AVOCADO

Post-harvest Operations

INPhO - Post-harvest Compendium

Food and Agriculture Organization
of the United Nations

AVOCADO: Post-Harvest Operation

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Preface

The importance of post-harvest operations in developing countries relies in the quality control of the fresh fruit that they achieve. Post-harvest operations begin with a selection of the fruit, then a cleaning, packing, proper storing and transporting. All these operations benefit producers because they enable the fruit to reach the market at higher prices, and also create jobs in the packinghouses and orchards for both educated and non-educated labor. The domestic and international consumer benefits with a high-quality fresh fruit, free of diseases and other defects.
Avocado is a fruit with an exquisite taste and aroma, which has been traditionally consumed even before the arrival of Spaniards to the Americas. It is called "aguacate" or "palta" in Latin

American countries. Nowadays, as a result of different investigations, it is recognized that besides being a source of energy and vitamins, it also delivers specific non-nutritive physiological benefits that may enhance health.
From this point of view, avocado can be considered as a "functional food", according to the definition of Mazza (1998). Some nutraceutical ingredients that have been found in avocado pulp are antioxidants, such as vitamin E or tocopherols (4.31 UI/100 g) and glutathion (17.7 mg/100g). They both work as antioxidants, neutralizing free radicals that may damage aging cells, the heart, and contribute to the development of some types of cancer, such as mouth and pharynx (O'Toole, 2000, Heber, 2001).
It has also been reported that avocado is a source of lutein (248 mg/100g, considered a high content), a carotenoid that helps to protect the eye from diseases such as cataracts. The amount of b-sitosterol in this fruit is similar to the one found in soy and olives. Animal studies have demonstrated that this compound is related to the inhibition of cancerous tumors (Heber, 2001).
An other nutraceutical component in avocado is a mix of high quality lipids: w_3, w_6, and w_9 fatty acids. When Carranza *et al* (1997) made clinical studies in patients with high cholesterol levels, they found that an avocado enriched diet produced a significant reduction in low-density lipoproteins ("bad cholesterol") and total cholesterol, while diets enriched with soy and sunflower did not change the total cholesterol concentrations.
Lerman *et al* in 1994 concluded that in non-insulin dependent diabetic patients it was beneficial to replace carbohydrates for lipids, such as the ones found in avocado. This will favor the reduction of triglycerides in the blood plasma.
For all of the above, it can be concluded that the inclusion of avocado in the everyday diet can bring health benefits to the health of human beings, bearing in mind that no food is 100% complete, and a single food will not provide all required nutrients and nutraceuticals (except for breast milk). The diet shall include several food items from all the different groups in order to deliver a good nutrition.

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1 Introduction

There are 57 avocado producing countries in the world. The land that is currently destined for the growing of this cultivar totals 348,769 ha, producing 2'583,226 tons a year. The average yield per ha is 7.40 tons. The main producing countries in the world are:

Table 1 Producing countries in 2002 (APROAM, 2003)

Country	% of world production	Country	% of world production
Mexico	36.8	Dominican Rep.	4.30
U.S.A	7.93	Chile	4.26
Colombia	5.56	Brazil	3.45
Indonesia	5.03	Israel	3.32
-	-	Other 49 countries	29.35

As it can be seen in Table 1, the main producer in the world is Mexico. Some countries can compete in terms of quality, such as Chile, Spain, Israel, South Africa, and Dominican Republic. However, still no country can compete with Mexico in terms of quantity.
Summarized characteristics and scientific name
Avocado is a dicotyledoneous plant from the *Ranales* order and the *Lauraceae* family. It was classified as *Persea gratissima* by Gaertner , and *Persea americana* by Miller. *P. americana* developed subspecies due to geographical isolation, that finally originated different botanical types (Figure 1 Avocados derived from Mexican ecological race), with different kinds of adaptation to climatic conditions.

Figure 1 Avocados derived from Mexican ecological race

Three of these botanical types are widely known as subspecies or botanical varieties of the *P. americana*. In horticultural circles, these varieties are known as ecological races: Mexican, Guatemalan, and Antillean (Figure 2 Avocados variety Hass). They are not different enough to be considered separate species, because they have a very similar genoma, hybridation among them occurs easily, and their hybrids have climatic adaptation advantages and improved agronomic characteristics.

Figure 2 Avocados variety Hass

The following Table describes the main characteristics of the three ecological races:

Table 2 Ecological races (elaborated with data from Sánchez-Pérez, 1999)

Characteristic	**Mexican**	**Guatemalan**	**Antillean**
Fruit weight (average)	98.8 g	309.8g	312.5 g
Peel thickness	Thin and very thin	Medium, thick or very thick	Thin, medium or thick
Peel texture	Membrane-like	Corky	Leathery
Medium annual temperature (°C) for native trees	13.5 to 20.5	21.0 to 28.0	24.0 to 27.0
Medium annual temperature (°C) for introduced trees	20.5 to 25.5	18.0 to 28.5	19.0 to 20.0
Medium annual precipitation (mm) for native trees	560 to 2200	800 to 3400	1100 to 3350
Medium annual precipitation (mm) for introduced trees	300 to 2250	250 to 7000	600 to 700
Altitude (m over sea level)	950 to 2250	20 to 1200	50 to 800

Avocado is a fruit from a tree that has a variable growth and development, reaching a height of 10 to 12 meters in its natural habitat (Figure 3 Avocado trees may grow at different altitudes). Such habitat is classified as subtropical-tropical. The tree has a ligneous trunk that can reach up to 80 cm to 1 m in diameter in trees that are 25 to 30 years old (raceme), that can be axillar or terminal.

Figure 3 Avocado trees may grow at different altitudes

Systematic studies have classified more than 500 varieties; however, most of them have been discarded in order to "create" commercial varieties, which adapt to production in commercial scale. From this large number of varieties, most have had productivity problems (production time, amount of fruit), quality (protein and fat content), and commercial handling problems (resistance to transportation, etc.).

Commercial varieties are developed from the selection and improvement of these types, or by hybridation (Figure 4 Production of hybrids in the orchard). For example, from the Antillean type the Pollock, Peterson, and Waldin varieties are obtained; from the Guatemalan, MacArthur, Orotava, Nabal, Anaheim, Hass (Figure 5 Small trees of avocados Hass derived from Guatemalan type), Booth 7, Booth 8; and from the Mexican: Puebla, Mayapán, Zutano, Topa-topa, and Bacon. Some hybrid varieties are: Mexican-Guatemalan: Fuerte, Ettinger, Rincón, Robusto, Lula. Antillean-Guatemalan: Gema, Choquette (Rodríguez-Suppo, 1992)

Figure 4 Production of hybrids in the orchard

Figure 5 Small trees of avocados Hass derived from Guatemala type

Origin

Based on the archeological evidence found in Tehuacán, Puebla (Mexico), it is believed that avocado appeared approximately 12,000 years ago. It has been determined that the country of origin of this fruit is the central part of Mexico, passing through Guatemala to Central America. In this region, the natural gene stock can be found, which can be useful to the biotechnological improvement of the species. As an evidence of this theory, primitive avocado trees have been found from the Oriental Sierra Madre in the State of Nuevo León, Mexico, to Costa Rica, in Central America.

From this origin center, avocado dispersed to the southeastern part of the U.S., to the Antilles, to a large part of South America: Colombia, Venezuela, Las Guyanas, Brasil, Ecuador, Perú, Bolivia, and Chile. This broad dispersion in areas of ancient civilizations can be explained by a high appreciation of the fruit in these cultures (Sánchez-Pérez, 1999; Rodríguez Suppo, 1992).

Seasonal production

The life cycle of avocado (longevity and productive period) is a long one. A tree of 1 to 4 years is considered young, from 8 years on is considered adult and fully productive, a period that can extend for more than 20 or 25 years. Some types of avocado in favorable conditions grow indefinitely (Figure 6 Avocado trees).

Avocado is a very productive tree that delivers fruit all year-round. The two harvest periods are classified as maximum and minimum. The maximum harvest period lasts from October to January, and minimum from February to September.

The yield of fruit per tree varies due to the avocado type, cultivation, and zone. An adult orchard typically stabilizes its production from 80 to 100 kg of fruit per tree and year. The yield is also modified by the age and the tree density within an orchard. Young trees have a lower yield than adults, producing from 10 to 20 kg per tree, and stabilize their production at 10-15 years of age. The maximum production of a tree is usually reached at 15 years of age (SAGAR, 1999, Rodríguez-Suppo, 1992, Ing. José Cortez, personal communication).

Figure 6 Avocado trees

Main causes of post-harvest losses and poor quality

From a physiological point of view, particularly during the post-harvest stage, the aesthetic and nutritional qualities of fruits can be affected, which could lead to a decrease in post-harvest life (Zamora, 1991). The quality of avocado is often diminished along the packing and marketing processes, and sometimes it does not reach its destination at its best. The following disorders of avocado have been classified as follows (Swarts, 1984):

- External: chilling injury fungal damage (including anthracnose and *Dothiorella*) and mechanical and friction damage.
- Internal: grey pulp, stained pulp, vascular browning, brown vascular stain, and peduncle rot (pathological), frost damage (extremely low temperatures in the orchard).

The main causes of post-harvest loss are:
Chilling injury. Temperature is the main environmental factor in the control of produce ripening. Thus, in order to obtain successful results, it is important to handle this factor properly, keeping the fruit under low, specific temperatures that should never be below 0ºC. However, some fruits suffer chilling injury at temperatures well over the freezing point. According to Pesis *et al* (1994), avocado is a subtropical fruit that is sensitive to chill injury when exposed to low temperatures, even if they are over the freezing point (for example, 2 to 4ºC). The main symptoms of chilling injury are black stains in the epidermis and a gray or brown discoloration in the mesocarp. Morris (1982) reported that another symptom is the alteration of internal metabolism, which leads to an increase of the levels of anaerobic respiration and, as a consequence, of abnormal metabolites, resulting in the development of foul taste and odor. However, the effects of chilling injury in avocados is clearly seen only when the fruit is ripe, which in some cases may be too late for marketing effects (Corrales-García, and Tlapa-Rangel, 1999).
However, refrigeration slows the speed of biological processes in the fruit, delaying ripening and senescence. In the case of avocado, storage under refrigeration should not exceed 30-40 days. In order to guarantee a higher efficiency in the refrigeration treatment, a pre-cooling process is recommended (Téliz, 2000, Morales, 2001).
Fungal damage: Anthracnose (*Colletotrichum gloeosporioides*) is the cause of a fungal infection that is considered of major importance. Besides the damages it causes in the production of avocado, it also reduces the fruit quality during its transport, storage and

marketing, where it causes the largest losses. The damages in a green fruit begin with discolored circular areas. The fungus penetrates the fruit and makes it rot. The lesions are of variable size, and of a dark brown color. In the surface of lesions, cotton-like spots appear. This and other funguses are capable of destroying entire boxes or pallets (Figure 7 Avocados showing fungal damage). It is favored by high relative humidity, damaged fruit and foliage, and when branches touch the ground. The chemical control is made with copper-based fungicides that are also used as a preventive measure on leaves and fruit still on the tree (Téliz, 2000, Ing. Salvador Torres, personal communication).

Figure 7 Avocados showing fungal damage

Mechanical damage

Many defects originate - or increase - because of an inadequate handling of the fruits from harvest to packaging. Friction damage, which is characterized by an oxidation of the tissue that later inclines downward and becomes necrotic, is one of the most frequent problems during harvest, and it has been estimated to be present up to 78% of the fruits.
Mechanical damage accelerates water loss and disrupts the superficial arrangement of the tissue allowing a faster gas exchange. Cuts break completely the protective layer of the fruit and expose the tissue directly to the environment. The cicatrisation and production of anti-fungal substances diminishes as avocado ripens (Zamora, 1991, Morales, 2001).
The damage is more notorious in fruits along the packaging process, mainly due to inadequate handling that affects the number of fruits with export quality.
Zamora-Magdaleno et al (1999) explained friction damage before harvest as a result of fruit friction during growth or as a result of friction with leaves or small branches. Damage proportion at this point may be from 2 to 35%, and increased at the packinghouse from 10 to 62%. Fruit coming immediately from harvest had a longer storage life, compared to the packed fruit. Ethylene production was higher in fruit recollected from the last phases of the packaging process, while their respiration rate was lower due probably to the result of mechanical injury.
The resistance to mechanical damage is given by the composition of the cells of the epidermis and the arrangement of the vascular tissue. A strong, elastic peel will not present any damage as a result of mishandling (Morales, 2001).
During growing, fruit loss can be due to a lack of technical counseling on a good nutrition of the trees, disease prevention and pest control (Figure 8 A well nourished leaf and others showing boron and zinc deficiencies). During harvest, a lack of planning and organization may cause: 1) avocados with improper sizes and dry matter contents (21% in the pulp, minimum) that are cut off the trees; 2) contaminated fruit, that is pulled from the tree or cut inadequately, and falls onto the ground; 3) sunburns due to exposure of the fruit. During

transport, dirty boxes and containers during transport are another source of contamination. If trucks and containers are not appropriate, the fruit may reach high temperatures when transported to the packinghouse (De los Santos-Vázquez, M., 2001)

Figure 8 A well nourished leaf (left) and others showing boron and zinc deficiencies

1.1. Economic and Social Impact

The economic and social importance of avocado resides in the benefit that its cultivation gives to producers, marketers, processors, and consumers. The orchards create jobs by demanding labor for farming operations, harvest, packinghouse operations, transportation, and marketing (Téliz, 2000). In Mexico, there are 21,511 producers (10,000 are located in Michoacán), 279 packinghouses and domestic traders, 17 packinghouses/exporters, 14 processing facilities for guacamole, pulp, halves, frozen products, refreshing drinks and non-refined oil. All these generate 47,000 direct jobs, 70,000 seasonal jobs, and 187,000 indirect permanent jobs (APROAM, 2003).

According to Lois Stanford "The varied topography of Michoacán's temperate region produces a wide range of microclimates suitable for avocado production almost year-round". The land tenure system is extremely heterogeneous, with an estimated 75% of the production area in private property, and only 25% in the "ejido" or communal sector. The avocado's industry production profile is equally heterogeneous. Orchard size varies greatly, ranging from small orchards of 1 to 5 hectares (both private and communal) to large commercial operation of 500 ha. Of the estimated 6,000 producers, only a handful of private producers have commercial operations and produce for the export market. Despite their limited numbers relative to large numbers of small producers, large avocado growers have played an important role in shaping the political and economic environment of Michoacán's avocado industry."

