Principles and practices of small- and medium-scale fruit juice processing

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FOREWORD

This bulletin presents both theoretical and practical information on the processing of fruit and vegetable juices, thus offering the reader both the principles and practices of small and medium-scale fruit juice processing.

While large-scale juice processing is the subject of many textbooks and other printed or electronic publications, small-scale operations generally receive very little attention.

The purpose of this publication is to fill the gap in information available to professionals as well as private entrepreneurs, mainly in developing countries. It is the medium and small-scale agro-industries that more appropriately fill the needs and capabilities of these countries, considering the available volume of production and the capacity of local markets to absorb products.

The bulletin is divided into two parts. The first gives the general principles of fruit and vegetable juice processing. It starts with a general history and background of juice production and continues through fruit composition, juice grades, harvesting and post-harvest handling of the fruit, and on to the general principles of juice manufacturing and presentation. It also covers the processing related products such as jams, jellies, pectin, essential oil etc.

The second part describes in detail the processing of specific juices as well as the major by-products. Citrus juice, especially orange juice, receives particular attention. Specific chapters are dedicated to grape, apple, stone fruits as well as a long list of tropical fruits. The methods of processing of major vegetable juices are also covered.

Finally, the publication presents a list of printed as well as electronic sources of information for further reading.

FAO will be pleased to receive comments and provide any additional information required.

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CHAPTER 1

INTRODUCTION AND HISTORICAL BACKGROUND

1.1 Purpose of publication

Over the past several decades there has been a growing trend toward adding value to raw agricultural products. As populations have become more urban, this trend has accelerated. The need for stable, convenient foods has increased along with the demand for exotic products for international cuisine. Within the globalization of the food industry, the demand for quality juice and juice type beverages has markedly expanded. Traditionally, only a handful of fruit and vegetable juices have served this market as large multinational companies or their affiliates, have captured the majority of national and international juice trade. Juices such as orange, grape, pineapple, apple, tomato and blends are well established in developed countries. Now, minor juices, tropical juices and juice products are attracting new attention.

Trade and technical literature available reflect these trends. There is an impressive body of published plus increasingly, Internet information on all aspects of the juice and juice beverage industry. Juice processing technology ranges from individuals preparing juice at home for family consumption to multinational conglomerates with several interconnected high capacity plants and juice product lines serving global demands. However, there is far less attention paid to minor juices, small or local manufacture of such products and the specific problems faced by producers who have not shared in this growth.

The purpose of this publication is to present technical and business information designed to address issues facing small and medium-size juice processors along with insights into the theory and practice of juice and juice beverage processing and utilization. Both major and minor fruits will be covered with emphasis upon limited-resource producers for local markets. Unique, high quality juice products can secure a niche position. With attention to quality, value, safety, health and an innovative approach to these parameters, a manufacturer can move beyond the niche category and become a major player. This is a more difficult but feasible task.

There are some general principles that should be understood by anyone contemplating entering the juice processing business. Many aspects of production, postharvest handling, food safety, quality, unit operations, processing and packaging procedures, as well as regulatory control, are common to practically all juice products. Then there are a number of product-specific details, dependent upon the morphology, composition and character of the individual fruit. This publication will provide adequate details so interested parties can either improve existing operations or develop new processing establishments. Potential capabilities include adding value to local agricultural products, providing employment, augmenting the quality, safety, economy and diversity of the local food supply.

This entails a working understanding of food science and technology. In turn, it requires attention to the knowledge resources available though unevenly accessible globally. A good technical library with the latest texts, supplemented by complete journal holdings, abstract services and as their electronic equivalent, Internet linkages and on line search capability, is an expensive undertaking for even the most affluent institutions. Such facilities remain a remote possibility in developing countries. However equipment and access costs are dropping and the pace of information technology advances has never been faster and will have global implications.

Dramatic advances in information technology (IT) promise to greatly enhance technical information transfer in all fields, including Food Science and Technology (FST). When that time arrives, texts such as this will be on line with the key subject matter including hyperlinks to relevant references, sources of suppliers, national and international regulatory aspects and marketing information. Updating will involve periodically introducing new material and replacing obsolete information. The FAO Website (FAO, 2000a) is an excellent example of this evolving trend. However, hard copy texts provide the necessary insights and guideline for the near term.

Elegant technology does not negate the need for a fundamental understanding and working knowledge of the science and technology behind juice manufacture. Sophisticated processing machinery, computer data acquisition and process control will not replace hands-on experience with specific commodities. Close observation and manipulation of a crop from breeding advances and cultivation to final juice consumption under varying circumstances will always be necessary. It is made easier by technology, but it is not replaced by it. In fact, the experienced juice technologist with a comprehensive understanding of local raw material, global practices can improve the efficiency and profitability of a juice operation.

International visitors to modern juice processing facilities are often in awe of the elegant, sophisticated, costly operations they view, unaware or forgetting the tremendous investment in human capital required to arrive at that point. Guests from even the poorer regions of the world should recognize that they possess untapped human resources, potentially skilled labour and, most importantly, an agricultural environment where many foods can be grown that are impractical to grow or process in the temperate zone.

Visitors may then recall vast heaps of fruits in their own country going to waste due to lack of markets or processing outlets. The logical conclusion is to consider developing a local juice processing industry based on the impressive operation they are viewing. This is, still, putting the cart before the horse. The many logistical and infrastructure hurdles, which must be overcome before the first fruit is processed will not be evident to most visitors. Indeed, the rusting hulks of once modern food processing plants can be found in many regions of the developing world, a testament to inadequate planning by the international assistance community and their local counterparts.

