POTENTIAL FOR LIME PROCESSING INDUSTRY IN MEXICO

by

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ABSTRACT

Although Mexico is one of the major lime producing countries in the world the crop is not completely utilized. In this paper some ideas are reviewed in relation to various possible products that can be obtained from the efficient processing of limes. Among these are the extraction of the juice, its uses and some of the problems that the canning of citrus products presents such as color, flavor, oxidation and the effect of enzymes on cloud stability, the recovery of all the soluble solids from the pulp using enzymes. The technology involved to prepare frozen concentrates and powders is also reviewed. The paper covers the different types of essential oils and their main uses in the industry.

The fact that most of the pectin produced in the world is from citrus and two of the best sources are lemon and lime peel makes pectin an important by-product. The procedure of pectin extraction is described.

As a means to avoid waste disposal problems the use of dried citrus peel as a livestock feed is suggested.

The nutritional value of limes and lemons in the diet, the main functions of ascorbic acid in the body and the factors that affect vitamin C levels are discussed. Finally suggestions for possible applications in Mexico are presented.
INTRODUCTION

Limes (Citrus aurantifolia, Swingle) and lemons (Citrus limonia, Merril) are grown in the tropic and subtropic climates where the humidity is high and no cold temperatures (below 3°C) are registered during the year. The lime crop is markedly cold-sensitive and has a high total heat requirement for the production of good size fruit (25, 134). Mexico is one of the major lime-producing countries in the world together with India, Egypt and the West Indies (39, 100). Its production increased from 326,000 metric tons in 1971 to 465,000 metric tons in 1979 (1, 23, 115, 134).

The principal lime growing areas of Mexico are located in the states of Colima, Michoacan, Tamaulipas, Jalisco, Veracruz, Nayarit, and Guerrero. This paper will focus attention on Veracruz where there is little industrialization and there are groups interested in the development of the lime industry. Total production in 1979-1980 in Veracruz was approximately 37,000 metric tons of limes (100). A considerable proportion of the fruit is shipped to fresh market. The rest is lost due to insufficient use of processing technology. The lime industry has not been fully developed. The majority of processing plants in Mexico have only the basic equipment needed to obtain juice and distilled oil (66). As a result Mexico is unable to take full advantage of either domestic or international markets for limes, lemons and all their by-products (1, 66, 134).

The need to present new ideas and technology enabling greater utilization of the raw fruit was one of the main objectives of this paper.
**Varieties**

There are two types of acid limes grown in Mexico, one with seeds (Persian lime) and the other without (Mexican lime) (66). Ninety-five percent of the output is the West Indian variety or Mexican lime which is also called the Key lime in North America. The Persian varieties account for only 5% of the crops (25).

**Structure of the fruit**

The tissues of the lime and citrus fruit in general can be divided into: flavedo or epicarp, albedo or mesocarp and edible portion or endocarp.

**Flavedo:** The flavedo consists of several morphologically different tissues. The outermost layer of the fruit is the epidermis, that has isodiametric, polygonal cells covering the entire surface of the fruit except where the numerous stomates are located. The outer cell walls of this layer are heavily cutinized and partly covered with a waxy substance. These cutinized walls and the wax prevent excessive loss of water from the fruit. Directly under the epidermis are layers of collenchyma and parenchyma cells in which the chromatophores are present. At different depths of the parenchymal tissues are located numerous oil glands from which the essential oil is obtained. These oil glands, ranging in size from 0.2 to 1.0 mm in diameter must be thoroughly broken and pressed before the oils are released (115).

**Albedo:** The albedo or mesocarp is the white, spongy portion and varies in thickness in different types of citrus (115).
Edible portion: The edible portions, sometimes called the pulp or endocarp are the segments (carpels) which are separated by carpel walls. Within the segments are many juice vesicles or sacs and some seeds. These vesicles enlarge as the fruit develops and are attached to the membrane with thread-like stalks through which are translocated water and solutes from other parts of the plant. Wax is the adhesive agent between the juice sacs. This wax contributes to the ability of the fruit to withstand cuticular transpiration (107). At maturity, the vacuoles are broken, the juice together with some thin cell walls and cell contents are released (115).

The flavedo contains the essential oil, the carotenoid pigments and the citrus steroids. The albedo is rich in cellulose, hemicelluloses, lignin, pectic substances, flavonoids, phenolic compounds, amino acids and vitamins. The segment membrane and the juice vesicle membrane have about the same chemical constituents as the albedo. Most of the sugars and nearly all of the citric acid occurs in the juice which also contains vitamins (C and B complex), minerals (K and Mg), lipids, nitrogenous and phenolic compounds (52, 115).

In tropical countries where limes may be secured at all seasons they are used almost entirely in place of lemons and each year it is becoming a more important fruit throughout the American continent (6).

Lemons and limes have similar structure and composition, but the lime is smaller in size. There are differences in climatic tolerances, but the extracting processes and technology are the same.

The fruit handling practices for limes are similar to those employed for lemons (48). The fruit is picked by size and is largely immature, and hence must undergo some storage and curing prior to packing and shipping.
The curing operation transforms lemons and limes into a product acceptable to consumers. Usually the juice content increases in both and the lemons also change in color (37). Lemons and limes are cured by holding at very high humidity (95%) and a temperature of 16°C for 2-3 weeks (118). Citrus fruits may be stored to provide a source of fruit at times other than the normal harvesting season and to hold the fruit until a market is available (79).

