The background of the cover is a warm, orange-brown color, overlaid with several slices of fresh oranges. The slices are arranged in a scattered pattern, showing the internal segments and the central pith. The text is centered and overlaid on these slices.

# **CITRUS PROCESSING**

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**A COMPLETE GUIDE**

**SECOND EDITION**

**DAN A. KIMBALL**



**AN ASPEN PUBLICATION**

# **Citrus Processing**

## **A Complete Guide**

### **Second Edition**

**Dan A. Kimball**

Kimball Consulting  
Lindsay, California

A Chapman & Hall Food Science Book



**AN ASPEN PUBLICATION®**

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# Dedication

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I would like to dedicate this to my wife, Pamela, the major influence in my life.

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# Preface

Citrus juices are the most common among the fruit juices around the world and constitute a major portion of the food industry. Even though juice-processing technology has been around for many years, interest in historical and modern innovations and applications is widespread. New juice enterprises are springing up constantly all over the world. Old enterprises are constantly undergoing change, growth, and development. The Internet has expanded the reach of many, not only for information but for marketing and production alterations. The World Wide Web has made the wide world one. Computer technology alone is growing faster than the oranges on the trees. With these multifaceted changes, a need has emerged for an update to the first edition of *Citrus Processing*.

The second edition of *Citrus Processing* has expanded its scope beyond the quality control theme of the first edition. I have used a more holistic approach to the subject of citrus processing. Those using this text in the classroom will find it more comprehensive in its treatment of the subject. The first edition targeted the industrial technologist. The second edition approaches citrus processing as a complete subject, assuming an audience interested in learning from the ground up. This new approach should be particularly appealing to those unfamiliar with the industry. Even so, experienced industrialists will find the information contained here contemporary, futuristic, and fundamental. Whereas the first edition was ideal for use in the university classroom or in the industrial laboratory, the second edition will provide an excellent text in the company boardroom and managerial offices.

This new direction has resulted in several new additions as well as updates and reorganizations. There is a more detailed description of processing equipment, procedures, and engineering along with information needed to plan a processing facility. Management principles are outlined in greater detail. Even though this chapter will be of value to any enterprise, the needs specific to the citrus-processing industry are addressed. The final chapter offers information on citrus-processing innovations that is sometimes difficult to find.

Emphasis has been placed on modern computer applications, especially the use of the Internet. Readers are referred to my home page, <http://www.angelfire.com/biz/DAKimbball>. There you will find free information, links, and places to obtain additional information. You can also e-mail me at [Kimball@ocsnet.net](mailto:Kimball@ocsnet.net) to inquire concerning my consulting services or call (559) 562-1027.

An effort has been made to zero in on information of most value to those who design, build, and run processing plants. Much of this information is basic and applies to related, as well as all, manufacturing entities. Management is, or should be, constantly looking for techniques that will enhance the bottom line. Making a profit is becoming more and more difficult, especially in third world countries. Employees are also struggling more and more to eke out a living. It is my intent and desire to assist the industry in increasing its productivity and becoming more successful both as a profitable enterprise and as a major contributor to the health and well-being of our worldwide family.

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# CHAPTER 1

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## Introduction

Citrus fruit date back as far as 2200 BC, when tributes of mandarins and pumelos were presented in the imperial court of Ta Yu in China (Webber 1967). However, it is believed that some citrus (lemons, limes, and citrons) originated in the Malay Archipelago in Southeast Asia and spread westward into India. From there, some citrus fruit (early forms of oranges and shaddocks, ancestors to the grapefruit) made their way to China. The present form of the orange is believed to have developed in eastern China. Mandarins first are mentioned in eighth-century BC Sanskrit literature. The first mention of the orange appears in the *Shu-ching*, a Chinese book of the sixth century BC (Jahoda 1976). The citron was first mentioned in 310 BC by Theophrastus. Alexander the Great is believed to have introduced citrus into Europe between about 300 and 400 BC. Chinese literature in 200 BC mentions easy-to-peel mandarins.

Sweet oranges were referred to as “Indian fruit” by the Romans, who seeded groves in southern Italy in the first century AD. Goths and Vandals destroyed the horticulture during the Dark Ages. Mandarins moved from China to Japan around the twelfth century. The Spanish Moors brought citrus into southern Spain from the abundant North African citrus plantings, which originated from earlier European citriculture.