Fruits are ubiquitous in most temperate and tropical zones. There may be ample raw materials available for short seasons, which mostly goes to waste due to the lack of processing facilities. There are opportunities for small and medium scale producers who are unlikely to compete directly with major international firms. Yet there are untapped national markets. With a realistic attitude, attention to competitive advantages and a strong business commitment, growth including export opportunities are achievable goals. Challenges are great, but success has been achieved in the past and will be again in the future. We hope readers of this text will be among the successful ones.

1.2 Historical background

The manufacture of juices from fruits and vegetables is as old (or older) than agriculture. During the ripening process most fruits soften to the point where simply handling or transporting them yields more juice than flesh, albeit often partially fermented. The resulting pulpy fluid, easily separated from seed and skin, is generally more flavourful than the more solid portion. Hunter-gatherers could either consume quasi juices directly or collect the soft fruit in reasonably leak-free containers for later use. Simply transporting the fruit any distance soon guaranteed juice. Except for cool temperature climates, storage life was limited to mere hours before incipient fermentation modified the character of the juice appreciably.

Figure 1.1: 18th Century olive oil jar from Caribbean shipwreck.
Courtesy Florida State Museum

Through trial and error humans learned practical ways of extracting juice from various sources and, most importantly, which attractive but toxic fruits to avoid. Tool making skills fostered the manufacture of devices for macerating fruits and extracting juices. Containers for storing foods, including receptacles for fluids were also devised from local resources, i.e. woven plant fibre and wood, clay soils and animal skin/intestine. Such methods and equipment can still be found in isolated pre-industrialized regions. Otherwise they are seen only in museums as prehistoric or early artifacts of extinct civilizations. Until fairly recently, liquid containers were quite primitive compared to those of the 20th century (Figure 1.1).

The perishable nature of juices dictated immediate consumption within less than 24 hours in warm climates and extended but still limited time in cooler environs. Natural chilling or freezing was the only alternative to microbial modification of the juice. Such fermentation was the basis for wine. It was found that the juice, after bubbling mysteriously, has a distinctly different character and affect on those consuming the product. Also, the material stored several days longer slowly turned harshly acidic or developed an even more unpalatable surface growth and taste. This early vinegar was used as a preservative for other fruits and vegetables. Grape domestication followed this discovery.

With the development of agriculture over the last 10 millennia, the cultivation of crops provided a fairly reliable source of food, including fruits appropriate for juice and beverage use. Unless the juice was consumed fresh, soon after pressing, fermentation was the likely, often desired consequence until preservation techniques were developed. In fact, the concept of maintaining a fruit destined for juicing in its whole, intact form until the juice is needed continues to be a sound principle. Even today, maintaining the fruit intact is one of the easiest ways of preserving juice quality.

1.3 The value of juice

The global market for juice and juice products was estimated to be about 50 billion litres in the late 1990s. In the United States of America alone, the retail commercial value of the almost 20 billion litres of juice and juice products exceeded US$18 billion, roughly 3 percent of a total food sales expenditure of US$630 billion. World trade has accelerated over the last decade with developing countries achieving over 60 percent of fruit juice exports. Brazil, the largest citrus producer, accounts for about 25 percent of world production. Juice utilization in decreasing order is: Orange, apple, grape and pineapple. (Brandon and Ferreiro, 1998; FAO, 1999).

Despite the more perishable nature of juices, there are many practical reasons for their manufacture, processing and increased consumption:

- The more delicate, soft fruits cannot be kept intact over long periods and tend to deteriorate before or at harvesting. Juicing is the logical alternative,

- Even more durable fruit may have poor size, shape or blemished portions that preclude marketing them as fresh whole fruit. Upon trimming and careful inspection, the sound portion can be juiced. In this text, it will be continually emphasized that unsound fruit or those undergoing incipient spoilage are not recommended for juicing. However, use of sound culls represents a sensible, technically and economically valid utilization strategy,

- Juices can be consumed more conveniently than whole fruits. Envision a motorist in speeding traffic (cell phone in hand?) or a mother holding an active child, both motorists attempting to peel an orange vs. handling an easily opened juice container. “Dashboard dining” is a way of life for many, therefore juice products and clever packaging play a key role,

- The very young, elderly and infirm may have problems eating, let alone peeling certain fruits. Drinking juice is an effective, nutritious alternative,

- In addition to the nutritive value of juices and the additional health benefits from phytochemicals, recently recognized components of many fruit juices will increase the popularity of such products,

- Even flavourful juices, that may not be balanced nutritionally or which lack articular nutrients or phytochemicals, can be blended or act as effective carriers for other natural or synthetic nutrients such as vitamins, minerals and nutraceuticals,

- Fluid food products, including juices are easier to process, to heat, cool, freeze, standardize, transport, etc., than solid foods or fluids containing particulates. Thus processing efficiency, safety and quality norms are easier to meet,

- The ease of mixing fluids promotes development of unique blends of juices with other products and practical combinations not found naturally,

- Highly flavoured juices are the basis for a range of juice co-products, such as syrups, ice cream and confectionery flavours, smoothies, bakery ingredients, etc.,

- Modern processing, packaging, ingredient technology and distribution systems insure safe, stable and appealing juice and beverage products in a convenient, economical form far from the raw material source or season.

Perusal of food markets the world over, suggest that juices of all types and in all forms have an important role in both food nourishment and enjoyment **(**Table 1.1**)**. This trend has certainly accelerated over the last half decade. Table 1.2 is an incomplete, but growing list of commercial wholesale juice products available in international trade. While some items or forms are now only custom manufactured in minor amounts, all could be scaled up upon demand. The goal of the food technologist is, therefore, to enhance the safety, quality and value and encourage the popularity of such products. Figure 1.2 contrasts the juice aisle in a well-stocked supermarket in the United States of America with a traditional market in Indonesia.