Lemons and limes are the frailest citrus fruit because they are normally picked through the wet summer season, making them extremely susceptible to oil spotting (oleocellosis) (118). Oil spotting is a common peel injury of citrus fruit, usually caused by mechanical damage. The oil is released from damaged glands. This oil is toxic to the surrounding healthy cells of the rind and causes a collapse and discoloration of the area. It causes extensive financial loss, particularly in the more humid areas where citrus fruit are grown for the fresh fruit market.

Oil spotting can be reduced by good handling practices. If possible the fruit should not be picked when damp or very early in the morning (75, 79, 118, 131).

The development of all possible technology for lime products has a great potential for the Mexican economy. As was described above, Mexico is one of the most important countries in the world in the production of limes. Knowing and applying this technology could cause an increase in the processing industry in areas where some of the production is lost and increase lime production in other areas of the country, increasing employment in those areas and assuring a better utilization of our natural resources.
The technology used for lemons can be applied to limes. Both fruits have similar composition and properties. For limes and lemons there are a large number of useful products that have a potential market and economic value such as: lime juice, frozen concentrates, powders, essential oil, pectin, dried juice sacs and dried peel for livestock feed.

THE JUICE

Lemon and lime juices probably have a greater variety of culinary, beverage, industrial and medicinal uses than any other fruit (111). The main uses of lime juice are: as acidulant in ice tea, on seafood, in mixed drinks, in home canned tomatoes, and as a flavor enhancer of foods (97). It is very important as a thirst quencher (limeade) (25, 68). It is very useful in the manufacture of carbonated and noncarbonated beverages (135). Because of the high acidity of lime and lemon juices smaller quantities are used at one time.

The current practices in citrus processing plants include: juice extraction, peel oil recovery, pulp washing, evaporative concentration and peel and waste dehydration.

The extraction of lemon and lime juice is accomplished with several different types of equipment. Until recently lemon and lime juice and oil were extracted simultaneously. Corrugated rolls and screw presses were widely used in the process by which the whole fruit was crushed. To separate most of the oil from the juice it was necessary to pass the juice through centrifugal machines. Not only was the final separation difficult but the prolonged contact of oil and juice was detrimental to both products, reducing the quality of the juice and introducing off-flavors and odors (110).
Most lemon and lime juices now produced are extracted with automatic machines such as those manufactured by Brown International Corp. (Covina, CA) and FMC Corp. (Lakeland, FL). These machines are adapted for simultaneous recovery of both juice and oil and the contact between them is greatly minimized (57, 111).

The Brown extractor permits the use of fruit that has not been sized or maturity graded, since the extractor pressure automatically adjusts itself to give optimum juice yield with minimum peel damage. The Brown extractor gives juice products with a higher oil content than the FMC extractor (111).

In the Brown extractor, the fruit is dropped between pairs of revolving, circular, synthetic rubber discs. The smaller fruits fall near the center and the larger ones are positioned near the periphery. The discs carry each fruit through a stainless steel knife which slices it in half. Each half travels in a converging path between a perforated stainless steel grid and the disc as it rotates. The peel is discharged out of the back of the machine and the juice flows to the bottom of the collector (111).

The FMC extractor machine is now one of the most widely used citrus juice extracting units (56). In this machine the fruit is fed into the extracting cups singly. The fruit is held in a stationary lower cup which automatically centers and positions it for extraction. The upper cup descends, and numerous metal fingers of the two cups intermesh and pressure is applied evenly to all the surface of the fruit. The bottom of the lower cup contains a stainless steel cutter tube. The cutter tube
cuts a small circular plug in the bottom of the fruit, and as pressure is applied by the cups the complete inside of the fruit is pressed into the finishing tube where the juice is instantaneously separated from seeds and membranes (40).

Screening to remove the seeds and coarser material of the extracted juice is important in controlling pectic enzyme content, the tendency for flocculation of suspended solids or gelation, and undesirable flavors from the seeds. To obtain a single-strength juice the first run juice is heated to stabilize it. Flash pasteurization at 82°C for 30 seconds is recommended. Lime juice is more acid than other citrus juices and lower temperatures of pasteurization would suffice; either 71°C for 35 seconds or 80°C for 30 seconds (15, 91, 93). At these temperatures destruction of microorganisms occurs and inactivation of the pectin esterase enzyme is 97%. Also a satisfactory cloud retention is observed and good flavor retention is achieved (15, 91).

After pasteurization the hot juice may be poured directly into cans or bottles which are then closed and rapidly cooled (111). Refrigerated storage at 1.7°C preserves the lime juice until used. No flavor change was noted in samples stored for 15 months at this temperature (15).

Antimicrobial agents are used to preserve lemon and lime juices. Sulfur dioxide, sodium benzoate and sodium bisulfite are the most widely used, often, after heat treatments (9, 69, 92, 111)*. Sulfur dioxide also prevents oxidative changes, but it has a flavor detectable at low levels in the juice.