The production of avocado in Mexico started in the 50's. During these years the first cultivars were developed in the state of Michoacán, and during the 60's this activity expanded within the state, up to 15,000 ha. More and more cultivars appeared, and the year of 1975 recorded that 23,000 ha of land were destined to avocado production. During the first 15 years of production, the Mexican government considered the fruit as "highly profitable", and did not support avocado producers with scientific research or credits.

In the 70's, small landholders (from 0.5 to 10 ha) and communal landholders ("comuneros" or "ejidos") began cultivating avocado. As a consequence, in the 80's the avocado crops occupied 43,200 ha with 5 million trees, and employed 15,000 labor workers. The scientific and technological support during these years allowed the increase of the fruit production in

20%, along six years (Figure 9 Agronomic engineer and avocado nutrition adviser in an orchard).

Figure 9 Agronomic engineer and avocado nutrition adviser in an orchard.

During the first 15 years of avocado cultivation in Michoacán, no relevant social changes in the region were accounted for. The wages paid to labor workers were below the minimal range established by the government, and only few farmers offered benefits such as overtime payments, loans, vacations, etc. However, the whole local population benefited form the cultivation of avocado due to investments, the growth of the transportation network and service industry, as well as banking activities. At the beginning of the 80's, new industries developed alongside the cultivation of avocado: packinghouses, industrialization, and avocado exporters. As mentioned before, jobs have been created for a large number of specialized professionals, administrative and labor workers (Figure 10 Labor workers at avocado orchard), whose wages are over the minimal and enjoy benefits.

Figure 10 Labor workers at avocado orchard

During the 80's and 90's, the government established changes in tax and labor laws, which force the farmers to pay taxes and offer higher salaries and benefits to the workers. In the long run, these changes proved to be beneficial to the local population. Because the profit margins were set in 20-80%, the wages are at least 50% higher than the minimum, and the tax payments supported the construction of roads, schools and hospitals (Morales, 2000).

1.2 World Trade

The presence of avocado in the world market has been growing steadily in the past two decades, and it is no longer considered an exotic fruit but part of the everyday diet of many countries. This tendency has been reinforced by the consumer tendency to look for natural products. Avocado has a large market as a fresh fruit, besides its use in the oil, cosmetic, soap, and shampoo industry; as well as processed foods derived from it, such as guacamole, frozen products and avocado paste (Téliz, 2000).

The NAFTA (North American Free Trade Agreement), has opened new markets for the Mexican producer, and at the same time, creates the necessity of offering fruits with an excellent quality in order to captivate foreign markets. Otherwise, fruit exports will be a cause for economic sanctions and, in the long run, it could mean the closure of these new opportunities (Zamora-Magdaleno *et al.*, 1999).

Nowadays, many Mexican producers have explored the possibility of exporting avocado, since the domestic price of the fruit is only 20% of its value in other countries, such as Europe, U.S., Canada, and Japan. Even though the demand for avocado exists in the developed world, the quality requirements are usually higher than the domestic ones (Figure 11 Standard for the international market). The producer has to take the responsibility of a better operation of his cultivation in order to obtain a product of the desired quality that is able to compete in the international markets. At this point, the volume of fruit that has enough quality to be exported is only a small percentage of the total production (Morales, 2000).

Figure 11 Standard for the international market
Source: Asociación Agrícola y Sanidad Vegetal, Salvador Escalante, Michoacán, México)

Generally speaking, the consumption of avocado in the world from 1990 to 1999 increased from 376 to 381 g per habitant, per year, meaning that the total volume rose from 2 to 2.3 million ton/year (Giacinti, 2002).

Importer countries

The main avocado importer country is France, which takes 39% of the total imported volume. Other importers are U.S.A. (10%), United Kingdom and Belgium (6.5% each). The leaders of international commerce are South Africa, Israel and Spain, countries that have been the main exporters since 1993. The world trade of avocado has increased significantly from 1980, and in the case of Mexico it has been limited to the U.S.A. and Europe. Japan has begun to import large volumes of the fruit, being the main importer in Asia. Japan imports have increased

73% since 1990, Mexican avocados are received from September to December, and avocados from the U.S.A. from February to September. The Mexican avocados get lower prices than the American. (Téliz 2000; El Aguacatero, 2001).
In the European Union (E. U.), familiarization with avocado has motivated an increase in its consumption for the past two decades. The per capita consumption in the E.U. is shown in the table 3:

Table 3 Consumption of avocado in the European Union (1999) (Tubello and Piccolo, 2001)

Country	Kg/habitant/year	Country	kg/habitant/year
Austria	0.160	Ireland	0.194
Bel-Lux	0.899	Italy	0.033
Denmark	0.580	Netherlands	1.128
Finland	0.150	Portugal	0.035
France	1.420	Spain	0.596
Germany	0.157	Sweden	0.610
Greece	0.228	United Kingdom	0.315

The Netherlands and France re-export an important percentage of their avocado imports to other countries in the Union, therefore the consumption data should be consider partial.
Among the factors that increased the acceptances of tropical fruits, such as avocado, in the European Union are:

- The interest of some French importers, together with Israel (as a producer) at the beginning of the 70's.
- Avocado natural versatility to be used in easy and fast dishes.
- The supply of avocado by South Africa and Israel during the 70's and 80's.
- The increase of the Spanish production of the fruit in the mid 80's.
- The entry of Mexican avocado into the E.U. in the 90's.
- The re-distributions into the European market made by The Netherlands, France, and Belgium.
- The recent incorporation of avocado from the southern hemisphere (Australia, Chile, Argentina, and Brazil) into the E.U.
- (Tubello and Piccolo, 2001).

Exporter countries

During 1996-2001, 305,383 tons of avocados were exported, with a value of 292.3 million dollars. A growth rate of 5.03% was registered in the same period. It is noteworthy that the 1993-2001 periods had a growth rate of 16%. The main exporter countries are shown in Table 4:

Table 4 Exporter countries (with data from APROAM, 2003)

Country	% of total exports	Country	% of total exports
Mexico	22.09	South Africa	9.07
Chile	17.78	France	5.38
Israel	12.65	Netherlands	4.95
Spain	12.23	U.S.A.	2.89
		Others	18.34

Mexican exports of avocado in 2003 were of 71,621 tons, which that represented 22.09% of the world exportations. This amount increased fourfold in the last four years. The main destinations of Mexican exportations are: U.S., Central America, France, Canada, Japan, United Kingdom, Netherlands, Germany, and Belgium-Luxemburg.

The 7.5% of Mexican production of avocado is exported as fresh fruit. The exportations of Mexico during the period 1996-2001 are valued in 350.3 million dollars. Only 3.4% of the avocados produced in Mexico are exported as a processed product, non-refined oil, and beverages, equivalent to 18,875 ton or 18.1 million dollars in 2001. The main destinations of the products derived from avocado are: U.S.A., Germany, France, Spain, New Zealand, Japan, Canada, and Australia.

The exportations for the period 1998-2004 are expected to increase 40% for the fresh fruit and 47% for processed avocado (Source: APROAM, 2003).

Exporter countries operate with different free on board (FOB) prices per kg of avocado that may be seen at table 5:

Table 5 FOB prices of exporter countries
(source: Giacinti, 2002)

Country	FOB Price in US$	Country	FOB Price in US$
Philippines	2,61	Israel	1,14
Morocco	2,06	Mexico	1,06
Peru	1,76	Dom. Republic	0,65
Belgium-Luxemburg	1,64	Indonesia	0,62
Germany	1,53	Brazil	0,57
United Stated	1,22	South Africa	0,44
Chile	1,16	Venezuela	0,33

Consumer countries:
The main avocado consumer countries may be observed in Table 6.

Table 6 Main consumer countries (1998/2000)
Source Giacinti, 2002, with data from FAOSTAT

Ranking	**Volume (ton)**	**Country**
1	815,749	Mexico
2	228,310	United States
3	128,447	Indonesia
4	127,697	Colombia
5	85,598	Brazil
6	79,298	Dominican Republic
7	79,020	France
8	76,355	Peru
9	63,667	China
10	49,000	Cameroon
11	45,000	Haiti
12	39,145	Venezuela
13	32,662	Chile
14	32,446	Israel
15	32,079	South Africa
83.7%	1'914,503	Partial Sum
100%	2'288,208	World Total

1.3 Primary Product (fresh)

Avocado is mainly consumed as a fresh fruit (Figure 12 Commercialization and consumption of avocados is mainly fresh). The nutritional content for some varieties cultivated in Mexico is described in the Table 7.

Figure 12 Commercialization and consumption of avocados is mainly fresh

Table 7 Nutritional content of some avocado varieties

Variety	**Energy**	**kJ/kcal**	**Moisture (g)**	**Ash (g)**	**Fat** (g)	**Protein (g)**	**Carbohy-drates (g)**	**Total fiber (g)**
Pellejo[a]	519/124	77.40	1.10	1.37	1.37	1.37	3.70	3.73
Grande[a]	176/42	88.60	0.50	1.37	1.37	1.37	4.82	2.25
Verde[a]	757/181	72.40	1.10	1.81	1.81	1.81	5.89	0.40
Hass[b]	715/171[c]	77.30	1.30	1.60	1.60	1.60	5.60	----

[a] INNSZ, 1996
[b] Ortiz, A., 2003
[c] this value was estimated from the nutrient contents.

Some recipes for fresh avocado are presented in the Annex (pag76), with the aim of illustrating some ways of consumption of the fresh fruit. (Verti and Villanueva 2001, APROAM 2000). Additionally, some examples of traditional recipes are presented. An example is presented in Figure 13 showing guacamole and main ingredients. The authors of the present work, encourage the reader to make its own recipes; combining a good source of high quality lipids and vitamins (avocado), with ingredients that contain proteins (meat, fish, egg white, soybean, cheese, nuts), carbohydrate sources such as bread or tortillas, and dietary fiber (lettuce, fruits, asparagus, etc.) . Add your favorite spices and enjoy your meals with avocado!

Figure 13 Guacamole and main ingredients

1.4 Secondary product (processed)

In order to increase commercialization on a large scale and give avocado an added value, it is important to develop food products derived from this fruit with a shelf life long enough their transportation and distribution to consumers (Figure 14 Avocado products guacamole).

Figure 14 Avocado products (guacamole)

This would also promote the creation of processing plants, which in turn would generate new jobs, and increase the profit of the farmers.
The main problems that a food processor faces when developing and preserving avocado products are:

- To control and maintain an optimal ripeness state on avocado.
- Enzymatic browning, catalyzed by the action of polyphenoloxidase and other oxidant-reducing enzymes.
- Loss of green color due to changes in the chlorophyll molecules at low pH values.
- Generation of off-flavors and loss of texture as a result of conventional thermal treatments.

The microbial contamination that is present in the fruit peel, due to lousy agricultural practices (particularly in developing countries). This contamination is hard to eliminate because of the rough texture of the peel, especially in the Hass variety.

Minimally processed avocado products meet the consumer demand of having fresh-like products; however, the shelf life of these products is relatively short, from one to several weeks. Usually, the preservation factors are a combination of additives and refrigeration. Welti-Chanes *et al.*, in 1998, recommended a firmness range of 800 to 1500 g for avocados to be minimally processed.

Table 8 presents some studies on avocado processing. The foundations of each method are different (second column). The temperature decrease in processes such as refrigeration and freezing has been extensively used in the development of guacamole-type products. Nowadays, methods are combined with the addition of additives to improve the sensory quality and avoid syneresis. Frozen avocado products have a shelf life of one to two years.

Table 8 Avocado preservation processes. Methods or barriers used in the preservation of avocado and guacamole purée

Method	**Foundations**	**Remarks**	**References**
Freezing	Decreases enzymatic and microbial activities.	Avocado mixture can be preserved for 9 months when packed with nitrogen (inert gas). Nowadays, shelf life of frozen guacamole is of 1 to 2 years.	Stephens, T.S., Lime, B.J., and F.P. Griffiths. 1957. J Rio Grande Valley Hort. Soc. 11, 82-89
Conventional thermal treatments	Decreases or eliminates microbial population, inactivates enzymes.	Off-flavors are generated, depending on the processing time and temperatures.	García, R. Et al. 1975. J Food Sci, 40:200
Freeze-dry	Decrease of water activity to avoid microbial growth and enzymatic activity.	Good results in samples with a <2.5% moisture content. It is considered expensive. Shelf life is up to 9 months.	Gomez, R.F., and R.P. Bates. 1970. J Food Sci, 35(4)
Additives plus refrigeration (minimal processing)	Compounds that inhibit polyphenoloxidase activity, at controlled pH and water activity to inhibit microbial growth.	Avocado slices treated with cystein and sodium pyrophosphate, at pH=5.5 lasted for 8 days in refrigeration.	Dorantes, L. 1998. Food Science and Technology International, 4, 107-113.
High hydrostatic	Pressure between 300 and 600 MPa can	When combining high pressure and	López-Malo et al. 1998. Food

Method	Foundations	Remarks	References
pressure	inactivate food spoilage and pathogenic microorganisms.	lowering pH, it was possible to obtain a good refrigerated product.	Research International, 31, 549-556.
Microwave, combined methods	A thermal microwave treatment, microwaves, pH lowering, and formation of complexes chlorophyll-zinc are combined.	Color is less deteriorated by the formation of stable complexes. Flavor is better preserved than in conventional processes.	Guzmán, R.I. et al. 2002. Innovative Food Science and Emerging Technologies 3, 47-53.

The combination of reducing substances, organic acids, and sequestering agents in refrigerated products has shown to be effective in delaying guacamole and avocado paste browning (Sánchez *et al.*, 1991, Dorantes-Alvarez *et al.*, 1998). Some type of bacteriostatic substance is added as well.

The decay of freeze-dried guacamole and avocado purée was studied by Gomez and Bates in 1970. Their freeze-dry method has been useful in samples with a moisture content <2.5%, because its efficiency is based on lowering water activity at a level that interferes with enzymatic activity and microbial growth. It is considered a relatively expensive method since it requires freezing and vacuuming (<5 mmHg), in order to sublimate the water present in the samples. The product that was packed with an inert gas such as nitrogen may last for 9 months, maintaining a high quality.

The application of novel technologies in the development of guacamole-type products presents some alternatives that eventually generate commercial products, as the high hydrostatic pressure process. This process damages the microbial cellular structures (mainly their membranes), inactivating them, and resulting in a safe product (López-Malo, 1998). The commercialization of this type of product is carried out mainly in developed countries, since the consumption of the fruit in developing countries is mainly as a fresh produce.

Other application of novel technologies in the development of avocado products is the microwave thermal treatment, combined with a decrease in pH and the formation of complexes chlorophyll-zinc (Guzmán *et al.*, 2002). Microwave heating can be considered as a high temperature-short time treatment (HTST), which decreases the generation of off-flavors and loss of texture. The addition of a zinc salt prevents the loss of green color by forming a complex chlorophyll a-zinc during the thermal process. Also, Ortiz *et al* (2003) reported that preheating with microwaves may lead to obtain a good quality and yield of avocado oil, free of *trans* fatty acids.