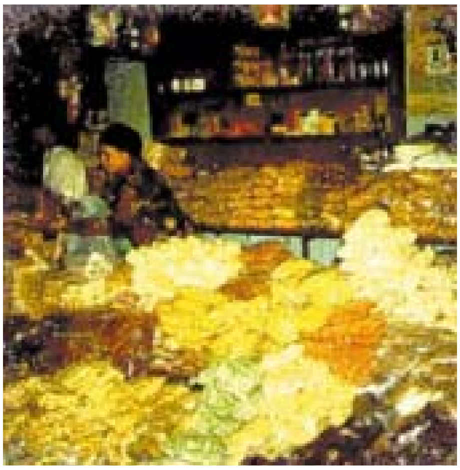


Figure 1.2: Food markets in Indonesia and the U.S.A.
Note the dramatic difference in food packaging and selection.

Table 1.1: Utilization of juices and co-products.

100% Pure juices and purees	Pastes/spreads
100% Juice blends	Pie fillings
<100% Juice beverage blends	Confectioneries
Carbonated beverages	Cocktail mixes
Fruit leathers	Yoghurt/fermented dairy products
Ice cream and sherbet	Smoothies
Jams and jellies	Wines
Flavour bases	Baby foods
Natural colours	Sports drinks
Natural nutrients/phytochemicals	Fruit flavoured waters
Nectars and nectar bases	Baked goods
Syrups	

Table 1.2: Juices and juice ingredients in international trade partial list.

Product Forms—Juice, Puree, Intact Sections. Juice Concentrate, Clarified Juice Concentrate, Powder, Aqueous Essence, Oil, Extract, Spray Dried, Skin/Seed/Peel Extracts, Industrial Chemical Feedstock and Animal Feed	
Acerola	Lychee
Ancho	Leek
Annona (Guanabana)	Lettuce
Apple	Mango
Apricot	Melon - Cantaloupe, honeydew
Banana	Papaya
Basil	Parsley
Beet	Onion
Blueberry	Passion fruit - Yellow and purple
Blackberry	Peach - Yellow, red and white
Caper	Pear
Cabbage	Pepper - Green, red, jalapeno
Carrot	Pineapple
Celery	Plum
Cherry - Sweet, sour, red, black, etc.	Pomegranate
Chokeberry	Prune
Cilantro	Raspberry
Citrus - Orange, grapefruit, tangerine, mandarin, lime, lemon	Scallion
Coconut - Milk and cream	Shallot
Cranberry	Spinach
Cucumber	Strawberry
Currant - Black and red	Tomato
Date	Tomatillo
Dill	Watercress
Elderberry	Watermelon
Garlic	Teas and herbal extracts
Ginger	Natural flavours
Grape Juice - White and red	Natural fruit sweeteners
Guava – Pink, white	Natural fruit/vegetable colours
Kiwi	Aloe vera

CHAPTER 2

DEFINING JUICES

2.1 Some definitions

Juice is defined in the most general sense as the extractable fluid contents of cells or tissues (Merriam-Webster, 1981**)**. Although many fruit juices are the obvious result of expressing the liquid from the whole or cut fruit, there are some fruits where the distinction is not so apparent. For example, squeezing peeled mango flesh yields little juice, until the flesh is comminuted. Even then a thick puree is the end result. In contrast, comminuted apples yield a readily expressible juice. Adding water to mango puree would decrease consistency, but it is not considered juice. The fluid expressed from lemons, limes and excessively acid fruits is certainly juice, but the liquid is too sour to consume directly without dilution with sugar and water to produce lemonade or limeade.

Codex Alimentarius defines juice as "unfermented but fermentable juice, intended for direct consumption, obtained by the mechanical process from sound, ripe fruits, preserved exclusively by physical means. The juice may be turbid or clear. The juice may have been concentrated and later reconstituted with water suitable for the purpose of maintaining the essential composition and quality factors of the juice. The addition of sugars or acids can be permitted but must be endorsed in the individual standard." **(**FAO, 1992).

Table 2.1 lists some juice and juice-like terms and designations. Tradition and manufacturing procedures dictate the distinction between juice, puree and pulp. Juices may be prepared from nearly all fruits, if desired, but purees or pulp may serve commercial needs more economically. Banana is easily pureed, but more effort and expense is required to produce a clear juice from the pulp. Even a fruit as refractory as mamey zapote that yields very little free juice can be extracted with added water and then concentrated back to the starting fruit soluble solids level. Strategies for dealing with difficult or impossible-to-juice produce will be examined later.

It is absolutely necessary for someone starting a juice manufacturing operation to become familiar with the regulations and requirements of their market. For commercial purposes it is important to define the differences carefully and insure that specifications and labelling are correct. There are circumstances where a 100 percent juice or puree product is impractical while dilution with other juices and/or water and sweeteners are practical, as long as the products are correctly identified. Water, sugar, organic acids and low cost bulk juices are much cheaper than higher value fruit solids. Thus, unlabelled dilution and adulteration are common, unethical trade practices to be rigorously avoided and condemned.

Table 2.1: Some common juice designations.