Oranges, lemons, and citrons were introduced into the Americas by Columbus, who brought the first seeds to Haiti in 1493. By 1498, sweet oranges were thriving in southern Europe. According to the Spanish historian Oviedo y Valdes, sweet oranges and limes were plentiful in the Caribbean around 1527. Limes spread to the Florida Keys around 1520 and adopted the name *key limes*. Sweet oranges were brought into the St. Augustine area of Florida by Pedro Menéndez de Avilés in 1565. Citrus was growing in abundance there by 1579. Indians scattered the seeds throughout Florida, but only the hardier wild sour oranges survived this scattering. These wild varieties were observed in 1773 by William Bartram, a Philadelphia naturalist, and still can be found today around the edges of

Florida's lakes and streams. It was not until 1763 that the fruit began to be shipped north as far as New York (Jahoda 1976). As early as 1707, Spanish missionaries spread citrus to Arizona and later to California. The first known cultivated groves appeared in 1769 at the San Diego Mission in California. It was around this time that Captain Shaddock from British East India introduced a variety of the pummelo that took his name and from which the modern grapefruit developed. The first cultivated citrus groves in Florida appeared between 1803 and 1820 in Pinellas County. Oranges in Florida began to prosper when Spain ceded Florida to the United States in 1821. New Yorkers and Bostonians incorporated citrus as a staple soon afterward. Grapefruit originated in the Caribbean and was brought to the Safety Harbor area near Tampa by Odet Phillippe, a French doctor, in 1823. Mandarins were first known to have entered Florida in 1825. The first known commercial grove in California was planted near Los Angeles in 1834 by Louis Vigner. Between 1838 and 1870, the pest scale slowed production in Florida but soon disappeared as mysteriously as it came. Around 1870, commercial lemons appeared in Florida, but they did not really take off until after 1953 with the advent of frozen lemonade. After 1870, citrus production boomed in Florida. Between 1874 and 1877, Florida began to import large quantities of oranges (200 million) from the Mediterranean and the Caribbean. King tangerines entered Florida in 1882 from Saigon. In 1885, the grapefruit industry began to take off in Florida. Satsuma mandarins were among the earliest plantings in Texas in the mid- to late 1800s. These commercial plantings were later driven to the Rio Grande Valley by severe freezes, where they remain today.

The commercialization of fruit juices has a long and colorful history. The first commercial fruit juice was produced in 1869 by Welch, who began bottling unfermented grape juice in Vineland, New Jersey. However, juice that could be preserved for long periods of time did not emerge until after Welch introduced the principles of heat sterilization. Citrus sections were first produced in Florida in 1921, and the first canned citrus juices appeared in 1923 (Neff 1998). By the 1930s, flash pasteurization was developed, and it was during this time that fruit juices emerged as a significant source of vitamin C in the public's eye and began to gain in popularity. World War II brought new needs to the juice industry that resulted in the development of dehydrated fruit juices and frozen concentrates. Prior to this time, California dominated the citrus industry with its fresh markets. But with the advent of frozen concentrated orange juice and its increase in popularity, the citrus industry moved east to Florida.

Today, Florida grows approximately 70 percent of the citrus in the United States, along with California's 25 percent and Arizona's 3 percent. Florida processes about 95 percent of its oranges into juice. In 1996, there were more than 107 million citrus trees in Florida, including more than 84 million orange, 15 million grapefruit, and 7 million specialty citrus fruit trees, all on 857,700 acres (Brown 1997). Florida increased its production to about 1.4 billion

single-strength equivalent (SSE) gallons in 1996–97 and was estimated to reach more than 1.5 billion in the 1997–98 season (Lesser 1997). In the next five years, there is expected to be a 12 percent increase in orange production in Florida. Florida produces about two-thirds of the world's grapefruit, reaching 162 million SSE gallons in the 1996–97 season (Lesser 1997). Seedless grapefruit is expected to remain about the same, while seedy grapefruit is expected to decrease nearly 17 percent over the next 10 years, and tangerines to increase 33 percent (Brown 1997). Florida produces about 77 percent of the grapefruit in the United States. Florida is also a primary producer of lime juice but only at about 0.2 percent of its orange production.

California and Arizona are the primary producers of lemons and lemon products, which are used extensively for the essential oils and pectin in the peel. California produces about 12 percent of the grapefruit in the United States, Texas about 8 percent, and Arizona about 3 percent.