The development of hurdle and novel technologies will result in the generation of new processes and products based on avocado that will hopefully benefit developing countries.

1.5 Elements on quality assurance and export marketing

Recently in the region of Michoacán, technical efforts have been made in order to improve the quality of avocados, with the aim of entering foreign markets, especially the US. These technical efforts have been further strengthened by legislation, specifically the publication of NOM-066-FITO-2002 on August 1996. This is a Mexican federal order that establishes the legal requirements and phytosanitary specifications for commercializing avocado in both national and international markets. This order also establishes the legal base for a regional system of phytosanitary control that requires that every avocado grower must enter the state pest control program and obtain certificates for their orchards if they intend to market their fruit at regional packinghouses.

The regulations established the procedures that growers must follow in the orchard maintenance, harvesting techniques, initial transport to the packinghouse, and registration of their orchards with the Agricultural Ministry (Stanford, 2002).

The federal order NMX FF-016-SCFI-2002 establishes quality specifications for fresh Hass avocados, excluding the fruit that is destined to industrial processing (Figure 15 Poster of the Union of Avocado Packers from Michoacán, México, showing the avocado standards of quality and damages).

This is done with the aim of creating a reference frame for producers, packers, brokers, traders, and consumers. Avocados shall be:

- Ripe, with a 21.5% dry matter in the pulp.
- Never in touch with the ground, transported in clean boxes and covered trucks from the orchard to the packinghouse.
- Wholesome fruits, free from rot and visible foreign matter.
- Free from pests and diseases.
- Free from strange flavors and with a normal humidity level.

Figure 15 Poster of the Union of Avocado Packers from Michoacán, México, showing the avocado standards of quality and damages.

Every box destined to the market shall contain, at least, the following data:

- Net weight
- The packer's name and address
- Quality level and caliber
- Packing date
- The phrase "Produce from Mexico" or the country of origin
- Generic name of the product "avocado"

Every package used in avocado transportation shall follow the next:

- To be clean and do not contain foreign matter
- To have an adequate resistance and ventilation
- To be made of wood, cardboard, or plastic, only
- The content should be homogeneous.

Federal order NMX-FF-008-1982 establishes the fruit calibers for commercialization (Figure 16 Fruit calibers for commercialization of avocados in México), as follows:

- "Super extra": over 266 g
- "Extra": 211 g-265 g
- "Primera": 171 g-210 g
- "Mediano": 136 g-170 g
- "Comercial": 85 g-135 g
- "Canica": under 85 g

Figure 16 Fruit calibers for commercialization of avocados in México.

There is also a federal order that establishes the requirements and specifications of the observation and certification of good agricultural practices in the production of fresh fruits and vegetables, NOM--034-FITO-1995. The main objective of this is to prevent food-borne illnesses due to contamination with fecal matter (human or animal), infectious diseases transmitted by workers in contact with the fruit, as well as lack of training in proper handling practices. These facts are decisive for delivering safe products to the consumer, which in turn influences their confidence to Mexican products (Morales, 2001).
On the other hand, Food and Drug Administration and the United States Department of Agriculture published in October 1998 the "Final guide: Guide to minimize microbial food safety hazards for fresh fruits and vegetables". Both "Final Guide" and NOM-034-FITO-1995 point out good handling and agricultural practices such as washing, selection, and packaging done with sanitary practices.
According to its authors, the guide is consistent with the commercial rights and obligations of the USA and does not try to impose barriers or unnecessary restrictions to foreign producers and exporters.

These regulations should also help to improve the safety and quality of fruits and vegetables of third world countries that export to the USA. A synthesis of the main points to consider when exporting produce to the USA is presented as follows:
Water quality
Water for agricultural practices: it can be temporally contaminated as a result of sewage discharges.
Water for processing: it is in high contact with the product.
Water for washing: washing can help to reduce microbial content in the surface of fruits and vegetables (Figure 17 Avocados submerged in chlorinated water).
Water for cooling: water and ice deposits might be contaminated by products carrying pathogens.
Some preventive measures to prevent water contamination are: the identification of the origin of the water and to keep it in good condition, identification of potential contamination sources, protection of deposits from wild or farm animals, periodical analyses of the water quality, disinfection of deposits and water.

Figure 17 Avocados submerged in chlorinated water

Manure and bio solids from sewage If used as soil fertilizers and handled inappropriately, constitute a source of hazardous microorganisms.
Treatments to reduce pathogen levels: such as pasteurization, heath drying, aerobic and anaerobic digestion, sterilization, etc.
The following practices are recommended to reduce the risks: place manure as far as possible from the fresh produce and inside containers, minimize leakages, minimize the potential of cross-contamination by birds or rodents, and obtain the manure specifications from the supplier.
Non-treated manure should not be applied to the soil during seeding and cultivation, the time between the application and the harvest should be maximized, and if not possible, non-treated manure should not be used at all.
Animal feces: domestic animals should be excluded from the fields and their waste removed.
Workers hygiene: the workers must understand and apply basic hygiene principles to avoid being a hazard (Figure 18 Workers with proper dressing in a packing house).

Figure 18 Workers with proper dressing in a packing house

Recommendations: It is important to assure that every person that comes close or in contact with the product will follow the hygiene rules. A training program should be established, including demonstrations, for example, of how to wash the hands. Operators should be able to recognize signs of infectious diseases and lesions of workers, who must be protected. All visitors must follow the hygiene rules too.
Lavatories: should be accessible to workers at every time; should be placed far from water deposits; well supplied with soap, paper towels and bins; keep facilities clean, and have an emergency plan in case of leakages.
Cultivars: clean all the storage facilities before use; be sure that all washed product is not re-contaminated.
Packinghouse: remove mud and soil (as much as possible) from the fruit before it leaves the field, dispose of all damaged packaging material that cannot be cleaned; clean all containers; protect the unused containers from contamination; clean all the machinery and equipments, as well as packing areas, at the end of the day.
Pest control: establish a supervision program for the affected areas; maintain the fields free of leaves, grass and rubbish; keep a list of all the actions taken to combat pests.
Transportation: make sure that trucks are clean before loading the product; keep the right storage temperature during transportation, minimize damage when loading and unloading.
Trace back: a trace back system will help identify the origin of a food borne disease and help eliminate the hazardous processes. An effective documentation system should include the harvest date, farm identification, and a list of people that worked in the batch. Technologies should be developed to identify the origin of the fruit.
As it can be seen in this short summary, the application of the recommendations given in the "Guide" implies that the farmer should make big great efforts and investments in order to assure the quality of fruits and vegetables. It also creates the necessity of a system that verifies, certifies and informs the consumers about the new quality assurance procedures.
All this is done with the aim of placing the product in national and international markets at higher prices.
From a technical point of view, and based on current scientific evidence, avocado has minimal risks of microbial contamination. Nevertheless, sanitary aspects have been (and

continue to be) a technical barrier to the commercialization of avocado in the U.S. In consequence, the general recommendation made to avocado producers is to comply with the Guide in order to avoid hurdles when entering this important market (Salazar-Arriaga and González Sánchez, 1999).

Quarantine pests in the United States

Nowadays, the only potentially importer country that limits the buying of avocado due to sanitary quarantines is the United States. The U.S. Department of Agriculture published a list with 21 species of fruit fly, classified in 10 genres, detected since 1905 and 1918. This information was verified in 1942-1965, and since then and 1979, weevils are mentioned (4 species). Except for the weevils, the rest of the species are not important as pests, and there are not published studies on their detection and control. Furthermore, they are not known by the farmers and do not appear in technical reports. However, in the case of fruit flies, international quarantines still apply to prevent their spread into free zones. Twelve weevil species are mentioned: 6 of *Conotrachelus*, 2 of *Helipus*, 2 of *Stenoma*, and 2 of *Copturus*.

1.6 Consumer preferences

In Mexico, avocado is mainly consumed as a fresh fruit, and it is considered a traditional food (Figure 19 The consumption per capita is 10.0 kg, the largest market in the world). It has no substitute products, and the domestic demand is fulfilled. However, it is believed that the demand for avocado will increase once it is recognized as a functional food. As years go by, the domestic market has had a positive response to the increase of the offer, by increasing the demand and maintaining an equilibrium in the prices that is enough to keep and promote the growth of the cultivars in the region.

Figure 19 Avocado is mainly consumed as fresh, in developing countries.

This status has been maintained without any marketing campaign aimed to raise avocado consumption or suggest other uses for the fruit. No overproduction has been generated, so its industrialization has not been carried out in large volumes, as it is done in other countries. The Mexican market is not characterized by the demand of high-quality avocado; the consumers tend to focus on low prices. The marketing categories for avocado, according to the Mexican federal order NMX FF-016-SCFI-2002 are:

- "Suprema 1" Only 5% of the fruit may present damages; the defects should not be larger than 2 cm^2. Damages done by worms, viruses, and sun or low temperatures in the orchard are not accepted.
- "Calidad I" It accepts 10% of damaged fruit, defects should not be larger than 6cm^2. Slight defects caused by viruses (as long as the pulp is healthy) and thrips are permitted.
- "Calidad II" 10% of fruits are of acceptable quality, 50% with superficial attacks, 30% with sunburns, virus damage not larger than 2 cm^2 (Figure 20 Standards for supreme, quality I and quality II avocados)

Figure 20 Standards for supreme, quality I and quality II Avocados
(Source: Unión de Empacadores de Michoacán, México).

The whole process required to supply the fruit to the domestic market lasts from 4 to 10 days. Under the current handling conditions, the medium shelf life of the fruit is 12 to 14 days, which gives an appropriate time frame for the fruit to reach the consumer. In Mexico, consumers prefer fruit that is already dark in the peel and soft to the touch, this condition covers up some lesions originated in the field, such as anthracnose, avocado blight, or slight mechanical damage.
The consumer preferences in non-producer countries that import avocado may vary. However, the general aspects that the consumers of these countries look for are:

- Medium size (275 g approximately)
- 3/4 to fully ripen
- No insect damage
- No toxic residues

(Morales *et al.*, 2000)
Recently, a big interest on organic foods has developed in many countries, particularly about organic fruits and vegetables. In the United States, sales of organic products have grown approx. 20% annually since 1991. According to Katherine DiMatteo, from the Organic Commerce Association in the U.S.A, the highest growth within this market is expected for

frozen and prepared organic foods. This can influence the market of avocado products such as dip and frozen guacamole.

In 1995, the first organic cultivar in Mexico was certified. By 1997, eight orchards were certified, which produced 10,000 tons of fruit by the year 1998. Organic avocado is becoming an important part of the national marketing strategy, because of the increasing number of consumers and producers that are concerned about the environment. The industries of developing countries can benefit from the production of oil, cosmetics, and guacamoles elaborated from organic avocado, while consumers can benefit from clean and free of residue fruit (Quintero-Sánchez, 2001).

On the other hand, people around the world have contributed to diversify the uses of avocado, for example: in Brazil, it is added to ice creams and sorbets, in Japan it is eaten in sushi rolls, in Cuba the pulp is mixed with capers, green olives, lemon juice and olive oil to make a sauce that is served with steamed fish, in Nicaragua is stuffed with cheese, fried and baked.

In other countries like Taiwan, it is eaten with milk and sugar, in Korea is mixed with milk and used as a facial cream and body lotion, in Indonesia is mixed with coffee, rum and milk to make a refreshing beverage, in the Caribbean mixed with salt, garlic, and coconut and served as an entry, in the Philippines the avocado purée is mixed with sugar and milk, to make a beverage that is served as dessert (Ayala, 2001)

2 Post- Production Operations

In the period of time that occurs from the harvest of a vegetable product to its final destination, quality and quantity losses take place. These losses can be of 5 to 25% in developed countries, and of 20 to 50% in developing countries.

One of the objectives of post-harvest technologies is to reduce the losses, and has the following objectives:

To understand the biological and environmental factors involved in product deterioration.

To apply technologies to delay the decay of the product and best preserve its quality.

All fresh vegetable products contain a high water percentage, and therefore they are prone to dehydration effects (blight, wrinkling), bacterial and fungal attacks, as well as mechanical injuries due to inadequate handling. As decay of the fruit increases, it becomes more sensitive to infections.

When avocado reaches the physiological maturation point (harvest point), it contains almost 80% of water. It is a climacteric fruit with high respiration rates, and releases carbon dioxide and ethylene. This means that after harvest, the live tissues degrade at a high rate, together with accelerated internal and irreversible changes. Avocado can dehydrate at the relatively high environmental temperatures, and the mechanical injuries during handling will stimulate higher and faster fruit decay.

Sometimes, physiological disorders in the post-harvest stage are originated in nutritional imbalances of the trees. Orchards should have a balanced nutrition, and the fruit should be handled carefully, in order to increase post-harvest life and preserve quality (Sánchez-Pérez, 2001).

2.1 Harvesting

Production or pre-harvesting

Special attention should be paid to the nutrition of avocado orchards, specially when producing fruit for international markets. The trees should not have a deficiency or an excess of nutrients. Even though the soil has natural nutrient contents, they are consumed or lost during the development of the trees and need to be supplemented with minerals in the same amount as they are extracted (Figure 21 Avocado leaf showing nutrition deficiency). The main elements for a proper nutrition are: nitrogen (N), phosphorous (P), calcium (Ca), potassium (K), magnesium (Mg) and zinc (Zn).

Figure 21 Avocado leaf showing nutrition deficiency.

The yield can decrease up to 70% when the soil is not properly fertilized, and the symptoms of nutrient deficiency vary according to the specific mineral. Fertilization should be done according to the age, size, and specific needs of every tree. If these factors are not properly assessed, an excess of fertilizer may contaminate the phreatic water (Eng. José Cortez personal communication, 2003; Sánchez-Pérez, 2001).

Harvesting

Harvesting of the fruit before reaching an optimal point can lead to deficient ripening and quality. On the other hand, when the harvest of the fruit is carried out after the optimal point, its post-harvest life could be diminished. In order to determine this optimal harvest point, two quantitative maturation and harvest indexes are used: oil and dry matter contents. However, other complementary indexes can be considered, such as the size of the fruit and the appearance of the seed skin.

Dry matter is measured by placing approximately 10 g of thin slices of avocado pulp into Petri dishes. The uncovered dishes are placed in a microwave oven and cooked until constant weight (from 5 to 15 min). Dry matter content should be 22.8% for "Hass" and 21% for "Fuerte". It is also important to consider that a large size of the fruit it is not always an indicator of advanced maturation. When the skin of the seed appears thin and changes its color to dark brown, the fruit tissue is probably ripe (Yahia, 2001).