Term	Criteria	Remarks
Pure juice 100%	All juice	No adjustment, not from concentrate
Fresh squeezed	Not pasteurized	Held refrigerated, Food safety concerns
Chilled, ready to serve	All juice	Held refrigerated, made from concentrate or pasteurized juice
Not from Concentrate	Single strength	Pasteurized after extraction
From concentrate	Made from concentrate	Reconstituted and pasteurized
Fresh frozen	Unpasteurized	Single strength, frozen after extraction
Juice blend	All juice	A mixture of pure juices
Puree	Pulp-containing	More viscous than juices, totally fruit
Nectar	Pulpy or clear	Sugar, water and acid added, 25 to 50% juice*
Nectar base	Requires reconstitution	Possesses sufficient flavour, acid and sugar to require water dilution for consumption*
Juice drink	Low in juice	Contains 10 to 20% juice*
Juice beverage	Low in juice	Contains 10 to 20% juice*
Juice cocktail	Low in juice	Contains 10 to 20% juice*
Fruit + ade	Lemonade	Contains >10% fruit juice, sugar and water*
Juice extract	Water extract	Fruit extracted by water, then concentrated*
Fruit punch	Token juice	~ 1% juice, + natural flavours
Natural flavoured	Token juice	Usually >1% juice

*Differing country standards for juice solids minimum

2.2 Juice criteria

For the purpose of this text, juice is the fluid expressed from plant material by crushing, comminuting and pressing. It can be clear, cloudy or pulpy. Juice is classified as puree, if the resulting consistency is fluid that pours very slowly, or pulp if it pours even more slowly. To complicate the matter further, juices that are concentrated for preservation, handling and storage and reconstituted for consumption (labelled “juice from concentrate”) should be diluted back to approximately the same solids level (designated as ºBrix or percent soluble solids) of the initial juice. The amount of add-back water can vary substantially even within a given fruit, so reasonable commercial standards are set (FDA, 1999). Table 2.2 illustrates some juice solids standards.

Codex Alimentarius reconstitution levels are slightly different and in all cases lower Brix than FDA **(**FAO, 2000b**)**. For example, single strength apple juice can be 10.2ºBrix, but reconstituted concentrate must attain 11.2ºBrix, unless the original juice was lower. In addition, Codex specifies the minimum juice and/or puree content for fruit nectars, between 25 and 50 percent, depending upon the given fruit.

Table 2.2: Reconstitution level for concentrates to qualify as juice.

Juice	Brix	Juice	Brix
Acerola	6.0	Kiwi	15.4
Apple	11.5	Lemon	4.5
Apricot	11.7	Lime	4.5
Banana	22.0	Loganberry	10.5
Blackberry	10.0	Mango	13.0
Blueberry	10.0	Nectarine	11.8
Boysenberry	10.0	Orange	11.8
Cantaloupe melon	9.6	Papaya	11.5
Carambola	7.8	Passion fruit	14.0
Carrot	8.0	Peach	10.5
Casaba melon	7.5	Pear	12.0
Cashew (Caju)	12.0	Pineapple	12.8
Celery	3.1	Plum	14.3
Cherry, dark, sweet	20.0	Pomegranate	16.0
Cherry, Red, Sour	14.0	Prune	18.5
Crabapple	15.4	Quince	13.3
Cranberry	7.5	Raspberry (Black)	11.1
Currant (Black)	11.0	Raspberry (Red)	9.2
Currant (Red)	10.5	Rhubarb	5.7
Date	18.5	Strawberry	8.0
Dewberry	10.0	Tangerine	11.8
Elderberry	11.0	Tomato	5.0
Fig	18.2	Watermelon	7.8
Gooseberry	8.3	Youngberry	10.0
Grape	16.0		
Grapefruit	10.0		
Guanabana (Soursop)	16.0		
Guava	7.7		
Honeydew melon	9.6		

In the case of a juice not listed in Table 2.2: “If there is no Brix level specified (Section 1.3), the labelled percentage of that juice from concentrate in a juice or juice beverage will be calculated on the basis of the single-strength (as originally expressed) juice used to produce such concentrated juice.” (FDA, 1999). Thus the original juice soluble solids or degree Brix defines reconstitution limits. This is not simply generic, since within a species Brix may vary over two-fold, i.e. depending on the species and cultivar, grape juice soluble solids at maturity can range from about 12 to 26ºBrix.

Clear or pulpy juices ameliorated with added sugar and water are termed “nectars” provided they contain a proscribed minimum of the juice. This minimum varies from country to country, ranging from 25 to 50 percent by weight. Juices or purees diluted down to 10 percent (or less) juice with added ingredients are termed “juice drink”, “juice cocktail”, or “juice punch”. The logical rationale for defining juices and distinguishing among the diluted juice products is to guide consumers and avoid economic fraud. However, many consumers are not aware of the subtle distinctions in the classification (Table 2.1). Advertising, promotion, presentation and price, become more important than juice content. Retail price differentials between fresh, premium juice and juice simulates can vary ten-fold. The various juice concoctions now clearly state juice percentage on the label, as proscribed by law (Figure 2.1).

Figure 2.1: Beverage labels specifying juice content.

Sometimes the common name for a juice varies contingent on culture. For example, Cider in the United States is usually understood to mean cloudy, unfermented, unpreserved apple juice. If the juice is processed or clarified, it is then called apple juice. Hard cider indicates the presence of alcohol by natural fermentation. Sweet cider also distinguishes non-fermented apple juice from hard cider. Other cloudy juices such as pear and grape are similarly designated pear cider (or perry) or grape cider and certainly contain no alcohol. However, in the United Kingdom and elsewhere, cider and perry are partially or fully fermented apple and pear juice. On the other hand, orange juice, also possessing a natural cloud, would in no instance be termed orange cider. Clarified, it is referred to by the unappetizing term, “orange serum”. Tomato juice and derivatives are another example of diverse names for similar items (Table 16.1)

CHAPTER 3

FRUIT MORPHOLOGY AND COMPOSITION

3.1 Distinctions

Botanically, fruit is the structure resulting from the growth of a flowering plant. The fleshy component, which is normally the portion eaten, serves to protect and eventually nourish the seed(s) as part of the natural development of the original plant's progeny. The morphology of fruits varies substantially as does the plant tissue consumed (Figure 3.1.).