Even so, the U.S. citrus juice industry imports heavily from Brazil and Mexico. The freezes of 1962 in the United States prompted citrus development in the milder climates of Brazil. Since that time, Brazil has emerged as the dominant citrus producer in the world. Even so, imports into the United States from Brazil have decreased to about half from 1983 to 1996 or to about 260 million SSE gallons. Brazil exports primarily to Europe, followed by the United States, Japan, Korea, and Canada. From 1983 to 1996, Brazil increased its production by about 45 percent to approximately 1.6 billion SSE gallons in the 1996–97 season, processing about 66 percent of its oranges (Lesser 1997). The 1997–98 season production was estimated to reach 1.8 billion SSE gallons, a record for Brazil. The Brazilian juice industry, including Cargill, Dreyfus, Cutrale, and Citrosuco, has purchased several major juice-processing facilities in Florida, as have the Japanese, Canadians, and French. The four major Brazilian citrus producers dominate 80 percent of the Brazilian citrus industry and have purchased about a third of the orange-processing capacity in Florida (Lesser 1997). Major tank farm outlets that are used to move Brazilian concentrates into the United States include Wilmington, Delaware; Port Elizabeth, New Jersey; and Tampa Bay, Florida. Brazilian concentrates bound for Europe enter through Rotterdam in Holland and through Tokyo into Japan. Citrus fruit production around the world is summarized in Exhibit 1–1. It should be remembered that Exhibit 1–1 includes fruit bound for both fresh fruit and juice markets.

Citrus juice manufacturing is varied and complex. It is my intent to describe the main aspects of citrus processing in a form that can be readily understood. The next chapter begins with a description of citrus taxonomy to give the reader a feeling for the great diversity in citrus classification. Chapter 3 portrays the basics of corporate management, including suggested steps in planning a juice facility. Chapter 4 illustrates common engineering schemes and information on citrus-processing equipment and related methodology. Chapter 5 details citrus

**Exhibit 1-1** Preliminary citrus fruit production, 1995-96 season.

<i>Oranges</i>	<i>1,000 MT</i>	<i>Tangerines</i>	<i>1,000 MT</i>
Brazil	16,450	China	4,667
United States	10,747	Japan	1,696
Mexico	2,600	Spain	1,566
Spain	2,440	South Korea	615
Italy	1,770	Brazil	535
China	1,725	Italy	510
Egypt	1,360	United States	412
Turkey	880	Turkey	410
Morocco	870	Morocco	360
Greece	850	Argentina	325
South Africa	850	Egypt	300
Argentina	640	Mexico	145
Australia	543	Israel	125
Israel	460	Greece	85
Cuba	380	Cuba	6
Cyprus	252		
Gaza Strip	87		
Japan	30		
TOTAL	42,932	TOTAL	11,757
<i>Grapefruit</i>	<i>1,000 MT</i>	<i>Lemons</i>	<i>1,000 MT</i>
United States	2,502	United States	896
Israel	395	Argentina	700
Cuba	250	Italy	680
Argentina	190	Spain	443
South Africa	172	Turkey	440
Mexico	120	Greece	135
Cyprus	112	South Africa	71
Turkey	60	Brazil	70
Gaza Strip	9	Cyprus	38
Italy	6	Australia	38
		Morocco	20
		Israel	20
		Mexico	12
		Gaza Strip	8
TOTAL	3,816	TOTAL	3,571

*Note:* MT, metric ton or 1,000 kilograms.  
*Source:* Reprinted from USDA Agricultural Statistics, 1997, U.S. Government Printing Office, Washington, D.C.

juice quality control, including quality control procedures, sampling, sanitation, and statistical analyses. Chapter 6 covers analyses of Brix, soluble solids, acids, oils, and pulp; Chapter 7, analyses of other juice characteristics including nutrition, cloud, color, bitterness, and rheology; Chapter 8, analyses of the microbiology of citrus juices; Chapter 9, analyses of processing contamination; and Chapter 10, analyses of adulteration. Chapter 11 relates the basics of byproduct production, including the handling of waste materials. Chapter 12 delves into basics concerning research and development, including current issues and future trends. Again, additional information can be downloaded from the author's web page mentioned in the preface.

There is much information contained in this book. It is designed to be a reference text. The first edition has proven the success of this intent. However, neither this text nor any text can really take the place of real training. Training goes beyond learning. It is one thing to read about a skill and another to learn how to use it and implement it. Training is a vital part of understanding and requires time, study, and effort. Often it requires a trainer. No text can replace the wealth of experience, knowledge, and talent of a professional. This book can be an excellent reference, but it cannot replace a professional trainer. Company training sessions with this book as a text can provide an excellent forum for increasing skills.

Laced throughout the text are up-to-date computer and technological applications. Many of the ideas contained here emerge from my vision. No single person can survey the entirety of citrus production and manufacturing activity. However, many have a view of extensive vistas of exciting enterprise. Automation has entered much of the industry but is almost absent in many locations. All companies can benefit from an outside viewpoint, someone to stimulate new ideas. Aspects of this important industry's past, present, and likely future are intermingled throughout each chapter. It is hoped that this book will not only provide an encyclopedia of information but also kindle new ideas that will become the vision, methods, and technology of the future.