Maturation indexes should be considered at the beginning of the export season. The dry matter analysis can also be performed using a domestic or microwave oven, and does not require an extensive or sophisticated training. Based on the experiences obtained in Mexico for export fruit, it can be established that avocados should have an average of 22% of dry matter, and the lowest value of a sample should not be under 20% (Sánchez-Pérez, 2001).

The harvest of the fruit destined to the Mexican domestic market is usually done by hand or with the help of hooks, which grab the fruit from the peduncle and let it fall into the ground. The fruit stays on the ground for several hours and in some cases overnight, before they are

collected into boxes or sacks. The first damage to the fruit is made by the pull-off, fall, and exposure to the elements (Morales *et al.*, 2000).
The harvest of higher-priced fruit is made with the help of a ladder and "ganchos" (hooks), which are metallic or wooden sticks of approx. 3 m long, with a collector bag and a sharp metallic hook attached at the end. The hook cuts the peduncle and the fruit falls into the bag. In Israel, a collector machine is used. This machine has a mobile tower of approx. 5 m in height, which cuts the fruit and collects it into a bag, as directed by an operator. In Mexico, harvesting machines consist of a platform that is elevated by an operator (Figure 22 Harvesting machine to collect avocado). A worker stands on the platform, cuts, and collects the fruit.

Figure 22 Harvesting machine to collect avocado

The manual harvest should be done bearing in mind the following points:

- Harvest should be done when fruits have reached 21% of dry matter in the pulp.
- Use of "ganchos" and ladders in good conditions (Figure 23 Hooks or "ganchos" to collect avocado)

Figure 23 Hooks or "ganchos" to collect avocado
source: SAGAR 1999.

- Avoid mechanical damage that could lower the commercial value, since it affects pulp firmness, turning it brown and soft. Mechanical damage and peel injuries accelerate water loss, respiration and ethylene release, and constitute entry pathways for pathogen attacks.

- The peduncle should be cut and not separated from the tree by pulling down the fruit. Avocados should never fall into the ground or be excessively exposed to the sun. The exposure of avocados to the sun increases the internal temperature of the fruit, which triggers physiological and chemical maturation processes that speed up maturation and decay.
- The cut of the peduncle should leave a portion of 8 to 10 mm on the branch, in order to avoid a fast maturation of the fruit. When the peduncle is completely separated, the internal respiration of the fruit increases, helping to the entry of pathogens
- The harvested fruit should be collected in proper places, such as boxes or baskets, in order to avoid mechanical damage.
- (Ing. S. Torres, personal communication, 2003; De los Santos-Vázquez, 2001; Rodríguez-Suppo, 1992).

2.2 Packinghouse operations

The processing of the fruit required for its packaging, preservation, and transportation is carried out as follows:
The fruit is received, weighed, and unloaded from the trucks. It comes in boxes of different colors to identify its final destination: domestic market, export, and organic fruit (Figure 24 Weighing avocados in a packing house).

Figure 24 Weighing avocados in a packing house.

The boxes are placed in a transport band that twist them over, and takes the fruit to a classification machine. This machine separates the small avocados.
Then the fruit is cleaned with rotating brushes, and goes to the selection band (Figure 25 Rotating brushes to clean avocado). The selection is carried out manually or with the help of machines, and considering the shape, size, and sanitary characteristics of the fruit, as well as all the defects caused by insects, rodents, mechanical mishandling, and illness (viruses, bacteria and fungi). The selection criteria also depend on the final destination of the fruit. In the case of the Global Frut packinghouse in Uruapan, Michoacán, the fruit is selected by weight, which is programmed in a machine according to the marketplace of destination. The weight classification allows having a uniform package and presentation in the marketplace.
The caliber is the number of fruits that can be packed in a single box. This avocado also varies according to the market of destination.

Figure 25 Rotating brushes to clean avocado.

Once the fruit size is selected, and the defected pieces have been discarded, it is packed. The packaging material varies according to the market, being cardboard, plastic, or wood. Individual boxes go to the "pallet" process, where boxes are stowed and tied together (Figure 26 Boxes with avocados are tied together, to form a packaging unit). Pallets are a packaging unit for transportation, and should comply with the measurements established by the containers they will be carried in. The number of boxes per pallet varies according to the packinghouse, but is usually 200 boxes of 4 kg each and a lower number when boxes weight 6 kg.

Figure 26 Boxes with avocados are tied together, to form a packaging unit.

Pallets pass immediately into refrigerated chambers where they first undergo a pre-cooling process. Afterwards, they will enter the preservation chamber (Figure 27 Refrigeration chamber to maintain avocados at 3 to 7 ºC), where they will stay until loaded into the transportation unit. Preservation temperature ranges from 4.5 to 6.5°C (Mario Rivas, personal communication, 2003; Sánchez-Pérez, 2001; and Rodríguez-Suppo, 1992).
Avocado has a very small chance of being contaminated by pathogens, because it grows suspended on the branches and it is not in contact with chemical or biological fertilizers, and irrigation water. Avocado is also protected by a thick peel. However, packing operations present a contamination hazard. Water (if used in the process) should be disinfected, insects and pests controlled, garbage recollected, and the people working with the product should be properly trained (Salazar-Arriaga and González-Sánchez, 1999).

Figure 27 Refrigeration chamber to maintain avocados at 3 to 7 ºC.

2.3. Packing and packaging materials

The purpose of packaging is to preserve the fruit in good condition. The container protects the product through all the stages of the distribution process, such as transportation, load, unload, stowing, and storage.

It has been determined that a well-designed package helps to reduce damages in food products, particularly in perishable ones such as fruits and vegetables. Bearing in mind that packaging may restrict gas diffusion; one might conclude that post-harvest losses could be increased. In this way, it is considered that 25 to 30% of food produced worldwide are lost due to deficient packaging (Kader, 1991, Rodríguez, 1997).

The use of packaging material implies an increment in the final cost of the product, nevertheless most of the times it improves the appearance and quality preservation of the fruit.

For the particular case of avocado, and exclusively for the ones destined to foreign markets, the types of packages and containers vary according to the different packinghouse specifications. The most common containers are single wall corrugated fiberboard or wooden boxes (Figure 28 Containers may be boxes of corrugated fiberboard, plastic or wood). The first ones usually have a capacity of 4 kg with one level of fruit, while the second ones contain 10 kg, and the fruit is placed in bulk. The wooden box has a lower demand than the fiberboard box. Cardboard boxes have different perforation designs, and resistance to compression: from 55 to 275 lb/sq ft, approximately (López-López, L., and Cajuste-Bontemps, J.F., 1999).

Figure 28 Containers may be boxes of corrugated fiberboard, plastic or wood

An adequate design of the packaging material should consider the following fundamental aspects:

Ventilation: should allow air circulation, particularly in the transportation container (Figure 29 Perforated boxes allow air circulation.).

Ventilation systems can be horizontal or vertical. Containers for maritime transportation are equipped with vertical air circulation, while cooling rooms and ground transportation containers have horizontal air circulation. Sometimes the box is designed for both air systems, which could make it weaker, and thus it is important to strengthen the box.

Piling force: type and quantity of the right materials should be use to avoid falling of the boxes.

Labeling: some information is legally required, such as the origin and identification of the product, net weight, and producer. It is up to the country or the buyer that will receive the fruit to require additional information. It is very convenient to inform the final consumer about ripening conditions, storage temperature, and uses of the product. For example, to inform that lemon juice prevents browning of the pulp (Yahia, 2001).

Figure 29 Perforated boxes allow air circulation.

López-López and Cajuste-Bontemps (1999) studied the effect of different fiberboard box designs on the quality of avocado, and concluded that those boxes with the highest perforation surface help to preserve the firmness, general appearance of the fruit, and delay maturation.

On the other hand, the United States Department of Agriculture requires that the original boxes for Mexican Hass avocados must each have a stamp that lists the distribution restrictions. Once in the approved states, if any avocados are removed from their original shipping boxes and repackaged, the stickers required on the fruit must not be removed or obscured and the new boxes must be clearly marked with all the following information: the identity of the grower, packinghouse, and exporter, and the statement "Not for distribution in AL, AK, AZ, AR, CA, FL, GA, HI, LA, MS, NV, NM, NC, OK, OR, SC, TN, TX, WA, Puerto Rico, and all other U.S. territories."

Each industry in the Mexican Hass avocado import process is responsible for following USDA regulations. Industry employees should be aware of these regulations and the penalties if the regulations are not followed (APHIS, 2003).

2.4. Cooling system

Pre-cooling

A pre-cooling operation is generally carried out after packaging. Pre-cooling is of prime importance for the shelf life of avocado, because it diminishes or slows the metabolic rate, ethylene synthesis and its action on the fruit, loss of texture, fungal infections, fruit ripening, and conditions the fruit for preservation at low-temperatures. Ideally, there should not be more than six hours from harvest to pre-cooling, and when this is not possible, the harvested fruit should not be allowed to reach an internal temperature higher than 26°C in the field and during its transportation to the packinghouse.

The quantity of the field heat is usually large, and cannot be eliminated fast enough in a regular refrigeration room. The freeze-blast method is the best suited for avocado pre-cooling. It is carried out until the temperature in the fruit reaches 6-7°C for "Fuerte" and "Hass". The time that is required to achieve these temperatures varies according to the initial

temperature of the fruit, temperature and velocity of the air, and the final temperature of the fruit.
However, it is important to end the pre-cooling process when the temperature of the fruit is 2°C above the ideal storage temperature. It is also of prime importance to assure that the storage temperature will not be lower than that established for the fruit, otherwise chilling injury can occur. The pre-cooling process lasts from 8 to 12 hours, with a relative humidity of 90 to 95% (Yahia, 2001, and Sánchez-Pérez, 2001).

Refrigeration

Temperature control during the post-harvest stage is the most important factor that helps maintain the quality and increase the shelf life of many fruits. Refrigeration is also useful to control illness and pests (Figure 30 Cooling chambers with avocados).Generally, the shelf life of avocado is inversely proportional to its respiration velocity.

Figure 30 Cooling chambers with avocados.

It is of prime importance to avoid temperature fluctuations during transportation, because this can cause chilling injury, ripening, irregular softening, and rot (Yahia, 2001).

2.5. Storage of avocado

When avocado reaches the packinghouse, special care should be taken so that different batches will not mix up. The origin of the fruit, supplier, date, etc., should be registered. Before processing of the fruit, the lot shall be sampled in order to detect quarantine pests and illnesses, and determine the general appearance of the fruit and its quality (stains, discolorations, injuries, mechanical damage, etc). At the same time, the characteristics of the particular variety are verified (Sánchez-Pérez, 2001).
The response of avocado to storage temperatures varies according to temperature ranges, as follows:
10 to 25°C: the fruit softens faster as storage temperature increases.
5 to 8°C: softening is controlled, and it will only occur if the fruit is transferred to higher temperatures.
0 to 4°C, softening at these temperatures is limited by time, due to the risk of chilling injury.
However recommended storage conditions may vary according to the avocado variety (Table 9)
Physiological disorders decrease when temperatures are kept at 7.5<°C at the beginning of storage, and then are lowered to 3.5°C, instead of maintaining 5.5°C the whole time (Yahia, 2001).

Table 9 Recommended storage conditions for some avocado varieties (Yahia, 2001) Modified or controlled atmospheres can increase shelf life when combined with controlled storage temperatures, as observed in the Table 10.

Table 10 Avocado preservation with controlled atmospheres (Yahia, 2003)

Variety	**%O_2**	**%CO_2**	**Temperature °C**	**Remarks**
Hass	2-10	4-10	7	Storage time of 7-9 weeks
Lula, Booth 8, Fuchs	2	10	7.5	Increase shelf life twofold
Fuerte, Edranol, Hass	2	10	---	Reduces internal disorders
Non-specific	---	25	---	Reduces disorders and increases anthracnose
Fuerte	---	25	---	Delays maturation
Fuerte	2	10	5.5	Less dark spots in the pulp
Fuerte	---	25	5.5	Less dark spots in the pulp
Fuerte	3	0	24 h at 17°C	After this treatment, fruit can be stored at 2°C for 3 weeks
Booth 8, Lula	2	10	4-7	Storage time of 8 weeks
Fuerte, Anaheim	6	10	7	Storage time of 38 days
Waldin, Fuchs	2	10	7	Storage of 4 weeks, prevents anthracnose and chilling injury
Hass	2	5	---	Storage time of 60 days

2.6. Transportation systems

Transportation of the fruit from orchards to packinghouses is done by trucks that carry one ton (Figure 31 Transportation of avocados from the orchard to the packing house). Once avocados are packed, they are distributed in trucks with a capacity of 10 tons. Export fruit travels 2 days from Uruapan to Altamira in the State of Tamaulipas (Gulf of Mexico) in a truck with refrigerated containers, and from there 15 days more to Europe in a cargo ship. It takes 17 days to the European continent when the fruit takes the route Manzanillo-Panama-Europe. Transportation to this market represents 30% of the final cost of avocado.

Figure 31 Transportation of avocados from the orchard to the packing house.

The storage temperature should be maintained with a maximum variation of 1°C, when transferring the fruit into refrigerated transports. This is particularly important when fruit will be stored along a relatively long period before it reaches the market. The threshold for chilling injury appears between the third and fourth weeks of the refrigeration period.
This should be considered for long-distance maritime transports. When reaching the port of destination, avocados should be sent immediately to the retail distribution channels, with the aim of shortening the refrigeration time (Yahia, 2001; Sánchez-Pérez, 2001; Mario Rivas, personal communication, 2003).

2.7. Processing

Aguamich is a Mexican processor based in Uruapan, Michoacan. They produce and market avocado salsa, guacamole blend, avocado pulp, spicy guacamole, and avocado drinks (Guacamaya brand). They have their own orchards, and they also buy fruit from other farmers.
Upon receiving the fruit, it is washed in a machine with rotating brushes and chlorinated water (200 ppm) (Figure 32 Avocados are cleansed by wet or dry process)
Then its temperature is homogenized to 5°C to allow an even ripening. Avocados are stored for 3 days at 20°C at a relative humidity over 85%, adding 10 ppm of ethylene. Afterwards, the temperature is lowered again to 5°C and the fruit is kept at that point until processing (3 to 4 days). Since many clients prefer a chunky texture, the fruit must be ripe and firm.

Figure 32 Avocados are cleansed by wet or dry process.

Processing begins with a selection step, where the unsuitable fruit is discarded, the peduncle is removed, and the fruit is submerged in chlorinated water (200 ppm) for 10 min. Then it is cut, seeded, peeled and put into a mixer with other ingredients, such as onion, chili pepper, fruit concentrate, erythorbic acid (to promote color retention), and ascorbic acid. The resulting product is vacuum-packed and sealed into co-extruded five-layer bags, with a high barrier to oxygen. They usually pack in 6 pound bags, because most of their customers are restaurants, but they also have a 250 g package for retail marketing. The bags are frozen in a blast-freezer at -30<°C, and afterwards the bags are stored at -18°C (Figure 33 Guacamole bags).