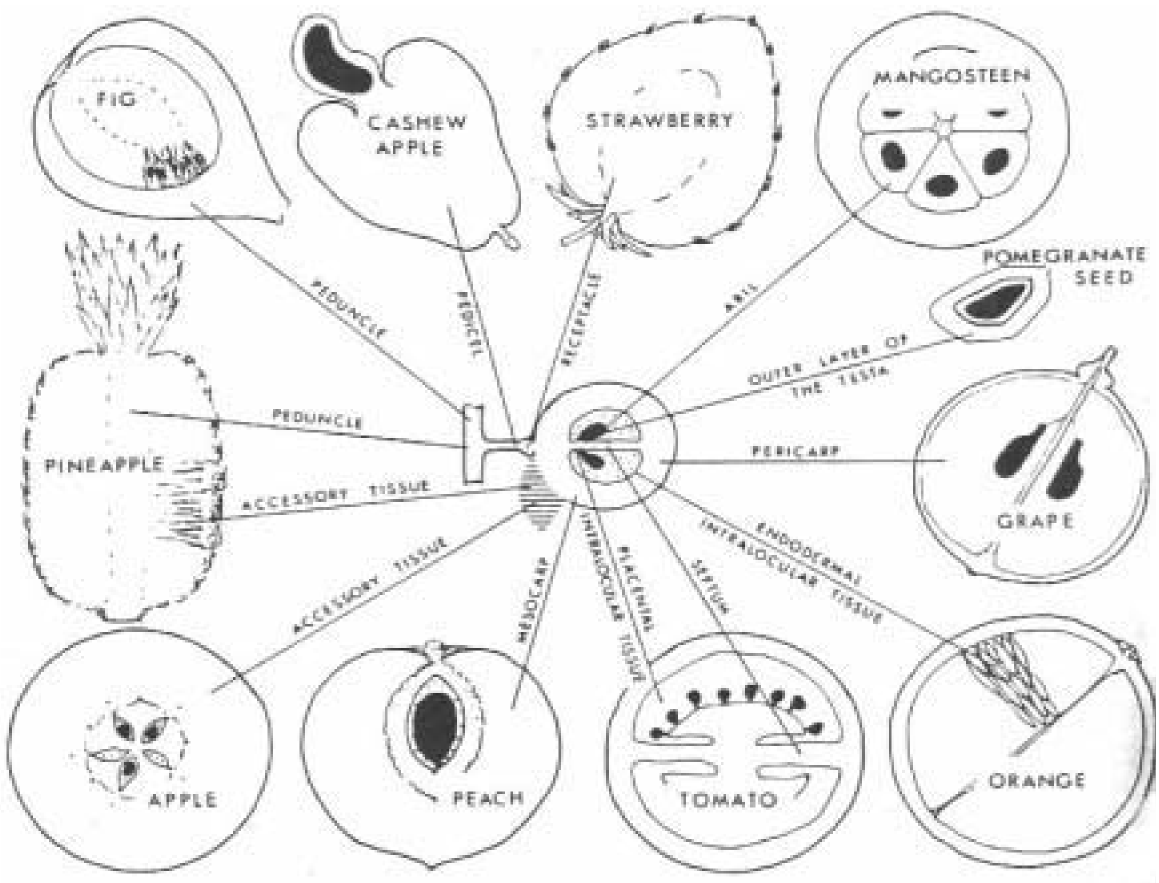


Figure 3.1: Plant tissue consumed as fruit.
(Coombe, 1976; Kays, 1991)

Fruit types dictate the mechanics and ease of juice extraction (Arthey and Ashurst, 1996). There are about nine categories of fruit/vegetable types (Kader, 1992; Kader and Barrett, Somogyi, *et al.*, 1996a):

- Pome fruits – Apple, pear and quince, are the classic examples,

- Citrus – A range of well and lesser know species make up this category. Orange, grapefruit, tangerine, lemon and lime are in wide use, but other citrus such as pummelo, tangerine and uglifruit, have unique characteristics worth exploring,

- Stone fruits – These have a well-distinguished pit and include peach, plum, apricot, cherry and mango,

- Soft Fruits – Although morphology varies greatly, these fruit have flesh that has a firm structure, but can be easily deformed. Grape, strawberry, pineapple, banana, berry fruits, kiwi, papaya and lychee, are some examples,

- Amorphous fruits – Fruits with little firm flesh structure under the skin such as passion fruit, naranjilla, guava and soursop, fit this category,

- Fruit vegetables – Watermelon, cantaloupe and various melons are fruits by use. Tomato and solanaceous vegetables are also in this category,

- Leafy, flower and stem vegetables – Only rhubarb has fruit-like character and is utilized from among the many vegetables of this type,

- Tree nuts – Although the seed is the desired crop, cashew fruit has value and there are undoubtedly, other fruits in this category where the outer flesh has juice potential. The ripe coffee berry is a remote example,

- Tropical and subtropical - Generally treated as a separate category, although the previous categories cover most species.

There are fruits that do not fit clearly into these definitions, or differ so much according to cultivar and maturity state that they are intermediate. For example, a soft mature mangosteen falls apart upon peeling, whereas a less ripe, firmer one can be peeled and eaten out of the hand.

