producers who select the apple sell it in the fresh market as rural development producers and those who select and refrigerate it to have a better price are business producers who are in the irrigated areas.

The biggest amount of apple in Mexico is imported from January to August of each year from the United States and Chile (**Figure 1**), the national production is only from August to December, very few producers make refrigeration storage to have apple until March. This causes greater apple imports, with capital flight and representing an increase in imports each year [3].

The apple is a climacteric fruit, after cutting the fruit rapid increase the respiration rate, in appearance it changes as softening, de-greening, wax accumulation and aroma

Figure 1.
Importation and exportation of apple in México.

production, inside the fruit increase the activity of organic acids, lipid, starch, sugar with reduced respiration with cuticle covers and cooling is the best way to known fruit storage potential [4].

Imports start from January, where most domestic production has already been sold and consumed. The varieties that enter by import are Red Delicious, Golden Delicious and Gala, are those that have had acceptance in the national market [5].

The apple harvest in Mexico begins in July until October and the highest production is in September (**Figure 2**), in this month if you want to store to have apple every month until March, you must have infrastructure of refrigeration rooms and only business producers have it and can get a higher sale price.

The state with the highest production, largest area and highest yield in Mexico, is the region of Cuauhtémoc and Guerrero in Chihuahua, a northern state of the country bordering the United States and the apple zone is on the mountain range of the Western Sierra Madre (**Table 1**), in this region of greater production is where

Figure 2.
Apple production in Mexico in months.

Entity	Superficies (ha)			Production (tons)	Yield (t/ha)
	Planted	Harvested	Sinister		
Chihuahua	33,936.25	32,429.75	0	627,603.13	19.35
Puebla	7499.00	6487.90	0	34,557.23	5.33
Durango	6577.04	6473.09	0	7085.20	1.09
Coahuila	5802.00	5725.00	0	44,748.22	7.82
Nuevo León	1290.00	1233.00	28	3110.20	2.52
Chiapas	1196.25	984.25	0	3460.51	3.52
Veracruz	833.00	822.00	0	9204.20	11.2
Hidalgo	804.30	744.50	0	3048.68	4.09
Oaxaca	768.01	721.16	0	2468.69	3.42
Zacatecas	701.5	558.5	0	4036.77	7.23

Table 1.
Apple production by the first 10 states in México.

refrigeration is mostly used to have apple until March, its use is for fresh consumption, the varieties that are produced are Golden, Red Delicious, Starkrimson and Rome Beauty.

The second region in importance is the state of Puebla, with two regions, Zacatlán which is located in the Eastern Sierra Madre, where Golden apple, Red and regional creole are produced, and Huejotzingo which is located on the slopes of the Iztaccíhuatl volcano whose production is for cider with creole trees that, over the years, they have improved them for the production of this drink. In Zacatlán very little apple enters refrigeration, the surplus of national consumption, they market it to Belize, a neighboring country with a subtropical climate with a border with Mexico.

The third region in importance is the Sierra de Arteaga, which is located in the Eastern Sierra Madre and includes the states of Coahuila and Nuevo León, where you have Gala apples, Red type, Golden type mainly, business producers market it as a fresh market and rural producers use it for preserves, jams and wines that they sell on Sundays in the public square in the views that tourists make to their communities. Business producers refrigerate it and market it in supermarkets.

The last region of apple importance in Mexico is Canatlán in the state of Durango, which is located in the western Sierra Madre and is mainly produced apple of red type, and the Golden type of regional varieties, this state for being south of the state of Chihuahua, mainly its market is fresh and few producers refrigerate the apple to market it.

These four regions represent 96.1% of the national production and 91.5% of the area planted with apple in Mexico, therefore, apple production is governed by these regions, and only less than 15% use refrigeration systems to market the apple when the imported apple enters the country [6].

2. Postharvest management

The apple is harvested when it begins to change color, the seeds become dark, the fruit is easily cut from the tree and the water content in the fruit is reduced, which

allows us to estimate a good storage of the apple [7]. These specimens are indicators of the firmness of the fruit, the change of color and the breathing of the fruit, which is inversely proportional to the firmness. Most apples in their ripening increase ethylene production which if it is not controlled cause senescence in apple storage [8]. There are genotypes with minimal ethylene production to reduce storage problems [9].