Figure 33 Guacamole bags.

80% of Aguamich's production is sold in the United States, the rest in Europe and Japan. They have only two clients in Mexico. When in high season (September to May), they produce 3 million pounds, However, in low season when the price of avocado is higher, they produce 2,000-3,000 pounds a day. They employ 150 people, 70 in pulp processing, and the rest in the packing of fresh fruit (Ing. Jorge León, personal communication, 2003).
Avocado is also used for the confection of baked products (such as cakes), to elaborate fine soup mixes, appetizers, and in the production of cosmetics (oils, skin lotions, soaps, shampoos, etc.) due to its oil content. Avocado oil is appreciated because it contains an easy to absorb sterol, and it is biodegradable.
Besides being an important cosmetic ingredient, the pharmaceutical industry considers the unsaponifiable fraction of the oil as a valuable raw material. From this fraction, the factor H is extracted, which is used in the pet food and cooking oil industries.
The avocado oil industry processes around 1000 tons of fruit per year, from which 500 tons of raw oil are obtained. From this, 5% is used in the production of edible oil (90%) and cosmetics (10%) in Mexico, and the rest is exported. The exported oil (495 tons per year) is sent to the United States, where it is refined and then sent to Japan and Europe as edible oil and cosmetic ingredient. Between 10 and 20% of the oil is lost in the refining process (SAGAR, 1999).

3. Pest control and decay

Pests have an economical impact on the avocado producer as they damage the branches, trunk, leaves and fruit. Pests are also a cause for quarantine restrictions when the fruit is exported.

Mexican avocado overcame the last sanitary barrier for its exportation to the United States, which limited its global commercialization. Since 1990, negotiations began with this country and, as a consequence, local, regional and state sanitary commissions were established, which began gathering information regarding infestation zones, population dynamics, biological cycles, as well as control and eradication techniques of quarantine pests (Morales, 2000).

In Chile, the change of Chilean avocado varieties to Hass variety has not meant an important change in the diversity of pest species that affect the fruit, but a change of the importance of each pest on the crop. Even though 31 species of insects are potentially harmful to Chilean avocado (Prado, 1991), only 9 species are considered as economically important (González, 1989) and among them, often only 1 or 2 species will be relevant for a particular crop. Most of the times, no chemical substances are needed to control them.

In Mexico, some authors reported different numbers of pest species of importance for avocado crops, for example, SAHR-DGSV (1981) mentioned 12 as important pests, Gallegos (1983) reported 46, and Coria (1993) enlisted 11 species for Michoacán. However, as it is the case in Chile, only few pest species are economically important for avocado crops (Téliz, 2000), except in areas with deficient handling, lack of problem diagnosis, and inadequate application of labor and supplies. Avocado pests affect 14% of avocado production and diminish the fruit quality in 10%, which increases the costs in 23% (Vidales-Fernández, 1999).

The International Sanitary Certificate is required at the sanitary inspection booths in order to permit the exportation of avocado. In Mexico, the orchards must be registered in the Agricultural Ministry and the producer must register all the activities related to the prevention and control of pests in a "Sanitary Calendar" (Morales, 2000).

3.1 Pest species

Avocado root-rot, *Phytophthora cinnamomi* Rand. Root-rot is the most important disease of avocado in the world. In Michoacán, it is present in every cultivar, affecting 5% of the total surface of crops. *Phytophthora* is one of the most pathogenic fungi in the world and causes the death of trees (Vidales-Fernández, 1999). As a first symptom of the disease, the foliage of the affected trees begins to decay and discolor to yellow. The leaves start to fall down until only the branches remain. Sometimes, a recovery can be observed in the dry season, when applying a nitrogen-rich fertilizer and fungicide to the ground. As a consequence, the farmers do not follow the recommendations of uprooting and disinfecting the trees, and thus the disease spreads around.

The Wurtz variety has a high tolerance to this fungus, growing in affected areas without any symptoms, and it is uncommon to lose this kind of tree to the disease. Some hybrid trees ("criollos") are also resistant, and efforts to preserve them have been enforced (Morales, 2000).

Avocado blight, *Sphaceloma perseae* (Myriangiales: Elsinoeaceae). It is found throughout Michoacán and it is considered an endemic pest. Avocado blight or "roña" is also found in Florida, where it is the second most important pest, Puerto Rico, Brazil, Africa, Peru, Cuba, Haiti and California.

The *Sphaceloma perseae* fungus attacks the fruit (in all stages), leaves, and young branches. The affected fruits present brown lesions of corky aspect with round or irregular shapes at first (Figure 34 Fruits affected by avocado blight or "roña").When these lesions grow and come together, they can cover a large part of the fruit or the whole fruit, and cause fissuring

in leaves and branches. In leaves, the pest forms small individual stains of dark brown color of less than 3 mm in diameter when the attack is severe, the leaves and nervations are also distorted. In nervations or green branch barks, the lesions are elongated and slightly prominent. In the fruit, the damages are exclusive of the exocarp, while the fruit remains healthy. However, the lesions can be an entry point for other organisms (Gallegos, 1983).
The *S. perseae* conidia have a size of 2.3 to 2.5 mm, with a cylindrical to oblong shape. The color of the colonies is variable, from grayish white to dark gray and darker with age, as opposed to the *Colletotrichum* colonies, which have a salmon color (Marroquín-Pimentel, 1999).
The *S. perseae* fungus requires a high relative humidity and high temperatures for its proper development. The most susceptible stage of the fruit is when it reaches a third or a half its normal size, because when the fruit ripens, the exocarp hardens. The damages of the fruit caused by insects, rodents or mechanically allow the entrance of the pest, which produces spores on the attacked tissue. The spores are carried away and disseminated by the wind, rain or insects.

Figure 34 Fruits affected by avocado blight or "roña"

Source: Sanidad Vegetal de Salvador Escalante Michoacán, México
From all the cultivars grown in the Michoacán region, "Fuerte" is the most susceptible to the disease. "Hass" can also be severely affected if the pest is not prevented. Booth 1, Pollock, and Waldin are considered slightly susceptible. The local hybrids ("criollos") are also likely to be affected by the fungus, although the incidence is lower because the fruit from these trees ripens in the spring (Gallegos, 1983).
Thrips *Liothrips persea* Watson, *Scirtothrips aceri* Moulton, *Frankiniella cephalica, Heliothrips haemorrhoidalis* (Insecta:Thysanoptera: Thriphidae). Similar to the red mite complex, the thrip pests are constituted by several species in every region. They are found in Florida, California, Mexico, Central and South America, Argentina and Chile. Thrips have a stronger presence in tropical and subtropical coastal zones, and their damage is reduced in the avocado cultivars located between 1900 and 2400 m of altitude.
Thrips are small insects, 0.3 to 14 mm in length, and white or pale yellow to dark brown in color. One of their main characteristics is two pairs of long wings that sometimes cover the abdomen. They have a sting-sucking mouth apparatus (Ullman *et al.*,1992). Johansen et al (1999) published a taxonomic study of 41 Mexican species of insecta Thysanoptera inhabiting *Persea americana* Mill floral and foliar structures. They reported that a total of 38 species are phytophagous, whereas only three are predators. Only six phytofagous species can be considered as primary pests for the young fruit or foliar structures, and the other 32 can be considered as incidental visitors. The three predatory species live in both natural ecosystems

and avocado agricultural ecosystems. The cacao thrips, *Selenothrips rubrocinctus*, and greenhouse thrips *Helipthrips haemorrhoidalis*, are the most common and relevant for avocado in the world. These species are poliphagous and have a worldwide distribution (Lewis *et al.*,1997).
All the species survive on foliage, by scraping and sucking the superficial cells, thereby causing the appearance of discolored spots, which are silver-white at firs, and later turn dark. This is observed more often on leaves and fruits, however, they can also be found on tender shoots, buds, and flowers. The damages produced by this pest can make the crop loose up to 50% of its commercial value (Adame, 1994; Gallegos, 1983).
Thrips are one of the most relevant pests for avocado cultivars in Mexico. They can cause malformation of the fruits, (Figure 35 Avocado affected by trips) premature falling from the tree and damage the vegetal tissues when feeding, producing lesions that become entry points for microorganisms such as *Sphaceloma perseae* (González-Hernández *et al.*,1999). The major damage is caused when the thrips feed on young fruits, producing crest-shaped malformations of the exocarp, which are more evident in ripe fruits Coria (1993) mentioned that some types of weed, such as *Asteraceae*, are alternative hosts for thrips.

Figure 35 Avocado affected by thrips
Source: Sanidad Vegetal de Salvador Escalante Michoacán, México

Small seed weevil, *Conotrachelus perseae* Barber (Coleoptera: Curculiondae: Cryptorhynchinae). It is found in the eastern central region of Mexico and northern parts of Central America, Guatemala, and Panama.
The adults are typical beaked weevils, dark brown in color, average size 7 mm, capped antenna with geniculated base. They emerge from pupae in the soil at the beginning of the rainy season. The females lay their eggs in the surface of the fruit. The eggs are transparent at first, turn to grayish white, and hatch after 6 or 7 days of incubation, measuring approx. 0.8 to 1.0 mm. The larvae are of yellowish white color with a dark cephalic capsule, and reach a length of 6 mm. They tunnel, forming a gallery throughout the pulp until they arrive at the seed, which is usually destroyed (Figure 36 Avocado damaged by large seed weevil)

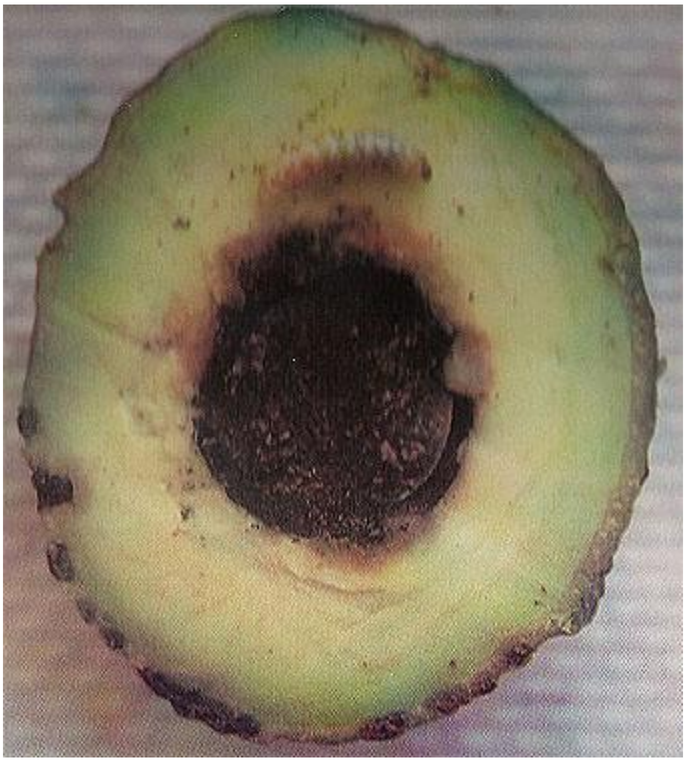

Figure 36 Avocado damaged by small seed weevil
Source: Sanidad vegetal de Ziracuaretiro, Michoacán, México

The larva cycle lasts from 18 to 20 days, followed by the prepupa that lasts from 22 to 23 days, and then the pupa that lasts for 13 more days. The larvae in their last stage leave the fruit and fall down to the ground, where they form a cocoon of about 5 cm beneath the soil. The adults are nocturnal in habits and feed on leaves, fruit, and tender branches. During the day they rest in the hollow of coiled leaves, leaf axis or inflorescences. The cycle from egg to adult lasts about 78.5 days for the female and about 76.5 days for the male. Their life span can be up to 140 and 111 days respectively, with two generations per year, but generations can overlap.

Highly infected areas can affect up to 85% of the fruit, destroy the seeds and notably affect the production since this situation induces the falling of the fruit from buds to maturity (Llanderal and Ortega, 1990; Martinez *et al.*,1987).

Large seed weevil, *Heilipus lauri* Boheman (Coleptera: Curculionidae: Hylobiinae). It is found in the western central region of Mexico, but not in the avocado cultivars of Michoacán. Other species of this weevil are *H. sguanosus* found in Florida and California, the Antilles, and in the Virgin Islands; *H. pihieri* in Central America; *H. cartagraphus* and *H. montei* in Brazil; and *H. persea* in Panama.