As with juice definitions, there is some disagreement over what constitutes a fruit. Custom dictates the distinction that a tomato is a fruit, but it is normally regarded and consumed as a vegetable. Similarly, peppers and cucumbers are vegetables; yet watermelon, a member of the *cucurbitaceae* family along with cucumber, is a vegetable but used as a fruit. Pepper juice is viewed as a strange concoction, although perhaps with some merit **(**Chapter 16**)**. In contrast, the plant stalk or petiole portion of the rhubarb is consumed as a fruit while the swollen inflorescence of broccoli is the epitome of a vegetable.

A rough, arbitrary, but recognizable distinction is if the juice is sweet and somewhat acid or sweetened with or without added acid for consumption, it is a fruit. If salt and/or spices enhance the juice flavour, it is a vegetable.

For the purpose of this text, most major and some minor horticultural crops capable of yielding a sweet (usually acidic) juice or puree from any portion of the plant customarily consumed and considered a fruit will be covered, along with some major vegetables. Leaf, stem and root extracts are presently gaining greater attention as “teas”, herbal medicines or phytochemicals and have relevance in the context of juice by-products and nutraceuticals (Section 3.3)

3.2 Fruit/juice general composition

The structure and functional aspects of fruits dictate their composition. Table 3.1 shows some typical constituents of fruit (and subsequently juices) and the range of values dependent upon fruit, cultivar, cultivation, maturity and other factors to be presented later.

Table 3.1: Fruit edible portion composition ranges* (Fresh weight basis).

Component	Range (%)	Comments
Water	97 - 70	Influenced by cultivation and post-harvest conditions
Carbohydrates	25 - 3	Sugars and polymers - pectin, hemicellulose, cellulose
Protein	5 - trace	More in oily fruit and seeds
Lipids	25 - trace	Traces in cell membrane, in seeds, high in avocado
Acids	3 - trace	Citric, tartaric, malic, lactic, acetic, ascorbic + minor
Phenolics	0.5 - trace	Tannins and complex phenols
Vitamins	0.2 - trace	Water soluble > fat soluble
Minerals	0.2 - trace	Soil and species dependent
Dietary fibre	<1 to >15	Peel and core dependent
Pigments	0.1 - trace	Carotenoids, anthocyanins, chlorophyll

* For more specific generalized values see USDA, 2000a.

- The major component is of course, water derived from the extra and intracellular fluid necessary for metabolic processes and maintenance of cell turgor. Water content can range from 97 percent in some wild berries to 70 percent in over ripe grapes and less than 50 percent in fruits drying naturally on the plant;

- The nonaqueous portion contains literally hundreds of identified compounds with a range of natural sugars and/or sugar polymers namely glucose, fructose, starch, cellulose, hemicellulose, pectin, usually representing the majority of solids. These solids are categorized as (1) soluble, which is readily expressed in the juice and (2) insoluble, consisting primarily of the press residue. Other solids such as stem and sometimes skin, core and seeds, are the inedible components, but may have by-product value;

- Other macro components are fruit acids, responsible for the tart taste and low pH of many, but not all fruits. These are water-soluble with specific acids contributing importantly to the flavour and character of fruits and juices. Principal organic acids are citric, tartaric, malic, lactic, acetic and ascorbic and range from trace amounts to over 3 percent. Trace amounts of phenolic acids are also present;

- Protein is generally less than 1 percent, except in oily fruits and all seeds and not readily expressed in juice;

- Next in abundance, are usually either phenolic compounds ranging from anthocyanin or carotenoid pigments to tannins which provide astringency;

- Nutrients such as proteins, lipids, amino acids, vitamins and minerals, are present to varying degrees, as are flavour and aroma substances;

- Lipids deserve special mention. With the exception of olive, avocado, ackee and oil palm fruits, fruit lipid content is very low less than 0.5 percent, except in seeds. The absence of lipids is reflected in the reasonably low caloric value of fruit juices and their important role in fat avoidance diets. Nevertheless, the fatty acid profile of fruit lipids and the accompanying fat-soluble vitamin level are quite good, actually “heart healthy”. High lipid fruits are incompatible with juices, although avocado puree merits consideration.

Despite the small amounts of some compounds, they can influence dramatically the appeal, stability, or health value of the fruit. Many intrinsic (fruit-specific) and extrinsic (extraction-dependent) factors influence juice composition, as will be emphasized. Food composition tables provide a reasonable first approximation to fruit and juice make up (USDA, 2000a**)**. Nevertheless, there can be substantial differences in the same species and analytical experience with a given cultivar under controlled production and processing conditions is very important.

3.3 Phytochemicals

This category of compounds, also known as nutraceuticals and functional foods, is increasing in importance and merits special attention. Phytochemicals are defined as:

- ”Non-nutritive or nutritive, biologically active compounds present in edible natural foods including fruits, vegetables, grains, nuts, seeds and tea, which prevent or delay the onset or continuation of chronic diseases in humans and animals.” (Guhr and LaChance, 1997).

- “Any food ingredient that may provide a health benefit beyond the traditional nutrients it contains” (Hasler, 1998).

Fruits and their juices are an especially good source of phytochemicals (Table 3.2). Close to one thousand different phytochemicals have been found in plants and the identification and promotion of hitherto unrecognized compounds with real or imputed health value continues unabated. In fact, the science is in its infancy and additional phytochemicals, mechanism of action and beneficial effects (toxic properties also), will become apparent and attributed to traditional and exotic juices.