The intensity of respiration of a fruit, depends on its degree of development, it is measured as the amount of CO₂ (mg) released from each kilogram of fruit per hour [10]. Respiration depends on the water content, because if there is a low water content at the time of harvest, the apple fruit when breathing dehydrates during storage, ages and lowers its value in the market.

There are products to reduce the respiration of the apple, bioplastics and conservation in controlled atmosphere with refrigeration that will increase the shelf life of the apple fruit, so the sale price at harvest that is \$ 15 / kg (0.73 USD), will increase at least \$ 35 / kg, (1.71 USD) being able to reach up to \$ 50 / kg (2.45 USD) in April which is the time of greatest import of apple from abroad.

The new varieties do not allow the fall of the fruit, they stay in the tree to be cut, this was a problem in the harvest because a lot of fruit was fallen and at the passage of the tractor with the boxes to place the harvest, it destroyed all fallen fruit. Its harvest is carried out in cloth bags (**Figure 3**), with a lower opening so as not to damage the apple and to be able to deposit it in the harvest box; the dimensions of the box are 1 × 1 × 1 m, one cubic meter [11].

The boxes with the fruit are taken to packing plant to enter a washing and waxing process. There are several methods to prolong the post-harvest life of the apple, which are: storage at low temperatures, the use of plastic packaging to create modified atmospheres, the application of hydrothermal treatments, irradiation and formulations containing biological agents, among others.

The controlled atmosphere (CA) and the use of bioplastics turn out to be the best alternative to prolong the shelf life of the fruit. So, to start you must have a controlled and automated atmosphere cooler for when there are failures in the electrical power [12].

The apple fruit is a climacteric fruit because its epidermis can be consumed, different from orange and avocado, whose bioplastic covers are not for consumption with epidermis [13].

Bioplastics are high molecular weight long chain polymers. They are based on waxes or other products (such as polysaccharides), and their use is to maintain the organoleptic quality of fruits during their shelf, commercialization and export processes [14].

Bioplastics reduce the rate of respiration and dehydration of coated products, in addition, these coatings allow the incorporation of food additives (antimicrobial agents, antioxidants, mineral salts, etc.) that slows down enzymatic browning by oxidation, the appearance of physiological disorders such as surface scalding, microbial growth, loss of texture, weight loss and total acidity due to the fermentation of sugars in the fruit; it allows to control wrinkles, increases the marketing period and improves their appearance by providing them with shine [15].

The fruit once harvested should be washed with detergents and fungicides such as Imazalil (maximum concentration allowed of 2 mg/kg) [16], Thiabendazole (allowed interval of 0.02 to 10.0 ppm) [17], Orthophenylphenol (0.4 mg/kg bw/day) [18], and then dried with air. The drying temperature can be up to 30°C, the higher the drying temperature, the greater the impact on the organoleptic and physiological characteristics of the fruit, since the higher the drying temperature the greater the dehydration of the fruits, reducing their weight.

Figure 3.
Bag to deposit apple when harvesting from apple tree.

Edible coatings have good results in the control of weight loss, have fewer metabolic problems (fermentations) and greater reduction in senescence, but provide little shine. The bioplastics that will be used are: beeswax, carnauba wax, shellac, candelilla wax, chitosan plus oleic oil and lemon oil and imported edible coatings such as sodium alginate and Hydroprofil-Methyl cellulose [19].

For disease control during cold storage, the agriculture sustainability in horticultural production has options like wheat gluten, corn zein, soy protein, oils, waxes, starch, pectin, A. vera polysaccharides, cellulose, plant gums and secondary metabolites which are citral, eugenol, thymol [20].

The use of bioplastics is made at harvest when the apple has greater firmness and greater hydration in its tissues. Once it goes through the waxing, it is selected by size and the packaging is made for marketing in the fresh market. The packers select by size (**Table 2**) and color, the size is given by the NMX – FF – 061 – SCFI – 2003