The adults are large beaked weevils, 12 to 15 mm in length, of bright reddish-black color with a rough dorsal section, and elytra with 2 yellow stripes that is more noticeable in males, which are slightly smaller than females. Females lay 1 to 2 oval-shaped eggs in a previously made cavity under the epidermis of the fruit, which at the first are green in color and later become darkened. The eggs incubate from 12 to 14 days, and then the larvae are hatched. The larvae are curved in shape, legless and of a creamy white color. They go through five instars in a period to 54 to 63 days, and they reach a length of 12.5 to 25 mm. They tunnel through the flesh of the fruit, forming a gallery that extends to the seed, which is usually destroyed. Furthermore, they produce secondary rotting of the flesh and the seed. The pupae develop inside the fruit after 14 to 16 days, in some cases leaving the fruit and forming chrysalis in

the ground. The adults have a life span of 3.4 to 4 months; they feed on leaves, buds, sprouts, and fruits, producing 2 generations of insects per year.
This pest affects up to 80% of the production as they destroy the flesh, seeds, and cause a premature falling of the fruits (Bravo *et al.*,1988; Gallegos, 1982)
Seed moth, *Stenoma catenifer* Walsingham (Lepidoptera: Stenomidae). This is one of the most widely distributed avocado pests in Mexico, being found in the east and coastal zones of the country. It is also found in Guatemala, Costa Rica, Panama, Colombia, Venezuela, Peru, Bolivia, Ecuador, Brazil, and Argentina.
Young adults are yellowish colored moths, and later change to a grayish-brown color. They measure 7 to 9 mm, with a wing length up to 25 mm. The forewings have 25 dark spots that form an "S" shape across the wing. These insects have night habits and mate after 1 or 2 days of their emergence, and lay their eggs a day after mating. The eggs are deposited on or near the fruit, and also on tender branches. The eggs are semi-spherical in shape, light-green colored, and no longer than 0.6 mm. Upon hatching, whitish larvae emerge and penetrate the fruit forming galleried which extend to the seed, and in branches extend to the central cylinder. They pass to 4 or 5 instars that last from 15 to 19 days. In the last of the instars they turn purple on the dorsal side and blue in the abdomen, reaching a maximum size of 18 to 22 mm. They abandon the fruit, which by this time is usually fallen in the ground, where pupation takes place, lasting for a period of 8 to 12 days, in a depth of 2 to 5 cm. The adults emerge and live an average of 8 days. The average life cycle is 46 days with 3 generations per year.
Seed moths can penetrate fruits of any size and destroy the seed completely. The galleries they form inside the branches cause withering, reduce flowering of the tree and seriously damage up to 90% of the production (Bravo *et al.*,1988; Gallegos, 1982; García-Martel *et al.*,1983).
Red or brown mites, *Oligonychus* (Homonychus): *Opunicae hirst*, *O. yothersi* Mc. Gregor, *O. platani* Mc. Gregor, and *Eotetranychus sexmaculatus* Riley. Acarina: Tetranychidae. The insect complex designed as red or brown mite is present in most of the avocado producing countries, different kinds prevailing in accordance to environmental and climatic conditions. For example, *O. punicae* is the most widely distributed, being found in California, Florida, Brazil, Argentina, Colombia, Ecuador, Chile and Central America. *O. platani* is found in the states of California, Arizona, and Texas, as well as in Coahuila (in the north of Mexico). *E. sexmaculatus* is found in California, Florida and Arizona.
O. punicae attacks the surface of leaves, mainly near the nervation where dusty-like colonies are formed. The adults are oval in shape, slightly elongated, of pink color and have purple or brown spots on the lateral areas of the abdomen. The males measure 0.3 mm and the females 0.4 mm. They lay eggs throughout the nervations and incubate for a period of 7 to 10 days. At hatching, the larvae are colorless, with six legs, and no larger than 0.1 mm. The instar lasts form 2 to 3 days, at the end they become protonymphs of pink or pale green color, double the size of the larvae and last for 2 days. Afterwards, they enter the neutonymph stage and turn a little darker but are still transparent. They increase in size to 0.2-0.3 mm, have 8 legs and last for 2-3 days. Upon concluding the nymphal stages, the insects reach adulthood having 8 legs, and a life span of 15 to 45 days, depending on climatic conditions. The total life cycles varies from 30 to 60 days.
These mites attack the surface of leaves, produce abundant colonies and hibernate as eggs. The adults emerge at temperatures of 15.5 to 21ºC, however, their best development and greater longevity happens at 26ºC. The attacks to the trees are more severe during the dry season, with a relative humidity lower than 60%. Rain severely affects these mites, violently decreasing their population at the beginning of the rainy season.

When sucking the sap out from the cells, the mites alter the proportions of chlorophyll and photosyntates, which produces the chlorosis symptom: brown coloration of leaves and defoliation. Furthermore, the carbon-nitrogen ratio is altered which reduces the production of growth elements. This results in the reduction of budding, flowering, foliage development, and consequently, the fruit production for the next season (Arias, 1984, Eveling, 1959, López, 1990).

White fly. *Trialeurodes floridensis* Quaintance, *Tetraleurodes* sp., *Paraleyrodes persea* Quaintance. (Homoptera: Aleyrodidae). White flies are an endemic pest of worldwide distribution. However, their attacks are more severe in regions with warm and humid climates, such as tropical coastal regions. They are present all year long, and it is during the months of spring and summer (rainy season) when their population is increased to important levels that require control. In the avocado growing regions of the Americas, white flies are found in Florida, Mexico, Central America, the northern part of South America, and of less importance in California, Chile and Argentina.

Paraleyrodes persea is the most widely distributed species in the Mexican avocado cultivars. The adults are small white moths, from 1.5 to 2.5 mm in length, with four wings covered by a white waxy powder. They form white powdery colonies of circular shape 1.0 to 1.5 cm in diameter. The females lay numerous white eggs of approximately 0.3 mm. A mobile oval nymph of yellowish-green color is hatched and after 5 days the legs fall off, it attaches itself to the leaf and turns black. The sides have short waxen filaments. In these immobile forms the insect passes two instars of 6 to 7 days, feeding on the tree sap. The complete nymphal period can vary from 18 to 30 days in the summer, and from 20 to 42 days in the winter, producing 3 generations per year.

In severe attacks, 15 or more colonies can be formed in the back and in the surface of the leaves, indicating the intensive sap absorption. The attack is usually stronger in the mature and lower leaves of the tree, causing intense defoliation. Chlorotic cycles of yellowish color are observed and the fruit production is reduced. The abundant wax secretions of the colonies are often associated with the growth of molds (Martinez, 1984).

Dog worm or swallow wing butterfly. *Papilio garamas garamas* Hübner, *Papilio victorinus merelius* Rothschild and Jordan, *Papilio crespontes* Cramerg (Lepidoptera: Papilionidae). Dog worm is widely distributed in the citrus and avocado zones of America. Its incidence is greater in tropical and subtropical zones, and much lesser in high zones.

The adults are medium to large size butterflies with a wing span of 8 to 10 cm. There is sexual dimorphism in wing size and color. They are black with parallel yellow stripes and arched on the distal edge of the wings. The back wings have prolongations in the posterior region, from which the name "swallow wing" originates. The eggs are light green in color, usually measure 1.8 mm in diameter, and are laid on the surface of the leaf near the central venation. Incubation lasts from 10 to 14 days. The larvae are small and voracious, quickly increase in size and go through 5 instars. They secrete a substance based on valerianic acid that gives them a strong, disagreeable odor that works as defense and protection. The 5 larvae instars last for 40 days, after which they pupate forming a chrysalis of 4 cm in length, with a grayish brown tip. They attach themselves to the end of a branch by weaving a silky thread around the branch and the pupae. This phase lasts an average of 25 to 40 days before the insect emerges as an adult.

Dog worms are voracious defoliators, generally of gregarious habits, but a few of the larvae of the last instars can completely devour the foliage of a medium size tree. Fortunately, in avocado orchards their incidence is low, isolated and only happens in the summer (from July to September). The affected trees can loose their flowers and fruit production for the following cycle (Bravo, 1988; Del Rio, 1978).

Leaf roller worm and Amorbia moth (called "gusano descarnador" in spanish) *Amorbia emigratella* Busck, *A. cuneana* Walsingham, *A. essigana* Busck (Lepidoptera:Tortricidae). The various species of *Amorbia* can be found in California, Mexico, and Central American countries such as Guatemala, Costa Rica and Panama. It is an endemic pest, present in the summer months.

The adults are small moths from 2.5 to 3.0 cm in length and reddish-brown in color. The males are slightly smaller, with dark triangular spots in the center of the front wings, and dark distal edges. They are nocturnal in habits and have a life span of 15 to 20 days. The females lay eggs on the surface of leaves: masses of light green eggs in overlapping layers that require 13-15 days to hatch. The larvae go through 5 to 7 instars, which are differentiated by their color and size. In the first instars, they are yellowish-green in color, from 2 to 3 mm, and in the last they are dark green, from 20 to 30 mm. When they are bothered, they let themselves fall down suspended by a silky thread, which they use to roll up the leaves or fruits, and sometimes 2 or 3 larvae can be found together. The pupae measure an average of 18 mm and are green at first, later turning brown, and last for an average of 17 days. The complete life cycle varies from 98 and 120 days depending on the location and season of the year. This insect produces 2 or 3 generations per year, however, only one generation is enough to produce important damage.

The damage is caused by the larvae, when destroying a large amount of foliage and tender shoots. (Figure 37 Leaf roller worms and Amorbia moth affects avocados).

More important is the damage done to the fruit, since they frequently bind together fruits and/or leaves with their webs, taking shelter and feeding of them, producing injuries that can favor secondary rotting (Bailey and Hoffman, 1980; Martínez and Adame, 1987).

Figure 37 Leaf roller worms and Amorbia moth affect avocados
Source: Sanidad Vegetal de Salvador Escalante Michoacán, México

Omnivorous looper, green worm, or burn worm *Copaxa multifenestrata* Henrich Schaffer, *Copaxa decrescens* olivine Draudt (Lepidoptera: Saturnidae). This is a pest of secondary importance, apparently attacking only the avocado producing regions of Mexico. However, the adult is also found in Central America.

The adults are large reddish-brown butterflies from 7.3 to 10.2 cm, the males have darker tonalities and large bipectinate antennae. The females are of lighter color, with smaller antennae. The front wings have 3 or 4 circular areas with no scales, and have wavy bands of darker color.

The females lay masses of tiny eggs on the surface of the leaves. The eggs are oblong, white and measure 1.9 mm in diameter, incubating 21-22 days. The larvae go through 5 instars after hatching, varying in size, color and duration. During the fifth instar, which lasts from 7 to 9

days, they reach their maximum size, up to 6.5 cm, with yellowish green color and black spots. All instars present 3 pairs of thoracic legs. The pupae measures from 2.5 to 2.9 cm in length, they hibernate in this stage under the fallen leaves or under host trees for a period of 40 to 45 days. The total life cycle lasts from 106 to 122 days, and two generations occur per year.
This pest defoliates severely, but the damage is only considered important in young trees or in the greenhouse (Figure 38 Avocado damaged by omnivorous looper or "gusano medidor") Defoliation in adult trees is concentrated in few branches and apparently does not affect production (Bravo, *et al.*,1988).

Figure 38 Avocado damaged by omnivorous looper or "gusano medidor"
Source: Sanidad Vegetal de Salvador Escalante Michoacán, México

Green fly *Aetalion quadratum* Fowler (Homoptera: Aetalionidae). The only host for this pest is the avocado tree, and fro this reason the green fly is considered monophysitic, or accentric. It prefers the native Mexican-Guatemalan ecotypes such as "Fuerte". It is found in the Mexican high plateau and in northern Guatemala.
The adults are insects that reach 1 cm in length. Their color is green to grayish brown, with some orange spots; the wings are membranous with marked venations and a little longer than the body. The eyes are red and the male is slightly smaller than the female. The females lay eggs in young branches and tender shoots where they make small incisions. The eggs are white, almost transparent, and oblong in shape, 1.4 by 0.5 mm and ordered in lines separated longitudinally as well as transversally by a waxen partition. The egg masses are oval in shape, slightly raised, 0.5 to 0.8 cm of width, and up to 1.0 to 1.5 cm in length. The female stays on top of the eggs until the nymphs emerge, which are white in color but rapidly change to a yellowish-green color, and then to a grayish color in only a few hours. They go through 5 instars, at first with semi-mobile wings. The complete life cycle can last from 129 to 140 days with two generations per year. The first adults appear in the spring (March-April) and the second generation at the end of the summer (August-September). They can hibernate as eggs or adults.
Given the fly's habits of forming numerous groups or colonies, and almost spending their lifespan on the same branch, they are able to affect many branches of a tree and kill the new shoots, causing loss of vigor and consequently diminishing the production. The mobility of the green fly is very limited, therefore their dispersion is slow, taking one generation to spread from tree to tree. A secondary damage caused by this pest is the association they often present with phytopathogenic fungi. The adults and the nymphs feed by puncturing and sucking the branches, producing injuries that secrete a white granular sap, that together with

the secretions of the insects, form a favorable medium for the development of fungi, such as *Glomerella singulata* and *Capnodium* spp. This causes the withering of the branches and sooty molds, respectively (Morales, 1957).

Avocado treehoppers or avocado parakeet *Metcalfiella (Hoplophorium) monogramma* Germar (Homoptera: Membracidae). This was a widely distributed pest in all the native Mexican avocado zones, mainly on the Mexican high plateau. Today, due to the expansion of the cultivation of the Hass variety, this pest is no longer of importance (Bravo *et al.*,1988, Morales, 1957).

Avocado leaf gall *Trionza anceps* Tuthill (Homoptera: Psilidae). It is considered a monophysitic pest since its only reported hosts are the native Mexican avocado tree and comes times the Mexican-Guatemalan variety known as "Fuerte", and on extremely rare occasions the Hass variety. It has only been reported in the avocado zones of Mexico and Guatemala.

The adults are very small, flattened insects of oval shape, no larger than 2.5 mm, of greenish-yellow color with transparent wings longer than the body. They have strong and short legs that help them to walk and jump easily. They have long and fine antennae consisting of nine segments; red eyes and a highly developed thorax. The females lay 1 to 7 eggs in the cut they have previously made on leaves, and place them between the surface and the parenchyma tissue. The eggs are no larger than 0.25 mm, and upon hatching, the nymphs begin feeding on the tissue, secreting substances that act as stimulant to the cells, which begin to grow in a hypertrophic manner. The nymphs pass 5 to 6 instars inside the leaves, gradually increasing in size from 0.3 to 2.5 mm. They are of flat, oval shape, yellowish-orange color, and have a border of hair or quills around the edges. In the last instar, they leave the gall through an orifice in its base or in the underside of the leaf. The life cycle is estimated to last approximately 60 days, and there are 5 or 6 overlapping generations per year.

Spectacular symptoms can be seen since a large number of galls are formed. The gall is light green at first, and then turns dark green, brown or dark brown once the adults have migrated. The dimensions also vary with time, growing from 2 to 3 mm in diameter to 4 to 5 mm. In intense attacks, there is defoliation with severe consequences in production, due to the loss of both quality and quantity of the fruit. When the trees have been infested with these parasites for a number of years, they are no longer productive (Bravo *et al.*,1988, Morales, 1957).

Measuring worm *Sabulodes aegrotata* Guenee (Lepidoptera: Geometridae). Several species of the genus *Sabulodes* have been found in California, Mexico and Central America.

The adults are small moths of light yellow or light brown color and from 2.5 to 3 cm in length, with a wingspan of 6 to 7 cm. They have two dark stripes across the upper part of the wings. They are nocturnal in habits, resting on leaves, branches, or shady trunks during the day. Their lifespan is of approximately 20 days. The females lay 200-300 eggs in groups, being of pale green color at first, and turning brown when hatched. After 8 days of incubation, small yellowish larvae are produced that feed on the epidermis of the leaves. After a second instar, they feed on the entire leaf, leaving only the nervation. After a third instar, they reach a length of 6 cm and turn dark green with dark lateral strips along the body. After 40 days, they transform into pupae of 2.5 to 3.0 cm in length, brown in color, and locate between two leaves, or in rolled leaves. They can stay in this stage from 15 to 30 days, depending on the weather. The total life cycle varies from 2 to 3 months.

The damage of the measuring worm is very severe, since it is a pest whose incidence varies from year to year, and only in patches of few trees in an orchard. However, in some regions and in certain years, greater damage is produced, defoliating the infested trees completely and destroying the new shoots. The greatest incidence occurs during the summer (Anonymous, 1979; Gallegos, 1982).