Given the propensity of some consumers to place the therapeutic value of medicines over foods, one company even incorporates the active ingredients from 17 different fruits, vegetables, grains, fibres and probiotics, into capsules and chewable pills. Their trademark, “Juice PLUS+” acknowledges the phytochemical value of juices. Of course, juices and blends are a less costly and more appetizing alternative, albeit requiring more attention and awareness on the consumer’s part.

One unique and fascinating class of phytochemicals is phytoalexins. These compounds are synthesized in plant parts, including fruit, as a response to external stress, i.e. drought, sunburn, temperature extremes, insect damage, pathogen infection, etc. Resveratrol, a stilbene type compound has been studied extensively as a stress mediated substance with likely chemopreventive effects against cardiovascular disease and cancer. Red grapes, juice and wines have significant amounts of such compounds, believed to be in part responsible for the health benefits of red wine and attributed to their antioxidant properties (Adrian, *et al.*, 2000).

Needless to say, the total composition of fruits and the expressed juice provide a range of pleasing sensory and health attributes that can be optimized by the juice processor, even to the extent of improving upon the raw material.

Table 3.2: Some phytochemicals in fruit and vegetable processing protective properties against cancer and cardiovascular disease*.

Class/Compound	Sources
Antioxidant Vitamins Ascorbic Acid (Vitamin C) Tocopherols (Vitamin E) Selenium (a soil mineral)	Many fruits and vegetables Incorporated from soil
Carotenoids (Some have Carotenes provitamin A Lycopene activity) Lutein Xanthins	Most yellow/red/orange fruits and vegetables, dark green leafy vegetables
Dietary Fibre Pectin Hemicellulose Cellulose Lignan	Ubiquitous cell wall constituents (lower in juice)
Flavonoids Anthocyanins Catechins Flavones Quercetin Naringen Resveratrol	Most fruits and vegetables Can be highly pigmented or colourless, highly astringent or flavourless
Flavones/Isoflavones Apigenin Luteolin	Some vegetables – celery, olives (others in soybean)
Glucosinolates/Indoles Dithiolthiones Sulfuranes Isothiocyanates	Cruciferous vegetables possessing pungent flavour – Brussels sprouts, cabbage, broccoli, cauliflower, etc.
Phenols and Phenolic Acids Capsaicin, Carnisol, Gingerol, Piperine, *p*-cresol, Caffeic, Ellagic, Gallic, Chlorogenic, Ferulic, Vanillic, *p*-coumaric	Most fruits and vegetables, some very highly flavoured, astringent or bitter; teas and herbals
Phytosterols and Stanols	
Sulphur (Allylics) Sulphides Disulphides Ajoene	*Allium* Vegetables possessing pungent flavour – onion, garlic, chive, shallot, etc.
Phytoalexins Resveratrol, Stilbenes	Some fruits and vegetables, especially red grapes
Saponins	Potato, beans, legumes
Terpenes/Liminoids Mycrene, d-Limonine, Carvone, Carnosol, Glycyrrhizin, Zingiberene	Citrus, cherries, ginger, liquorice

* Adapted from Broihier, (1999); Guhr and LaChance, (1997) and expanded.

CHAPTER 4

JUICE SAFETY, GRADES AND STANDARDS

4.1 Safety, safety and safety

If there is any theme worthy of emphasis to the extreme in this text, it must be safety. Lapses in food safety do not only adversely impact the health of consumers. Flagrant safety errors have and will ruin the reputation and financial health of the offending food company. Food safety violations have caused the demise of companies and prison sentences for culpable executives. Worse yet, highly publicized safety lapses indict an entire industry, implicating the innocent majority together with the single guilty company.

The combination of fruit raw materials, food ingredients, juice preparation and processing methods, provide the technologist with an practically infinite range of possible juice products varying in quality, price and value. The liquid nature of juices and the availability of many natural and manufactured juice constituents offer a blending opportunity not available to formulators working with solid foods. The versatility of juices plus the many mixing options are also a temptation to cut corners by economic adulteration.

The ease with which juices can be altered with sugar, water or inferior juices has and continues to attract unethical suppliers. Fortunately, advancements in analytical chemistry and instrumentation together with fruit and juice composition data banks make adulteration easier to detect (Nagy and Wade, 1995). Detection methods have more than kept up with adulteration schemes. Detection of doctored juices is expensive but fairly straightforward **(**Fry, Martin and Lees in *Ashurst*, 1995). Thus large international movements of juice are reasonably well monitored, although local, marginal producers continue to slip though the net.

Such unethical practices can also be dangerous, as there have been many tragic incidences of poisonous ingredients being added to juices. Fortunately, most countries now have food regulations and enforcement mechanisms that prevent such deception. Despite these efforts, another serious safety problem associated with juice consumption has arisen. Contamination of juices with pathogenic microorganisms such as *E-coli* O157 H7 and salmonella have caused numerous illnesses and some fatalities (Table 4.1). Although it appears that such incidences are increasing, in reality, surveillance and detection method are becoming much more sensitive. At the same time, outbreaks are becoming quite newsworthy. All reported cases of contamination by pathogenic microorganisms were due to fresh, unpasteurized juices. This is an increasingly popular segment of the juice industry, whose sales are now jeopardized by new regulations.

There is a curious irony in juice-induced food borne illnesses. Many common foods of plant and animal origin are much more hazardous and contain higher levels of more dangerous microbes than do fruits. However, if these foods are normally cooked before

Table 4.1: Fruit–associated food poisoning outbreaks*.