*Usual concentrations are: 0.05% to 0.2% of sodium benzoate and 200 to 500 ppm of SO₂. However, current food regulations should be consulted.
Some of the problems in canning citrus juices

**Color:** The main color problem is the non-enzymic browning occurring during storage. This is particularly troublesome in the more acid light-colored products such as lemons and limes. Factors having a major effect in the rate and type of browning are: acidity, temperature, presence or absence of oxygen and the nature of the container. The Maillard reaction seems to be of minor importance as acidity of the citrus is high (76). Lemon juice is particularly susceptible to browning in the presence of air, mainly due to reactions between ascorbic and citric acid. At an advanced stage of the browning reaction, amino acids increase the reaction considerably. Citric acid is one of the reactants leading directly to the formation of brown polymers (17, 77).

**Flavor:** Four main groups of chemical constituents contribute to the taste and flavor of citrus products: organic acids, of which citric is predominante (26, 122), sugars, bitter principles and volatile flavor constituents mainly terpenes and carbonyls (17, 49).

The method of extraction of the juice profoundly influences the amount of bitterness found in the product (32, 43, 51, 73, 121). The bitter principles can be divided into two classes: flavonoids and a family of triterpenoids compounds known as limonoids most of which are lactones. The flavonoids found in highest concentration in citrus are the bitter naringin and the tasteless hesperidin. Naringin is highest in immature fruit (43). The use of flavonoid hydrolyzing enzymes (naringinase) and hesperidinase for debittering was successful in Japan for canned oranges and sweet lemon wine (80). The main bitter principle of the lactone type
is limonin which has been isolated from seeds and peel (73, 74, 112).

**Effect of oxygen.** The amount of oxygen in the container or the head-space of the product is of great significance in the development of autoxidative changes causing off-flavors in citrus juice. Inclusion of peel oil in orange juice reduces the incidence of off-flavors due to the presence of natural anti-oxidants in the peel of the fruit. However, lemon and lime peel oil has little anti-oxidant activity (114).

Addition of sucrose, fructose or glucose to canned juices helps to maintain satisfactory flavor (17).

**The cloud.** Fresh citrus juice contains a variety of insoluble particles. The more finely divided particles (< 2 μm) are referred to as the cloud. The color and flavor of citrus juices depends principally on the presence of components in the cloud. The presence of pectin esterase in the juice leads to clarification or possibly gelling unless the juice is stabilized by heat treatment or by the addition of polygalacturonase (34, 80, 96). The addition of low methoxyl pectin makes the heat inactivation of pectin esterase in juices non essential for cloud stabilization (7, 62, 80, 85).

The lipid fraction of citrus makes a significant contribution to the color, flavor, and cloudy appearance. All three of these properties are important factors in consumer acceptance of citrus juices (123, 126). The major phospholipids in lemons are: phosphatidyl ethanolamine, phosphatidyl choline and phosphatidyl inositol in concentrations of 11, 12 and 5 mg/100 ml of juice, respectively. Commercial phospholipids such as soybean lecithin might be potential adulterants as clouding agents or emulsifiers in citrus juices (123). It has been proposed that the loss
of cloud in citrus juices is due to the deesterification of pectin by pectin esterase and formation of insoluble calcium pectates (7, 34, 61, 62, 85). High acidity also causes cloud loss. Cloud loss has been reported to be reduced by keeping the product in cold storage (5°C) (92).

Determination of acidity and residual pectin esterase activity in pasteurized citrus products can be used as a means to predict cloud loss which may occur after many months of storage. Optimal storage conditions and marketing the products within their respective periods of cloud stability help to avoid clarification of the product (92).

Lime juice is also marketed as clarified juice in which polygalacturonic acid is used for clarification (8).

Production of a Beverage Base

Following juice extraction, additional soluble solids can be recovered from the pulp by efficient washing with water. This process is termed "pulp washing" (22, 24) and is accomplished by multiple stage countercurrent washing with water. The suspension recovered is known as "pulp wash" and contains the soluble solids. To increase the soluble solids recovery, the pulp should be soaked with water several hours although fermentation may occur. Pectinase enzymes are, therefore, recommended in concentrations from 50 to 500 ppm based on the weight of the juice pulp (24).

The pulp wash is concentrated in an evaporator and is an integral part of the citrus by-products industry. It is sold worldwide for cloud, flavor or beverage base purposes. One of the main uses for citrus pulp wash is to impart cloud to certain fruit drinks and beverages. The pectic
enzymes used to increase soluble solids yield from pulp-washing reduces the clouding ability of the liquid recovered. However, if the liquid is properly heat stabilized (88°C) during processing, cloud loss is usually not sufficient to be of concern.

The use of pectinases also reduces the viscosity of the liquid and facilitates concentration to highly soluble solids in the evaporation. The evaporators operate more efficiently at low temperatures, thus saving in fuel cost (22).

Dried Juice Sacs

From the washed pulp the juice sacs can be recovered, dried and used as a human food. This facilitates waste disposal and increases the profits of the citrus industry.

The juice sacs can be dried by foam-mat drying, drum dryers or freeze drying. The latter method produces a very good quality product but it is expensive.