Grade	Commercial size Number of apples per box	Equatorial diameter (cm)		Fruit weight (grams)	kg per box (grams)
		Class	Average		
Extra	48	Greater than 9.2	Greater than 9.2	375	18.00
Extra	56	8.4 a 9.2	8.80	324	18.14
Extra	64	8.1 a 8.9	8.50	284	18.18
Extra	72	7.8 a 8.6	8.20	253	18.22
Extra	80	7.5 a 8.3	7.90	227	18.16
Extra	88	7.2 a 8.0	7.60	207	18.22
First	100	6.9 a 7.7	7.30	182	18.20
First	113	6.6 a 7.4	7.00	162	18.31
Second	125	6.4 a 7.2	6.80	145	18.13
Second	138	6.3 a 7.1	6.70	131	18.08
Second	150	6.2 a 7.0	6.60	122	18.30
Third	163	6.0 a 6.8	6.40	111	18.09
Third	175	5.6 a 6.4	6.00	105	18.38
Fourth	198	5.2 a 6.0	5.60	91	18.02
Fourth	216	4.8 a 5.6	5.20	85	18.36
Marble	234	4.0 a 4.8	4.40		
Mean					18.19

Table 2.
Mexican classification norm for packing apple fruit.

Box Size	Diameter		Weight	
	Inches	mm	grams	ounces
234	2 1/4	57.2	79	—
216	2 5/16	58.7	86	3.1
198	2 3/8	60.3	94	3.4
175	2.46	62.5	—	3.8
163	2 9/16	65.1	114	4.1
150	2 5/8	66.7	124	4.5
138	2 11/16	68.3	135	4.8
125	2 3/4	69.9	149	5.4
113	2 13/16	71.4	165	5.9
100	2 15/16	74.6	186	6.7
88	3	76.2	211	7.6
80	3 3/16	81	232	8.4
72	3 5/16	84.1	258	9.3
64	3 3/8	85.7	291	10.5
56	3 1/2	88.9	332	12
48	3 5/8	92.1	387	14

Table 3.
USDA Washington standards for apple fruit.

standard, which is a Mexican classification system that considers size as extra, first, second, third, fourth and marble [21]. There is the USDA Washington Standards (Table 3) rating system, which uses the size of the box as a reference, if the box is 175 has apple with a diameter of 2.46 inches, a weight of 3.8 ounces, the commercial box will have 175 apples [22].

The commercial box is made of cardboard and the harvest box is made of wood, both types of box can be stored in refrigeration, because in supermarkets the two presentations are placed, the wooden box only has a single variety of apple (Figure 4), and

Figure 4.
Wood box presentation in supermarket to commercialization.

Figure 5.
Carton box presentation in supermarket to commercialization.

they are considered in bulk at a price of \$ 40 / kg (1.94 USD) in March; in cardboard boxes you can present several varieties for the taste of the consumer (**Figure 5**) to be taken by customers and carry the amount they need, but the price rises to \$ 50/kg (2.45 USD) in March, when the import of apple is greater in Mexico.

3. Refrigeration

A CA is an environment that is artificially produced, in which the oxygen, nitrogen and carbon dioxide concentrations as well as the temperature and humidity are regulated [23]. Firmness, soluble solids and acidity are the most important quality indices relating with best sales. Reduction in temperature and O_2 or increase in CO_2 in CA storage reduce the rate of loss in acid [24].

Figure 6.
Liquid nitrogen tank and controller.

The cooling process is to circulate refrigerant gases to reduce or maintain the temperature below the ambient temperature. The refrigerant gas begins in an initial state (liquid or gaseous), to go through a series of processes and return to its initial condition. This series of processes are known as the cooling cycle. This cycle will be repeated as many times as necessary to absorb heat through the refrigerant [25].

The use of refrigerant gases is in full evolution and modernization due to the application of the European F-Gas regulation, whose main objective is the reduction of the use of hydrofluorinated greenhouse gases (GHG) by 70% by 2030. This regulation is associated with the application of the Tax on fluorinated gases entered into force since January 1, 2014, because hydrofluorinated carbon gases (HFCs) have a high Global Warming Potential (GWP), which has caused professionals and manufacturers of HFC gases to look for alternatives and substitute gases that are compatible with

Figure 7.
Automatic nitrogen compressor.

the refrigeration equipment already installed and that are equally efficient in their application [26].

Low-GWP refrigerant gases such as R-407c have been generated, is a mixture of hydrofluorocarbons used as a refrigerant. It is an azeotropic blend of R 32, R 125, and R 134a, his applications include residential and commercial air conditioning systems, and some commercial refrigeration systems. The R134a refrigerant is mainly used as a refrigerant in automobile air-conditioning and commercial refrigerant applications and the R410A refrigerant is used in new residential and commercial air conditioning systems.