---

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## CHAPTER 2

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# Description of Citrus Fruit

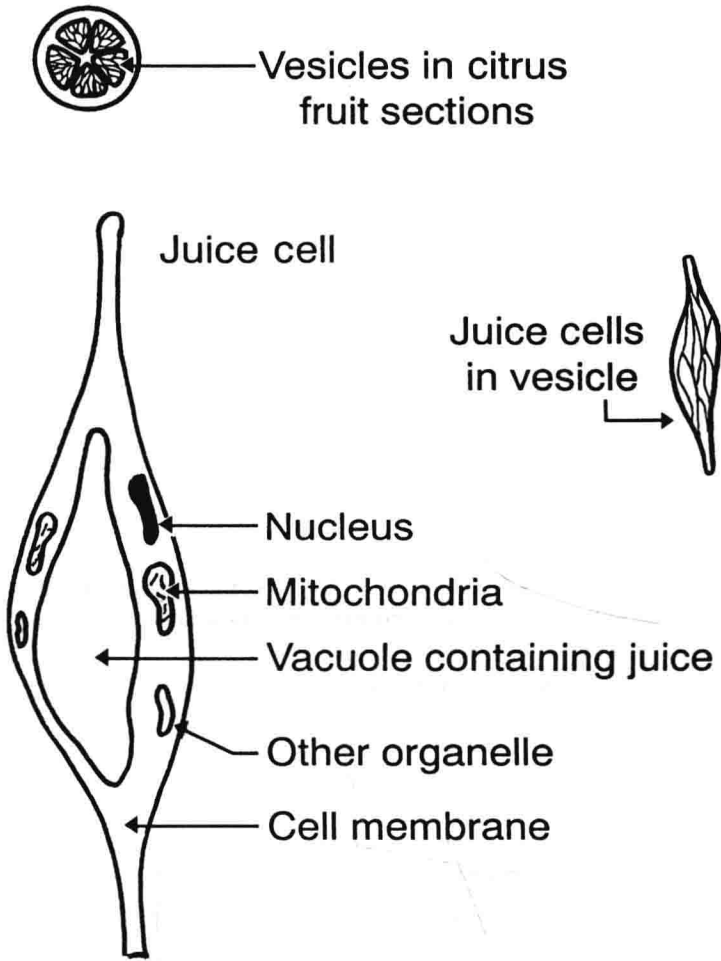
Citrus fruit holds a unique place in the plant kingdom. Its anatomy is unparalleled, and it occupies a resulting solitary position in the human diet. Just how or why citrus grows into what it does remains largely a mystery. The first step in solving these mysteries involves classification of citrus fruit. Just describing the differences between species and varieties has become a monumental effort. In this chapter, we will explore the currently accepted description of citrus fruits.

### CITRUS ANATOMY AND BIOLOGY

Citrus fruit are composed of an outer flavedo layer that contains the exterior fruit color and sesquiterpene oil sacs that protect the fruit from insects and microorganisms. Just under the flavedo is a white spongy albedo layer. Tangerines are characterized by a looser flavedo/albedo layer that makes them easier to peel. This loose rind makes juicing operations more difficult or messy. Tangerine fruit requires much gentler handling and usually cannot be stored for any length of time prior to processing. In the Orient, however, they take advantage of this by producing canned tangerine sections. The looser rind facilitates easier peeling and sectioning.

Under this layer are the fruit sections, divided by membrane material. Each section contains many vesicles that are elongated and attached to the core or center of the fruit. Within the vesicles are many juice cells (Figure 2-1). These juice cells are also elongated and attached to the center of the fruit and consist primarily of enlarged vacuoles that contain the juice. The nucleus of these cells and the other organelles are located essentially in the membrane of the expanded juice vacuole. It has been shown that the juice in the vacuole is clear or devoid of cloud material (Bennett 1987). As the fruit matures, carbohydrates and water from the sap flow of the tree accumulate in the juice vacuole. The mitochondria in the membrane of the juice cell is active during maturation, producing, in the Krebs





**Figure 2-1** Juice cell anatomy and location in the fruit. Juice accumulates in the vacuole and occupies the majority of the volume of the mature cell.

cycle, citric acid that also accumulates in the juice vacuole. This accumulation and subsequent dilution with water and carbohydrate accumulation results in the change in acidity of various juices with maturation. The general trend is for acid to reach high concentrations in early-season fruit and then to be diluted out by fruit growth or citric acid depletion or both through increased metabolic demand in warmer weather (Kimball 1984). The combination of water, carbohydrates, or-