The dried juice sacs have excellent water and fat absorption capacities and could be used as emulsifiers in meat products such as meats, bologna, sausages and frankfurters. They can be used for gravies, puddings and dehydrated beverage mixes (56).

Frozen Concentrates

The juice may also be evaporated, frozen and sold as a frozen concentrate. Two methods of concentration have been suggested to be adequate for citrus juices. Both keep the characteristics of the original juice. One is using vacuum, thus avoiding high temperatures (124).
The other is using freeze concentration (44), but this method is expensive.

Each method of concentration has a distinct effect on the juice. In general, frozen concentrated lemon juice has superior quality. Higher losses of ascorbic acid were observed in lemon juice concentrated using vacuum than using freeze concentration (44).

Industrially the citrus juices are concentrated by evaporation at atmospheric pressure using two or more effects to increase the efficiency of the process. Recently new evaporators have been developed such as the "temperature accelerated short time evaporator" (TASTE). This type of evaporator usually has 7 stages and the temperature gradually rises from 21°C to 96°C and then goes down to 16°C. This process simultaneously evaporates, pasteurizes and enzyme stabilizes the juice (11).

Both, high- and low-temperature evaporators require regular cleaning with hot caustic solution throughout the system. On low-temperature evaporators microbial contamination could appear.

This kind of equipment removes the volatile aroma of the citrus juice. To restore its natural flavor and aroma, two procedures have been developed. One is the recovery of the essence. The volatile fraction is concentrated in a series of condensers. After the juice has been concentrated this essence is added back to the product (3, 11, 18, 27, 90, 105, 125, 129). The other procedure is to overconcentrate the juice at 55-65°Bx and diluted to 45°Bx with cut-back juice of about 12°Bx. This cut-back juice is freshly squeezed juice that after heat treatment is quickly cooled to maintain its fresh aromatic quality. This addition of cut-back juice restores the full flavor of the concentrate product (18, 90, 129).
Once the juice has been evaporated it is prechilled by passing it through a slush freeze. It is then packed for storage (11, 117).

The retention of quality of the product is influenced by handling and storage temperatures. No significant changes were noted in cloud retention or flavor during 11 months of storage at -32°C or below (36, 58). Temperatures of -10°C were reported to be good for the storage of lemon concentrates (44).

One advantage of concentrates is saving space. Frozen lime juice appeared in the market several years ago and received good consumer acceptance. To facilitate the concentration, sometimes sugar is added to the juice and in the case of lime is called limeade.

Limeade must have a proper soluble solids-acid ratio. Preference was shown for the 15:1 ratio. 11°Bx was considered optimum (16). The flavor of lime concentrates can also be enhanced by adding cold pressed or distilled oil (16).

All of the increase in lemon juice processing in the past decades in the United States, has been in lemonade concentrates, mostly in frozen forms (135). This suggests that a similar market for limeade products could be developed.

**Powders**

The removal of the remaining water from a concentrated juice product would harm the quality of the reconstituted products. Removal of additional water requires additional energy and therefore increases processing cost. Thus a product with equal or less flavor quality will be produced and will be more expensive (11). However, there are some advantages; dehydration
permits food preservation by taking away water available to support the growth of microorganisms. The dried product is stable at room temperature, easy to store, and the shipping and handling are also facilitated. Finally the product is easy to reconstitute (11, 45, 53, 120).

Powders are very useful in areas where refrigeration is not available such as rural areas, in military services, in export trades and in space exploration (11).

Various methods have been developed to improve retention of flavors in dried foods. These include drying under reduced temperature or pressure, and also the addition of lemon and lime oils that are retained by the powder (81). However, with dried food there is a loss in water-soluble vitamins because of their potential oxidation. Rapid drying retains greater amounts of ascorbic acid than slow drying (120).

The shelf life of citrus powders is reduced by water absorption caking and non-enzymatic browning. The first two are due to the amorphous structure of sugars (45, 60). The third effect is associated with caramelization of the sugars and degradation of ascorbic acid (60).

Lemon crystals are extremely hygroscopic and tend to stick even after short exposure to ambient conditions (25°C and 60% relative humidity) (60).

Among the different methods of drying the best results for citrus juices are with foam-mat drying, freeze drying and vacuum drum drying.

**Foam-mat drying.** In this process thin layers of stabilized foam are dried by heated air at atmospheric pressure. The foam is prepared in a continuous mixer by the addition of gas. In case of citrus a foam stabilizer like hydrolyzed soy protein or methyl cellulose is required
After drying the foam is crushed into powder. The powder has a very porous structure capable of nearly instant rehydration. Lemon and lime juices have been successfully foamed and dehydrated (12, 31, 54).

The principal advantage of the process is that the foam permits high initial rates of water removal and the product is dried at relatively low temperatures in a short time.

Additional marketable products which have been developed for orange products could be used in the case of lime. For example the stable foam itself can be packed in aerosol pressure cans. The foam may be extruded into long thin spaghetti-like strips which can be dried to form lime "sticks" (11, 13).

**Freeze drying.** In this process the water is removed from the product by sublimation, converting ice directly into vapor. The following operations are involved; freezing, dehydration and packing (31, 91). The equipment operates at high vacuum (0.1-2 mm Hg, absolute pressure) and supplies a steady flow of heat to the frozen food (120). The advantages of this method include a high degree of flavor, odor and color retention, maximum retention of nutritive value, and porous dried particles for fast and complete rehydration. The disadvantages of the process include high initial capital investment and high processing costs. Finished products require special packing to avoid oxidation and moisture pick-up (31, 33).