A cooling room of $13 \times 16 \times 6$ meters by 2021, has a cost of \$3048,893 (147,717.7 USD), but operates with 404 Y refrigerant gas, which is a hydrofluorocarbon (HFC) refrigerant. However, these low-WGP gases will not be able to be used in 2022 for new equipment,

Figure 8.
Nitrogen refrigerant pumps.

Figure 9.
Expansion device that distributes the cold.

Figure 10.
Nitrogen recycling as refrigerant and automation panel.

although they do not yet have a deadline for service and maintenance, to conserve the quality of apples fruit [4].

The conditions of refrigeration gases to reduce the effect of greenhouse gases have caused ammonia (NH_3) to be considered again, it is a gas whose use dates back to the nineteenth century and its application in commercial refrigeration equipment is widespread even today, in medicine, livestock, agriculture, industry, hospitals, hotels or airports and other areas where refrigeration is needed [27]. NH_3 as a refrigerant has the ability to achieve cooling at temperatures down to -70°C , but great care must be taken in its handling because it is a colorless, odorless, tasteless and deadly gas.

The use of liquid nitrogen in the refrigeration and freezing of food is booming because it is a gas that does not affect the ozone layer, although its implementation is expensive. Liquid nitrogen reaches extremely cold temperatures (-70°C), making it the fastest method of individual food freezing [28].

Figure 11.
Wood box with apple in stacked order into the refrigerator.

The operation of ammonia cooling consists of a liquid nitrogen flow reservoir and controller (**Figure 6**) from there it passes to a compressor (**Figure 7**) that compresses to condensation temperature the dry gas that comes from the separator at evaporation temperature and pumps the gas for cooling to the condenser (**Figure 8**). The coolant arrives from the condenser to the expansion device that distributes the cold in the room where it is located at the top of the room where the apple boxes are (**Figure 9**) and then recycles it to continue with the cooling cycle (**Figure 10**).

A CA cooler with nitrogen cooling of $4 \times 6 \times 4$ m has a cost of \$ 3,781,646 (183,219.3 USD), if we compare it with the cooling with HFC, it is higher but with less volume, which indicates that cooling with nitrogen has more cost.

The refrigeration system must keep the apple at a temperature of 3.3 to 3.9° C, a CO₂ concentration of less than 10% and a concentration of oxygen from 2.0 to 2.5%, with a relative humidity of 90%, for a storage period of 6 months [29], this means that if harvested in August, the apple would be coming out in its entirety by March. The wooden drawers with the apple are stacked in the cellar with refrigeration (**Figure 11**), so that they are taking out boxes every month according to the needs of the market.

4. Merchandising

The apple of the business producers would leave in March at the price of \$ 50 per kilogram (2.45 USD) in cardboard boxes and every month in box from September to March in wooden box at a price of \$ 40 per kilogram (1.94 USD), the price is to recover the costs of investment in energy, which now in Mexico with the energy reform, it is unknown what the cost of energy will be, this is a formal trade with supermarkets y only use brand names when they are associated with the supermarket, the name of apple orchard is only identification.

Figure 12.
Apple with tamarind at \$12 per piece.

Figure 13.
100% apple artisan liquor at \$ 300 per liter.

The apple of rural production that does not have refrigeration systems, in Mexico it is known as informal trade for that reason do not use brand names, the sold as an added value in sweets (**Figure 12**), alcoholic beverages (**Figure 13**), jams, juices, cider and very little as a fresh market, so the apple is a profitable crop and that one apple per day is recommended in the work or school week as a snack [30].

5. Conclusions

The CA is the best form to maintain and commercialization of the refrigerated apple to give it added value, the business producer uses refrigerators to store the apple for 6 months from September to March in Mexico.

Liquid nitrogen is the best option for cooling, but its cost is high as those cooled with GHG.

In the selection of the crop to be stored, the apple is washed, dried, covered with bioplastic or organic products, and separated by size, to be stored.

Mexico has four apple-producing regions, even so, it does not supply the national demand, so imports must be made.

The commercialization of the apple of the rural producer is carried out after harvest and is sold as a snack, entremes or appetizer.

Conflict of interest

The authors declare no conflict of interest.

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