3.2 Relative status of major pest species

Morales et al (2000) developed a sampling technique to determine the status of avocado pests in the state of Michoacán, Mexico. According to their method, they randomly selected 96 trees from a total of 27 ha or 2760 trees, which were divided into sections. 110 fruits were analyzed in each of the 96 selected trees. The results are shown in the table 11.

Table 11 Relative status of major pests or damages

Pest or type of damage	Number of affected fruits	Percentage %
Avocado blight (roña)	749.7	7.1
Anthracnose	211.2	2.0
Thrips	475.2	4.5
Mix of pests	167.0	1.6
Other insects	64.0	0.6
Mechanical or sunburn	95.0	0.9
Total damaged fruits	1764.1	16.7
Undamaged	8796.0	83.3

These authors observed that the major pathogen in Michoacán are: *Colletotrichum* sp, that causes anthracnose (Figure 39 Avocado affected by anthracnose); *Sphaceloma persea*, causing avocado blight (roña); *Alternaria* sp, causing rot; *Fusarium* sp and *Diplodia* sp, causing black spots in the peduncle; and finally bacteria as secondary agents causing watery rot.

Figure 39 Avocado affected by anthacnose
Source: Sanidad Vegetal de Salvador Escalante Michoacán, México

3.3 Pest control

Root-rot: Watering must be suspended for trees with slight symptoms, their roots exposed and the fungicide "Upritán" applied. Some farmers apply copper fungicides at high doses, however the causal agent in these cases was not fully identified. Strongly attacked trees must be uprooted and disinfected with a solution of 40% formic alcohol or commercial fungicides such as "Vapam" of methyl bromide. Ditches (50 cm wide and 50 to 100 cm deep) shall be dug around the affected trees (Morales, 2000).

Avocado blight (roña): Pruning of trees helps control the fungus because it grows better in closed orchards (Figure 40 Avocado blight). It is also important to remove the fallen and ill fruit, because they are the primary medium for the incubation of the pest. In some avocado producing regions, this disease has been controlled with applications of micronized copper (53% copper) in doses of 1 to 2 kg per 400 L of solution or using a mix of 1-1-100 lime-copper sulfate -water (Martinez, 1975) (Figure 41 Avocado trees are sprayed with lime -copper sulphate- water).

Figure 40 Avocado blight

Thrips: A natural biological control exists when wasps (*Desycapus pariopennis* Gaham, Trichogramatidae family) parasite the thrips eggs. There are other predators such as *Leptothrips*, *Franlinothrips*, and *Watsoniella*. An important cultural control is the elimination of weed, and keeping the orchard clean. This is a pest easily controlled by chemical pesticides, such as malathion and parathion. For severe attacks, pyrethrines such as fluvalinates are recommended (Adame, 1994; Gallegos, 1982). Chemical pesticides should be applied when 10% and 100% of flowers appear, and when fruits are in bud stage (Téliz, 2000).

Figure 41 Avocado trees are sprayed with lime -copper sulphate- water.

Small seed weevil: An integrated management is required in order to control the pest, including cultural labors, chemical, and legal control. Eradication is considered in most cases since this is a pest under quarantine. The cultural control consists in the destruction of infested fruits, together with soil labor to destroy the pupa. The chemical control is carried out using methylic parathion or malathion in powder (2 to 3%) applied to the soil during the emergence of adults. Aspersions with the same products in doses of 1 to 2 L / 1000 L of water every 10 days while adults are present. The legal control includes the establishment of campaigns for prevention in free zones and quarantines to avoid dispersion (Bravo *et al.*,1988; Llanderal de la P. and Ortega, 1990; Martínez *et al.*,1987).

Large seed weevil: The greatest efficiency in the control of this pest is achieved when combining chemical and cultural controls. The spraying of the foliage every 8 to 10 days after adult insects appear is recommended, using phosphate-containing chemicals such as methylic parathion, malathion and ethylic gustathion in doses of 1.0 to 2.0 L in 1000 L of water. As a cultural control, it is important not to leave fruits on the tree after the harvest, gather all the fallen fruits and destroy them. A biological control that gives 20% efficiency can be achieved with *Bracon* sp (Bravo *et al.*,1988; Gallegos, 1982).

Seed moth: A combination of chemical and cultural control is needed. The cultural control consists in pruning the affected branches, gathering the fallen fruit and burying or incinerating it. Chemical control can be used for adult insects by spraying phosphate-pesticides, carbamate, or piretroid pesticides, such as malathion, gustathion, sevin and permetrines in commercial doses. Phosphate-containing pesticide in powder form can also be applied at 2% to the soil when the fruit begins to fall of during the emergence of adults (Bravo *et al.*,1988; Gallegos, 1982; García-Martel *et al.*, 1983).

Red or brown mites: There are mentions of natural control by means of predators such as *Stethorus picipes* Casey, *Oligota oviformis* Casey, *O. pigmaea*, *Crysopa* spp., *Scolothrips sexmaculatus* Pergande, and of several species of mites of the *Typhlodromus* genus. However, their control is limited and the chemical control is recommended with the use of various products such as powder of liquid sulfur, in doses of 3 to 5 g per 1000 L of water; mineral oil; Endosulfan, Abamectine (Avermectine), Metamidofos, Fluvianato, Propargite, and Ethion in commercial doses. Resistance and limited control of phosphate-containing pesticide has been reported, therefore their use has been limited in this case (Arias, 1984, Eveling, 1959, López, 1990).

White fly: due to the characteristics of this particular pest, and to the environmental conditions of high humidity and shade that they require to survive, the elimination of weeds and the pruning of trees are very useful labors for the control of white flies. For chemical control, phosphate-containing pesticides and pyrethrins are recommended (Martínez, 1984).

Dog worm or Swallow wing butterfly: A natural control is carried out with beneficial species in the different stages of their cycle. A parasite of the worm's egg (*Telenomus*, Scelionidae family), and a wasp parasite of the pupae (Pteromalidae *Pteromalus*) are of importance in Mexican cultivars. The release of *Trichogramma minutum* is also very efficient. The chemical control is almost never required, except in particular cases when the infected trees are sprayed with pyrethrines or carbamates in commercial doses (Bravo, 1988; Del Rio, 1978).

Leaf roller worm and Amorbia moth: Like other Lepidopters, they can be severely attacked by natural enemies in their different stages. The eggs are attacked by *Trichogramma platneri* in California, and *T. minutum* in Mexico. Spraying with *Bacillus thruringinesis* in commercial doses is also helpful. Pyrethrins and carbamates in commercial doses are used occasionally when severe infestations occur (Bailey, and Hoffman, 1980; Martínez, and Adame, 1987).

Omnivorous looper, green worm, or burn worm: The larvae are controlled naturally by the Ichneumonidae wasp parasite *Enicospilus*. The pest can also be chemically controlled by spraying only the affected trees with a mix of carbamates, phosphate-containing pesticides, or pyrethrins in commercial doses (Bravo *et al.*,1988).

Green fly: It is very susceptible to pesticides, and can be controlled in the nymphal stage as well as in the adult stage. Given their low mobility, they are easy to control with products such as malathion ot parathion, sprayed on the foliage in doses of 100 to 200 mL/100 L of water (Morales, 1957).
Avocado treehoppers or avocado parakeet: The exchange of the Mexican avocado varieties for Hass, eliminates the presence of this pest in commercial orchards. Native trees can be sprayed with parathion or malathion in commercial doses (Bravo, *et al.,*1988, Morales, 1957).
Avocado leaf gall: Its natural enemies are unknown. This pest is very resistant to climatic conditions such as cold or rain. Furthermore, in the nymph stage (inside the gall) it is very resistant to pesticides. However, the adults can be easily controlled when coming in contact with parathion and malathion in commercial doses (Bravo *et al.,*1988, Morales, 1957).
Measuring worm: The environmental conditions, as well as natural enemies, control the pest. It is often found that virus, bacteria, and wasps (*Apanteles, Bracon, Zele* and *Meteorus*) also attack the larvae, *Trichogramma* and *Telenomus* parasites attack the eggs, and flies of the *Tachinidae* family attack the pupae. Commercial applications of the *Bacillus thuringiensis* entomotoxin and releases of *Trichogramma minutum* produce excellent results. The application of chemicals is almost never required, but if necessary, should be applied only to a few isolated trees. Pesticides containing phosphates are only efficient in high doses, therefore permetrines or carbamides are recommended in commercial doses (Bravo *et al.,*1988, Morales, 1957).

3.4 Others

In order to establish a good strategy for integral pest control, thresholds and levels of economical damage need to be determined. This can help to reduce the frequency of fumigations, lower the crop handling costs, as well as to increase the production. The study of beneficial fauna can lead to the development of biological controls (Téliz, 2000).
In Mexico, only four pesticide products are recommended for chemical control: 1) parafinic petroleum oil (Saf-T-Side), 2) Malathion CE 47; 3) Methylic parathion (Folidol) CE 47, and 4) Permetrine CE 49 (Téliz, 2000).
In Chile, the presence of a large fauna of biological controllers has helped to contain potential avocado pests. However, there is no doubt that the use of pesticides in the orchards contribute to maintain this situation. Different pests that sometimes need to be restrained can be handled with selective pesticides that do not interfere significantly with biological controllers. In other cases, the spraying specific sectors of the orchard helps to maintain the beneficial fauna.
In the same way, the establishments of reservoirs for biological controllers, together with cultural practices such as the elimination of low branches, removal of branches that constitute the origin of infections, and the maintenance of vegetation that feed beneficial fauna in adult stage, are also biological control practices. Finally, the artificial introduction of biological controls through a development and release method can help solve those situations in which the beneficial fauna is not efficient enough or does not colonize the orchard on time (López-Laport, 1999).

4. Economic and social considerations

Considering that Mexico is a developing country whose avocado production is the highest in the world, the following data focus on the economical and social considerations related to avocado production in this country.

4.1 Overview of costs and losses

Big private producers: The acquisition and application of organic manure and chemical fertilizers constitute a high proportion of the total farming cost of cultivars, since the content of nutrients in the soil is low. Sometimes, the fertilization of the soil is not carried out properly, which leads to an over-concentration of certain nutrients and a lack of others (SARH/INIFAP, 1988). The irregularity of the terrain makes difficult the use of machines for tasks such as the removal of weeds and application of fertilizers and fungicides, and thus these tasks must be done by labor workers, which elevate the costs (Figure 42 Application of chemical fertilizers in the orchard). Nevertheless, and from a social point of view, the employment of labor workers in the orchards is very important for developing countries, since the survival of many families depends on this type of activity.

Figure 42 Application of chemical fertilizers in the orchard

Communal landholders ("ejidos" and "comuneros"). They have lower farming costs, due to their limited resources. For example, a private producer is able to fertilize once a month, while they fertilize twice a year at the most. These landholders are also characterized by an inadequate handling of their cultivars, which reflects in a low yield and lower profits. Private producers often reach 14 tons/ha, while communal farmers reach only 4 tons/ha. (Figure 43 an open truck to transport avocados).

Figure 43 an open truck to transport avocados.

Big packinghouses are supplied with their own avocado production in a 30% (at the most) of total packed volume. For example, in the region of Peribán, only 15 of the 60 owners of packinghouses are also producers. The rest of the volume is bought directly from farmers. The prices are negotiated as a function of the economic needs of the producer and the availability of the fruit. In times of a high production, the prices are low and the packers delay payments (approx. 15 days), and in times of high demand and low production, the farmers get cash payments (COABASTO, SNIM, BANPECO, 1991).
Since 84% of the Mexican avocado is produced in one State, it takes a big effort to distribute the fruit to the majority of the cities, which involves a lot of people in commercialization activities, most of them strange to the fruit's production and packing. It is estimated that 63% of the fruit is marketed by local intermediaries, 15% by intermediaries from other cities, 15% from local packinghouses, and the rest (7%) is exported (SAGAR, 1999).
The table 12 presents an overview of the cost and profit margin of two wholesalers in the Mexican domestic market, in two different months (January and July, 1989). The data is based on COABASTO, SNIM, BANPECO (1991), has been averaged and it is presented in percentages.

Table 12 Wholesaler's cost and profit margin in the Mexican domestic market.

Concept	**Percentage (%)**
I. Total cost	100
a) Price [1]	85.9
b) Packing costs, from which	8.5
Box	6.2
Labor[2]	2.3
c) Transportation (Michoacán-distribution center)	3.7
d) Fruit loss[3]	0.8
e) Warehouse operations[4]	1.1
II. Selling price[5]	113.4
III. Profit margin	13.4

[1]Price that was paid for the fruit in the farms
[2]Some dealers do not have packing labor costs, because they handle unpacked fruit, or reuse the plastic boxes that are employed in the fields.
[3]The loss was estimated as 200 g per 24 kg box, or 8.33 g per kg.
[4]This includes the rent of the warehouse, telephone, electricity, water, loading and unloading, etc.

APROAM (2003) calculated the costs a farmer faces when growing avocado, with technical assistance in order to obtain an optimal production. With this kind of approach, and depending on the particular characteristics of the orchard (altitude, climate, rain, low temperatures, type of soil), it is expected to obtain from 8 to 15 ton per hectare (table 13).

Table 13 Avocado producing costs in the field (APROAM, 2003)

Concept	Cost/ha/year, in Mexican pesos	Cost as a percentage
Cultural labors	$ 885.75	3.01%
Fertilization[1]	$ 6,155.94	20.96%
Sanitary control	$ 4,838.94	16.47%
Machines and equipment	$ 8,356.90	28.46%
Others[2]	$ 4,977.59	16.95%
Sub-Total	$25,215.12	---
Financial cost	$ 4,147.88	14.12%
Total cost	$29,363.00	100%
[1]Includes the cost of the fertilizers and 3 applications per year [2]Includes technical assistance, benefits to labor workers that are paid to the government, other taxes, membership to the producer's association, and a payment to the sanitary committee.		

However, the costs vary according to the number of hectares, as may be observed in table 14.

Table 14 Avocado producing cost as a function of the size of the orchard (APROAM, 2003)

Production per hectare in tons	Cost per kg of avocado (Mexican pesos)	Cost per kg of avocado (USD[1])
8	$ 3.67	$ 0.35
9	$ 3.26	$ 0.31
10	$ 2.94	$ 0.28
11	$ 2.67	$ 0.25
12	$ 2.44	$ 0.23
13	$ 2.26	$ 0.21
14	$ 2.10	$ 0.20
15	$ 1.96	$ 0.18
[1]At the time the present document was written, $1 USD = approximately $10.50 Mexican pesos.		

4.2 Major problems

The florescence and fructification of the avocado tree may allow a single harvest, collecting the entire orchard's fruit at once ("*a pela palo*"). This results in a wide variety of sizes and maturation stages, that decrement the price of the fruit, and thus the price in the market is also affected.