**Vacuum drum drying.** This is a relatively low cost drying method although the initial cost of vacuum installation is high. An important feature of the vacuum process is the relative absence of air during
dehydration thus minimizing oxidation (31). Additions of sugar and pectin accelerate the drying process and help to keep the original flavor (53).

Essential Oils

Citrus oils are the major by-product of the citrus processing industry (102). There are different types of citrus essential oils: cold-pressed oil, distilled oil and concentrated oils. In all of them the main difference is the procedure of extraction from the fruit.

At the same time the juice is extracted, water is sprayed over the peel which is pushed through an annular opening formed by the ends of the upper cup fingers. The stresses developed in the peel as it is forced through this opening is such that substantially all oil glands are ruptured. The water captures and carries away the oil expressed. This oil/water slurry is collected, the peel and particles are removed and the slurry is centrifuged to recover the cold-press oil (40, 111). The peel is damaged by the squashing action so that it cannot be used for other by-products such as candied peel.

Essential oils are composed mainly of mixtures of hydrocarbons and terpenes, while the oxygenated compounds include acids, alcohols, esters, aldehydes, ketones, ethers and phenols. Non-volatile residues consist of resins and waxes (50, 51, 67, 102).

Among the oxygenated constituents the aldehydes have the most profound influence on the flavor quality of the oil (102). The characteristic odor of lemon and lime oil is mainly due to citral (71).

Cold pressed oil. The highest quality of natural citrus oil is the cold-pressed oil that is obtained by pressing the peel. There are
several methods of expressing citrus peel oil, but all of them give an emulsion of oil and water. The oil is separated by centrifugation. After that step the oil is stored at low temperatures (-4°C) for several weeks. This process is called winterization and its purpose is to precipitate waxy materials. The clear oil is decanted into stainless steel storage tanks with a minimum of headspace air to prevent deterioration. This is accomplished by complete filling of the tanks or by displacement of the air with an inert gas (86, 112). To increase stability during storage some antioxidants are used such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT).

Cold pressed lime oil resembles lemon oil in composition and flavor, but lime oil has stronger and distinctive taste and smell. This may be due to the higher citral content and the higher amount in number and concentration of coumarins (72, 106, 109).

Lemon and lime cold-pressed oils have a higher market value than any other citrus oil (106). There is a good demand in the food, beverage, flavor and cosmetic industries for these oils (55, 116).

Distilled oil. The distilled oil may be recovered in the citrus process by steam distillation of the peel after the cold-pressed oil has been obtained.

Distilled oil is also obtained from flash pasteurization, from the concentration of the juice and from oil-mill waste centrifuge effluent (38, 71).

The distilled oils are less stable and lack true bouquet of the cold-pressed oil and, therefore, are less expensive.
Through long usage, the flavor of distilled lime oil has become the accepted standard of quality (109, 112). Distilled lime oil has an important place in the commerce (4, 103, 112). This oil is produced in large quantities in Mexico, by steam distillation of crushed whole limes. In this case the main product is the essential oil but the juice is wasted.

The composition of essential oils is complex. It has been studied using gas-liquid chromatography and mass spectrophotometry. Thirty one volatile components have been found in Mexican cold-pressed lime oil and 37 constituents in the Mexican distilled lime oil (4).

**Concentrated oils.** The concentrated oils are obtained by vacuum distillation of cold-pressed oils as the terpene portion is removed, a concentration of the oxygenated flavoring compounds occur (119). The most widely used is the five-fold concentrate.

Four different methods are generally used for concentrating citrus oil: fractional distillation, steam distillation, alcohol distillation and extraction methods using vacuum distillation and solvents.

The main uses of essential oils are: in the soft drink industry, in confectionary products such as hard candies, puddings, ice cream and frozen desserts (102). Also, essential oils are used in non-food industries for the production of soaps, perfumes and cosmetic products.

**Pectin**

Pectins are complex colloidal carbohydrates that consist largely of chains of galacturonic acid residues some of which have the C-6 acid group esterified with a methyl group (46, 101).
Actually, most of the pectin produced in the world is from citrus. Both the peel and the pulp of citrus fruit are potential sources of pectic substances (41, 82). The best source for pectin manufacture is the lemon and lime peels after the oil has been removed (21, 84, 112, 119).

The principal steps for pectin preparation include preparation of the peel for extraction, or storage for later use; removal of bitter glycosides and sugars; conversion of protopectin into pectin; filtration of extracted pectin and drying of the pectin (119).

The wet or fresh peel must be quickly extracted or dried to prevent enzymatic destruction of the pectic substances.

There are two main advantages in producing pectin from dried pomace. First, the convenience of stabilizing quickly the peel that allows storage, and second, the dried peel can be processed in large batches overcoming the time limitations imposed by the use of fresh peel (29). However, it was observed that dehydration of lime peel to 3-7% moisture decreases both the yield and grade of pectin as well as the consistency of the pectin solution compared to pectin made from fresh peel (29).

The extraction procedure for the peel involves the mixing of chopped peel with water at 27°C in a counter-current system with a holding time of 20 minutes. This mix is passed through a continuous press to remove excess water and soluble solids, mainly sugars. The recovery of pectin includes the hydrolysis of peel protopectin to soluble pectin. This is accomplished by treating the peel with water and acid. The time, temperature and pH of extraction are critical to achieve maximum yield and jelly units. Generally extraction temperatures range from 80 to 100°C, with length of extraction of 20 to 60 minutes at a pH range of 1.4 to
2.6 (95). The optimum conditions for extraction are 30 minutes at 95°C with nitric acid at pH 1.6 (94).

Precipitation of the soluble pectin is done with organic solvents such as isopropanol, ethanol, methanol or isobutanol (97, 112), followed by a series of filtrations and washings with increasing alcoholic concentrations to facilitate the drying step. Finally, the pectin is dried, ground and packed (112, 119).

The "jelly grade" denotes the quality of pectin which is estimated by measuring jelly sag of a standard 65% soluble solids jelly on a Ridgelimeter (94). The jelly grade of a pectin specifies how much sugar must be added to the pectin to make a standard 150 grade pectin (30, 94).

Jelly grades of pectin extracted from lime peel were always higher than those from lemon peel (94). There is a decrease in the yield and grade of pectin when the fruit is more mature. The fruit should be processed early in the season for greatest pectin yields (23).

Pectin is used for many purposes such as a gel forming agent like the high methoxyl pectin with sugar or the low methoxyl pectin that forms a gel with calcium ions, as thickeners, for suspending solids, as body producing agents and as an emulsifier (35, 83). In the food industry the main applications are for the manufacture of jams, preserves, marmalades, pie fillings, sauces and puddings.

Pectin is also used in the pharmaceutical industry as a carrier for drugs to enable more prolonged effect. Pectin is a useful product in the cosmetic industry.
Dried Peel

In citrus processing plants the purpose of the feed mill is to convert all of the waste materials from the juice extraction, pectin manufacture and other applications into saleable products (65, 87).

The peel, pulp, and seeds, because of their high water content and perishable nature, could not be transported economically for feeding purposes. This material is difficult to handle, ferments rapidly and sours. Stabilization of the waste by drying seemed the logical manner for preservation to permit distribution and storage (119).

Due to the high moisture content of the pulp, peel and seeds are first pressed. This reduces the moisture, then the press cake is dried in a rotary direct fired type dryer and is sold for use as cattle feed (87, 119).

Another method reported for drying citrus peel involves two stages: the first stage uses air at 98-100°C for 50-60 minutes and the second stage uses air at 50-60°C for 25-30 minutes. This process improves the quality of the product (20).

Nutritional Aspects of Limes and Lemons

The importance of fruits and vegetables in the diet has been emphasized through the years, due to their vitamin and mineral contribution.

The role and importance of citrus fruit was discovered in the long naval expeditions, where the explorers died of scurvy due to the lack of fresh fruits and vegetables in their diet. They observed that scurvy did not occur if fruit and vegetables (especially oranges, limes and
lemons) were included in the daily ration. It was attributed to the antiscorbutic factor that fruits and vegetables contain. This factor is known as vitamin C or ascorbic acid (99).

Only a few species of animals need to consume ascorbic acid. Man is one of these species because of the lack of the terminal enzyme in the synthetic pathway. The enzyme is L-gulonolactone oxidase that converts 2 keto L-gulonolactone to ascorbic acid (47).

Foods that are good sources of vitamin C are citrus fruit and their juices, broccoli, guava, cabbage, cauliflower, papaya, tomato, spinach and potato (52, 99).

The functions of vitamin C are: as a coenzyme in the maintenance of copper and iron in a reduced state necessary for hydroxylation reactions of proline and lysine within the fibroblast for the synthesis of collagen (104, 127). Vitamin C also acts in the helix formation of collagen and elaboration of the cement required to maintain the integrity and mechanical strength of blood vessels and capillary walls (47).

At the biochemical level, ascorbic acid may function in hydrogen ion transfer systems and aid in regulation of intracellular oxido-reduction potentials.

Ascorbic acid is a powerful water-soluble antioxidant and protects other antioxidants even some lipid soluble vitamins such as vitamin E and A.

Due to its reducing properties, ascorbic acid facilitates gastrointestinal absorption of iron.

Ascorbic acid has a cofactorial role in the following hydroxylation reactions: hydroxylation of tryptophan to 5-hydroxytryptophan, detoxification of poisonous substances, and formation of tyrosine and metabolism
of norepinephrine.

Ascorbic acid may play a role in the reduction of body cholesterol levels. This effect has been proposed to be related to its role in hydroxylation reactions that are prominent in the transformation of cholesterol into bile acids (major excretion route for cholesterol) (2).

Some of these functions of vitamin C help to explain the physiological and psychological changes that have been observed in patients with scurvy.

Nutritional requirements

The human requirement for vitamin C has been estimated from the amount of vitamin necessary to prevent scurvy, the amount metabolized by the body and the amount necessary to maintain adequate reserves (88).