Another major problem is the lack of proper contracts. Even though so many different people participate in the production and commercialization of avocado, most of the time agreements are done verbally, without proper documentation. This originates many problems, because the conditions of quality, packaging, quantity, delivery, price, and payment are not established. In this way, it is often the last person in the commercialization chain who gets the largest profits. The payment situation is noteworthy, because the fruit is usually not paid at the time it is delivered. Often the buyer may not pay at the time that he agreed with the farmer, arguing cash problems, and may also reduce the price or not pay at all. In this transaction, the farmer has the biggest problem and cash need, because the buyer can easily switch to other fruits such as mangoes or pineapples and always keep his upper hand and arbitrariness. Even though this is not the case of all buyers, the farmers are always depending on traders.
Another problem is that avocados are distributed from only three large national commercialization centers. This results in a raise of the fruit's price, because it is excessively handled before reaching the final consumer. Sometimes, it even passes twice through the same place before it reaches its final destination.
The same situation prevails in the supermarkets, which distribute the products from a national storing center to the rest of the country. This excessive movement reduces the farmer's chances of getting higher profits.
In recent years, foreign companies have established in Mexico and have begun operating as packinghouses. These companies are stronger when it comes to cash flow and financing, and have the purpose of moving the local companies out of business. However, local companies have a better knowledge of the market conditions and possess the property of productive areas. These facts are noteworthy because there is a possibility that foreign companies would get a hold on the exportation market. This tendency is shown by their participation in the year 1995-1996, that was estimated as 7%; and in 1997-1998, 48% (SAGAR, 1999; APROAM, 2003).
On the other hand, small producers such as the ones from Ario de Rosales and Villa Escalante (Michoacán, Mexico) do not have a nearby packinghouse, and lack resources to transport their fruit. They often sell the product of whole orchards to buyers that gather the avocado from many small farmers and, in turn, transport it and sell it to the packinghouses. These small producers often get lower prices for their cultivars, estimated in 50% of their real value. They also market unpacked fruit in "tianguis" (local small markets).
This type of commercialization may diminish the quality of the fruit due to improper handling and growing techniques, but on the other hand they cut the costs, as they eliminate the need for agricultural supplies, transportation from the orchard to the packinghouse, use of the packing facilities, packaging material, etc. This situation is perceived by the farmers who invest in technical assistance and disloyal competition, because the domestic market looks for price instead of quality.
On the other hand, small producers often lack legal documentation to assure the commercialization of their fruit, and this is the main problem they have to face when sending the production to the wholesalers in Mexico City. The legal documents assure the payments (COABASTO, SNIM, BANPECO, 1991, APROAM, 2003).
For many years, the construction of roads and highways in the state of Michoacán has not progressed enough to match the demands of the local producers. As a consequence, nowadays there are not enough well maintained roads to transport the fruit as well as the supplies needed for its cultivation. Something similar happened to the electric energy supply and telephone lines, which are only available to a small percentage of producers, limiting their access to technology.
Sometimes, supplies, machinery, and fertilizers are overused or improperly used due to a lack of technology and knowledge of the proper techniques (Morales, 2000).

The economic crises in the years 1982-1988 and 1994 seriously affected the economic activity in Mexico, including the production of avocado. This fact, together with the production growth, lead to the non-payment of credits to both private and public banks. Nowadays, most of the producers are unable to survive without bank loans, and some have a high debt due to a great inefficiency in the administration of their own resources.
Even though there are many beneficial effects derived from the production of avocado, it is important to bear in mind that every agricultural-industrial growth of a single cultivar may carry secondary effects, which in some cases can make it disappear in the long run. Avocado cultivation carries a toll on the environment, due to the deforestation of woods and rainforests, which eliminates the original ecosystem where avocado trees naturally grow (Morales, 2000; SAGAR, 1999).
The greatest problems for the exportation of avocado are due to the lack of collaboration of different domestic organizations; as well as the international differences due to economical, social, and political interests (Morales, 2000).
According to an improvement plan ("Proyecto de Mejora") proposed by APROAM, the commitment of some growers to change is inconsistent and they have reticence to share information. In Mexico, there are many producers' organizations, some with additional roles and unaccomplished objectives. In general, their attitude towards organization and change is contingent upon short-time results. There are also wide differences in educational level among them. All these facts contribute to an underdevelopment of the market.

4.3 Proposed improvements

Some recommendations to improve the quality of the fruit and decrease post-harvest losses are:

- To renovate old orchards
- To implement efficient fertilization programs.
- To strictly control pests and illnesses
- To establish adequate indexes of ripeness and harvest
- To carry out a quality selection in the orchard to increase the efficiency of the packing process
- To strictly control the processes of packinghouses
- To reduce mechanical damage
- To wash the fruit and apply fungicides
- To properly select the size of the fruit Weight selectors give the best results.
- The fruit should be promptly pre-cooled with a freeze-blast to 8-10°C. The storage, transport, and market temperature should be set according to the maturation stage and the time form harvest to marketplace.
- (Yahia, 2003)

Other general recommendations are:

- Producers should continue to work in their own organization, opening of new markets, advertising of the properties of avocado, and research from cultivation to post-harvest aspects (SAGAR, 1999).
- In order to reduce the problem of low-quality fruit reaching the market and affecting prices, producers and packers should work in their own organization. Low prices result in a lower investment of resources (both human and technical) in the orchards.
- The production increase of countries such as Chile and others close to the European market is considered a problem for Mexican producers and packers.

- To create a research program based on the need of producers and packers that will give the technical basis for obtaining a higher-quality fruit and a homogeneous production. However, it is the producer himself who should impulse the technology transfer that is already available, and actively participates in technical programs (SAGAR, 1999).
- Producer need to work more on their organization as a group sharing common interests. A good example of this type of organization is APROAM, dedicated to the implementation of improvement projects for the production, distribution, and commercialization of avocado.
- A market research is needed in order to know the facts affecting the demand, uses, reasons for purchase, etc.
- The distribution and commercialization chain need to be improved and made more efficient (Proyecto de Mejora, APROAM, 2000).
- Communal landholders (ejidos or comuneros) should adopt basic sanitary practices, such as the construction of latrines and sewage disposal facilities, in order to avoid the contamination of the soil and the fruit.
- During harvesting, avocados should be cut leaving a portion of the peduncle attached to the fruit, and never let fall into the ground because of the risk of contamination with pathogens.
- Small producers should have access to credit in order to improve the production yield and handling operations. They should also get proper training on the use of agricultural supplies and machinery. The government should help these producers with low or no taxations, as long as they invest in the improvement of their orchards.
- The government should be a driving force for the development, education, and efficiency of the producers.
- Universities and research centers should have stronger relations with producers in developing countries in order to improve all the stages of the production process, from the use of genetically modified crops to the final stages of commercialization.
- Research on new avocado products, based on its nutraceutical and cosmetic properties, could expand the market and increase the demand for the fruit, giving it an added value.
- New and traditional uses, as well as recipes for avocado should be divulged in the importer countries, using the local language. For example, brochures could be freely distributed in the markets where the fruit is sold. They could also explain the nutritional properties of avocado. The recipes must consider local food habits, as well as the ingredient combination that would result in a nutritionally balanced dish. This could be done by the exporters, in collaboration with food technologists.
- Avocado's high nutritional value, the research about its properties that is being carried out in different countries, the increase in the avocado use for industrial purposes, as well as the diversification of added-value products for the domestic and international market, will help to increase the world's consumption of this fruit.

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6 Annex

An avocado drink

Shake Isabel
Ingredients:
½ avocado (chopped in medium pieces)
1 tablespoon of honey
1 cup of milk
1 teaspoon of cinnamon
1 banana (chopped in medium pieces)
1 orange (the juice)
Mix all the ingredients using a blender Control the texture of the liquid by adding orange juice. The shake is served with cinnamon on top.

Hazelnut and Avocado Shake

Ingredients:
½ avocado (chopped in medium pieces)
2 tablespoons of brown sugar or honey
5 tablespoons of grounded hazelnuts
2 cups of milk
1 teaspoon of vanilla extract
A pinch of nutmeg
Place the milk, hazelnuts, sugar or honey and vanilla extract in a blender. Mix for 4 min. Add the avocado and blend until a creamy mix is formed. Add the milk until desired texture. The shake is served with nutmeg on top.

Guacamole with tortilla chips

Guacamole
Ingredients:
4 medium-sized avocados (in purée)
½ onion, finely chopped
1 green bell pepper, finely chopped
1 lemon (the juice)
1 tablespoon of olive oil
2 garlic cloves, finely chopped
1 tomato, finely chopped
1 teaspoon of chopped parsley
Tabasco sauce or chilli pepper to taste
Salt
Mix all the ingredients until a soft and creamy mixture is obtained. It can be served with tortillas. The live green color of the avocado is obtained with the addition of lemon juice.

Cactus and avocado salad, and main ingredients

Cactus (nopales) with avocado salad
Ingredients:
4 cooked cactus (nopales)

onion slices
1 avocado
1 tablespoon chopped parsley
1 tablespoons of vinegar
1 tablespoon of avocado or olive oil
chilli peppers and fresh cheese as desired
Avocado and apple salad
Ingredients:
2 good quality apples
1 avocado
Brown sugar or honey
1 lemon (the juice)
1 orange (the juice)
1 tablespoon of grounded hazelnuts
Chop all the fruit into small pieces and mix with the citric juices. Add the sugar or honey and mix again. Put the grounded hazelnut on top on the salad and serve.

Avocado and apple salad

Avocado Sandwiches
Avocado, Swiss cheese and onion sandwich
(Serves 8)

Avocado sandwiches

Ingredients:
2 big avocados, sliced
8 slices of Swiss cheese, or a hard cheese
Russian dressing, or a mix of mustard and mayonnaise
Lettuce
8 thin slices of onion
18 slices of white or whole wheat bread (slightly toasted) with butter
Form the sandwiches with the avocado and the rest of the ingredients.
Avocado and crab sandwich
(Serves 8)
4 avocados in thin slices
¼ cup mayonnaise
8 teaspoons of lemon juice
¼ teaspoon white pepper
8 cans of crab meat, without the liquid. It can be substituted by tuna or other fish.
1 teaspoon of salt
1 teaspoon of dill
8 slices of rye bread (slightly toasted and buttered)
Mix the crab meat, mayonnaise, lemon juice, salt, and spices in a small bowl. Chill the mix. Place the avocado slices on top of the bread slices, and then add the crab mix. Garnish with fried bacon or chopped walnuts.
Avocado soup and "tacos"

Mexican soup

Mexican soup

Ingredients:
8 large avocados
3 tablespoons of lemon juice
¾ teaspoon of salt
light cream
1 2/3 cups of chicken stock
Pepper and powder garlic
Press the avocado pulp into a purée together with the chicken stock, lemon juice, salt and spices. Add the cream and blend. Cover up the bowl and chill. Serve with one of the

following garnishes: chopped bacon, toasted almonds, chopped tomato, hard egg, tortilla chips, or anchovies.

Tacos with guacamole and avocado slices

Tacos with avocado

Ingredients:

1 avocado (the purée) or guacamole prepared as indicated above

3 or 4 tortillas per serving

1 green bell pepper or hot pepper

1 cup of chicken or beef meat previously cooked

2 tablespoons of olive oil

Salt, cheese, lettuce, and tomato slices as desired

The tortillas are rolled with the meat inside. The tacos are fried in olive or vegetal oil; the excess of oil is removed with a paper towel The tacos are covered with guacamole, tomato, avocado slices, cheese and lettuce as desired

1.3.5. Main courses with avocado

Salmon filet with avocado

(Serves 4)

Ingredients:

2 avocado (in purée)

4 salmon filets, 1 ½ cm thick

½ onion, chopped

1 garlic clove, chopped

Parsley, clove, tarragon, black pepper

50 g of butter

1 cup of Sherry type wine

1 cup of natural yogurt (with no sugar added)

Salt

2 tablespoons of cream

Cut the salmon filets horizontally to make 4 thinner filets (160 g) from each. Place over aluminum foil, previously buttered and added with tarragon. Season the salmon with salt and pepper and wrap it up with the foil. Bake in a pre-heated oven at 200ºC for 25 min. Meanwhile, cook the wine with onion, garlic, tarragon and parsley under low fire. Add the avocado purée, yogurt and cream, and cook for 5 more minutes. Sieve the sauce, add salt and pepper to taste, and keep it very hot.

Remove the salmon from the oven and using a fork, get rid of the skin and bones. Serve immediately covered with the avocado sauce. Garnish with cloves.

Beef loins with avocado and fresh herbs

(Serves 4)

Beef loins with avocado and fresh herbs

Ingredients:
4 beef loins, lean, 3 to 4 cm thick
2 avocados (in purée)
2 tablespoons of olive oil or butter
Black pepper, coarsely grounded
1 cup of yogurt or cream
4 slices of pathé
½ cup of white wine
Salt

Marinate the beef for two hours in the following mix: 1 cup of red wine, the juice of 1 lemon, ½ onion chopped, 2 chopped garlic cloves, 1 tablespoon of mustard, 1 tablespoon of soy sauce, 2 tablespoons of brandy, tarragon, parsley and nutmeg.

Remove the beef loins from the marinade and blot them. Season the loins with salt and pepper and fry in the fat for a few minutes each side. Remove, place the pathé slices over and keep warm Cook the rest of the marinade under low fire. Add the wine, avocado purée, and yogurt. Season with salt and pepper and pass it through a sieve. Serve the sauce covering the beef loins in a pre-heated plate.

Avocado desserts

Avocado sorbet
(Serves 4)
Ingredients:
500 g of avocado purée
120 g of sugar, or 4 tablespoons of honey
2 tablespoons of rum
1 lemon (the juice)
1 teaspoon of ground cinnamon
4 egg whites
3 tablespoons of cream

Bring a cup of water to boil and dissolve the sugar in it, let it cool down. Bear in mind that the whole mixture of ingredients should not be over 845 g. Whip the egg whites and add, little by little, the avocado purée, cream, lemon juice, cinnamon, rum and the sugar in water. Place in the freezer, and mix the sorbet 2 or 3 times with a spoon before it becomes firm. Serve with fruit as a garnish.

Mango and avocado dessert
(Serves 4 to 6)

Ingredients:
2 avocados (in purée)
4 mangoes (in purée)
1 lemon (the juice)
4 whipped eggs
180 g of sugar
400 g of cream
Salt
1 teaspoon of ground cinnamon
1 tablespoon of Liqueur 43
Whip the cream on the stove (low fire) until ready to boil, and add -slowly- sugar, salt, cinnamon, eggs, and the liqueur. Let the mix cool down and then mix with the fruit purées and the lemon juice, forming lines of color. Serve chilled and garnish with toasted almonds.