A number of factors may alter the need for ascorbic acid. Under acute emotional or environmental stress such as exposure to elevated temperatures increased intake of vitamin C is required to maintain the normal plasma levels. Sex and age affect the ascorbic acid requirement, slightly higher amounts are required for females than for males. An older person requires more ascorbic acid than a young one. It is advisable for smokers to increase their consumption of vitamin C. In vitro, aspirin blocks the uptake of ascorbic acid by blood platelets. Oral contraceptives also depress the plasma ascorbic acid level (70).

Since vitamin C is rapidly and efficiently absorbed (89%) a deficiency of this vitamin indicates an improper dietary intake.

A dietary allowance of 60 mg of vitamin C per day is recommended for adults of both sexes (88). Infants require 35 mg/day. During pregnancy, an additional 20 mg of ascorbic acid is recommended. For lactation, an
additional 40 mg/day of vitamin C is suggested to assure a satisfactory level of the vitamin in breast milk. For premature infants there is an increased requirement of vitamin C (100 mg/day) due to the metabolism of tyrosine (88).

The demand for ascorbic acid rises after surgery, burns, stress and infection (127).

**Deficiency in man**

The onset of scurvy can be detected between 60 and 90 days after consuming a diet that does not contain ascorbic acid. The earliest manifestations consist of a few petechial spots. Later larger ecchymosis appear and follicular hyperkeratosis develops. A little later the gums become swollen and bleed easily. This is accompanied by dryness of the mouth and eyes, dry itchy skin and loosening of teeth and dental fillings. Delayed wound healing and an increased risk of infection are often present (47).

Scurvy is also characterized by weakness, lethargy, edema in feet and ankles, hysteria, depression and hypochondriasis. Anemia is often present due to the hemorrhages. Scurvy treatment consists in giving different doses of vitamin C causing prompt improvement of the symptoms. It generally starts with low doses of vitamin C to prevent intestinal distress, electrolyte disturbance and hemolysis.

Scurvy can result in sudden death, therefore treatment should not be delayed (130).
Vitamin C in citrus fruit

Since citrus fruit and their products are one of the largest suppliers of dietary vitamin C it is important to know which factors affect vitamin C levels in citrus fruits.

Vitamin C potency (antiscorbutic activity) is based on the combined levels of L-ascorbic acid and dehydro-L-ascorbic acid. This is considered as total active vitamin C (108).

Vitamin C levels in citrus fruit are influenced by: climatic conditions position of the fruit on the tree, maturity, variety, fresh fruit handling practices, processing conditions, type of product container and storage conditions (78).

Climatic conditions. Environmental conditions could modify vitamin C content. Weather temperatures of 20-22°C during the day and 11-13°C at night are necessary for optimum yield of fruit having high levels of ascorbic acid (78).

Position of the fruit in the tree. Unshaded fruit had higher Vitamin C content than shaded fruit. It was proposed that photosynthesis must be in progress in order to supply hexoses from which ascorbic acid is synthesized.

Maturity. Immature fruit contains the highest concentration of vitamin C in mg/ml of juice. However, during ripening the total vitamin C content per fruit tends to increase because the volume of juice and the size of fruit also increase at maturity.

Variety. Vitamin C in limes, including all varieties, show a range of 15-45 mg/100 ml of juice. There are other parts of the fruit which also contain vitamin C. These are not recognized in nutrition
because they are non-edible components such as peel, rag or pulp and seeds. In fact only about one-fourth of the ascorbic acid content of the entire fruit is found in the juice (78).

Processing practices. Vitamin C in foods is heat labile and easily destroyed by oxidation, therefore, prolonged cooking at high temperatures, exposure to oxygen, copper and iron should be avoided during processing of citrus fruit. Ascorbic acid is rapidly destroyed under neutral or alkaline conditions (17, 19, 59, 113).

Destruction of vitamin C may occur during processing by non-enzymic or enzymic degradation.

Non-enzymic degradation has two pathways aerobic and anaerobic. The incorporation of air into the juice during extraction, blending and container filling causes vitamin C losses.

A rapid loss of vitamin C is caused by the presence of free oxygen. After oxygen has been consumed, vitamin C is degraded anaerobically at lower rates than the aerobic process (89, 113).

Ascorbic acid in presence of oxygen can form brown intermediates via the formation of dicarbonylic compounds (76).

The kinetics of ascorbic acid degradation was reported by Laing et al. to be of zero order, depending upon the temperature, oxygen availability and water activity (a_w) (64). However, other investigators (78, 89, 113, 128) have found that ascorbic acid degradation is a first order reaction, in which log vitamin C content is linearly related to storage time. This discrepancy may be due to the fact that the former investigators considered degradation of ascorbic acid at higher temperatures (above 60°C) while later ones worked in storage conditions.
Enzymic degradation. There are several enzymes commonly present in citrus fruit. Among these are ascorbic acid oxidase, cytochrome oxidase, peroxidase and phenolase. These enzymes in intact fruit are balanced by reductases. When this balance is disturbed by cellular disruption as occurs in juice extraction, the oxidases may destroy all the ascorbic acid content unless they are inactivated.

Methods used to inactivate the enzymes are pasteurization temperature and blending the juice (17, 78).

Effects of the container. To retain ascorbic acid, it is preferable to can citrus products in plain tin cans rather than in enamel-lined cans. The difference is due to the preferential reactivity of the residual oxygen with tin rather than with the ascorbic acid. Glass bottles also protect ascorbic acid, but plastic containers and cardboard cartons are permeable to oxygen, lowering vitamin C retention. Commercial containers used for frozen concentrates are satisfactory as long as the product remains frozen (14, 78).

Influence of other juice constituents. Among the three major sugars found in citrus juice (glucose, fructose and sucrose), fructose has been suggested to enhance the vitamin C breakdown, due to the reaction between its carbonyl group and vitamin C (78).

Hydroxyacids such as citric and malic stabilize vitamin C by chelating metals and also increasing the juice acidity (26, 78).

Storage conditions. After heat processing the subsequent retention of vitamin C is dependent on temperature and storage time.

Storage temperatures in excess of 20°C cause accelerated destruction of vitamin C. To retain as much vitamin C as possible, storage temperatures
of 4-10°C have been recommended (17, 78).

Vitamins other than ascorbic acid are also found in the edible portion and juice of citrus fruit in sufficient quantity to make small to moderate contributions to dietary needs. These vitamins are folacin and vitamin B-6 (2).

Some important minerals such as potassium and iron are also present in citrus fruit.
APPLICATIONS IN MEXICO

A common problem in Mexico is the lack of planning in agriculture for the production and utilization of different products. This problem is enhanced in areas in which industrialization is poor. Due to scarcity of transportation and perishability of products entire crops are lost.

In this paper are suggested some of the possible uses and technology of products and by-products than can be obtained from one important Mexican agricultural product, namely limes.

The first thing to consider is harvesting the fruit which should be done under optimal conditions avoiding collection when the fruit is wet and also carefully handling the fresh fruit.

Another important aspect is optimization of storage conditions with controlled atmospheres and using wax and fungicides as a protective coat for limes produced under the environmental and economical conditions prevailing in Mexico (This work is already in progress by the Mexican government, CONAFRUT).

To achieve maximum benefit of food crops, it is necessary to utilize the entire crop. If it cannot be consumed in the fresh state, the surplus should be processed into usable products. Thus the number of processing plants should be increased. On this assumption it is suggested that processing plants be constructed in areas close to the production centers. These processing plants should be designed to obtain all possible products from the fruit. In Mexico two main processed products; the essential oils and the juice have been emphasized. However, from the peel pectin also can be obtained and the juice can be converted to successfully useful
products such as frozen concentrates and powders. Both products are very useful for the housewife, easy to reconstitute and save time in the preparation of refreshments. At the same time it will increase the consumption of fruit juices with the subsequent nutritional benefits.

Lime juice can be used blended with various fruits like strawberry, grapefruit, pineapple, apple or pear to prepare mixed drinks.

Lime powder can be used to make candy-like citrus products that will be a novelty and children will enjoy the acid flavor of the lime juice.

Some citrus dried peel has been used as a flour in baked products for human consumption. However, the major use is as cattle feed.

Complete use of limes can be achieved by a gradual introduction of new technology in areas in which so far, the only profits are obtained from the fresh fruit. This approach would encourage lime producers to increase the cultivated areas, that at present time tend to decrease due to the periodic loss of crops.
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APPENDIX I. BOTANIC DESCRIPTION OF LIME

The lime belongs to the Rutaceae (Rue family). This family is rich in aromatic qualities and yields essential oils, edible fruits, ornamental and odorous plants (5).

The tree is medium in vigor and size with stiff sharp spines. Foliage is dense and consists of small elliptic-oblong leaves, sometimes rounded at the apex. Both buds and flowers are small. The mature flower has a receptacle in the upper end of the peduncle to which the floral parts are attached. The calyx is a persistent cup-like structure with five petals which alternate with the sepals. The pistil is composed of stigma, style and ovary. Flowering occurs throughout the year but mainly in spring and late summer (48, 98, 110, 133).

The fruit is a type of berry sometimes called a hesperidium. It is a superior fruit with all of the tissues derived from the ovary and consists of approximately 10 united carpels clustered around and joined to the floral axis (1, 98).

The fruit is small, round, oblong. The base is usually rounded but sometimes has a slight neck. The apex is also rounded but usually has a small, low and faint nipple. The rind is very thin, the surface smooth, leathery and tightly adherent. The color is greenish-yellow at maturity. The flesh color is greenish-yellow, fine grained, tender, juicy and highly acid with a distinctive aroma.
APPENDIX II

DIAGRAM FOR THE COMPLETE USE OF LIMES

UNLOADING THE FRUIT → WASHING → EXTRACTION → PULP & SEEDS → WASHING → BEVERAGE BASE

JUICE

PREHEATED → EVAPORATORS → ESSENCE

FLASH PASTEURIZATION

PACKING

CONCENTRATE

SINGLE-STRENGTH JUICE

FREEZE

FROZEN CONCENTRATES

PEEL

DISTILLED OIL

PEEL

PECTIN

ESSENTIAL OILS

STORAGE AT COLD TEMPERATURE

WAX

COLD PRESSED ESSENTIAL OILS

CONCENTRATED ESSENTIAL OIL

DRYER

LIVESTOCK FEED