Juice Product (Year)	Infectious Agent
Sweet cider (1923)	*Salmonella typhi*
Orange juice (1944)	*S. typhi*
Orange juice (1962)	Hepatitis A
Orange juice (1966)	Gastroenteritis agent
Apple cider (1974)	*S. typhimurium*
Apple cider (1980)	*Enterotoxigenic E. coli*
Orange juice (1989)	*S. typhi*
Apple cider (1991)	*E.coli* O157:H7
Orange juice (1992)	*Enterotoxigenic E. coli*
Apple cider (1993)	*E.coli* O157:H7
Apple cider (1993)	*Cryptosporidium spp*
Carrot juice (1993)	*C. Botulinum*
Watermelon juice (1993)	*Salmonella spp.*
Orange juice (1994)	Gastroenteritis agent
Orange juice (1995)	*S. hartford, S. gaminera, S. rubislaw*
Apple juice (1996)	*E.coli* O157:H7
Apple juice (1996)	*E.coli* O157:H7
Apple juice (1996)	*Cryptosporidium parvum*
Apple cider (1997)	*E.coli* O157
Orange juice (1998)	*Salmonella*
Apple cider (1998)	*E. coli* O157:H7
Mamey juice (1999)	*Salmonella typhi*
Orange juice (1999)	*Salmonella enterica*
Orange juice (1999)	*Salmonella muenchen*
Apple cider (1999)	*E. coli* O157:H7
Orange, grapefruit, lemonade (2000)	*Salmonella enterica*

*Adapted from Parish, 1997; Beuchat, 1998; Powell and Luedtke, 2000 and expanded

consumption, the inherently dangerous pathogens are eliminated. Fresh, unpasteurized juices receive no such treatment and, despite their health-promoting image, can harbour dangerous contaminants. Strategies to minimize such hazards are discussed in subsequent chapters.

Acid fruit juices below pH 4.6 were once deemed a minor health threat due to the high acid. Furthermore, refrigeration temperatures (below 5ºC) represented an additional hurdle to pathogen growth, until the discovery that *Listeria monocytogenes* can grow down to 2ºC. When juice spoilage did occur, it was usually a reflection of the indigenous microflora, yeast, mould and lactic acid bacteria. Nonetheless, the emergence of hitherto unsuspected food pathogens with acid resistance combined with increase in susceptible individuals, immunocompromised, chronically ill, the very young and very elderly, has dramatically changed this picture. More stringent regulatory safeguards are now called for at all levels, i.e. provincial, national and international. Thus for safety and economic reasons commercial fruit juices are subject to strict regulatory control. Safety must always take precedent and strict limits on production, harvest, transportation, storage, manufacture, processing, labelling and distribution now exist. These are incorporated into Good Agricultural Practices (GAPs) and Good Manufacturing Practices (GMPs) with Hazard Analysis and Critical Control Point (HACCP) procedures being applied throughout the food chain. These will be emphasized as appropriate.

4.2 Quality

After safety concerns comes economic and quality considerations. A product can be perfectly safe and completely fraudulent. As the sale of a product labelled fruit juices may in fact consist of no or little actual fruit components. Thus the development of standards for fruit juices is incorporated into most country's regulatory codes. These regulations include the processing employed, the amount of fruit content required for various juice designations (Table 2.1), the soluble solids and acid levels, amount of added substances allowed such as sugar, acid, water, preservatives and reasonable sanitary standards.

In addition, grades may be assigned depending on the colour, flavour, consistency and absence of defects. Codex Alimentarius grades and standards are being promulgated and continue to be refined to provide a useful guide for standardizing national norms and facilitating intra and international trade (FAO, 2000b). In the matter of a large volume juice trade, specific standards are negotiated between major suppliers and users. For example, the Florida Department of Citrus, the state's industry controlling agency, has standards that exceed other norms and prohibit citrus juice manufacturing practices common in other regions (Florida Dept. Citrus, 2000).

In addition to existing international, national and local fruit/juice standards, detailed, industry-specific written quality specifications should be developed. Along with the safety and regulatory aspects, clear raw material specifications facilitate efficient processing (no surprises on the production floor) and uniform, consistent quality to the wholesale and retail purchasers. Reliability and trust throughout the food chain is essential. These standards should consist of physical, compositional, organoleptic specifications, as well as limits for microbial and chemical contaminants. Table 4.2 indicates some appropriate general specifications worth developing, if enforceable national regulations and/or controlling authorities do not already exist.

Analyses can readily detect trace amounts of pesticides, industrial chemicals and vanishing low numbers of pathogens, some with "zero" tolerance levels. Thus there has been a substantial increase in import denials and product recalls based on levels of contaminants, microbial and chemical, that were undetectable and unimportant a decade ago. The economic loss, not to mention the liability and poor publicity, is adequate incentive for juice processors to consistently take regulatory matters very seriously.

4.3 Regulatory concerns

In industrialized nations and international trade, every step of juice manufacture from raw material cultivation through marketing is subjected to some type of regulatory control. Although some regulations can be onerous, burdensome, even unnecessary, there is a definite need to control food commerce items. The history of food control and the situations existing prior to development and enforcement of food laws surely justifies governmental oversight (Hui, Somogyi, *et al.*, 1996a; FAO, 2000b and c). The two principal needs are:

- Insure the safety of all food materials, ingredients, processes and packaging.

  Safety is of paramount importance. In high throughput manufacture, if a safety hazard is not detected and corrected somewhere in the production/supply chain, many consumers can be adversely affected. We have seen how microbial or chemical contaminants (defects in a small amount of raw material) can be blended into a large batch to be rapidly and efficiently distributed and consumed over a wide region. Hence, mistakes have correspondingly greater consequences. Errors can affect large numbers or, in the case of undeclared allergens or low level hazards, only susceptible individuals, usually with more serious results. Neither is acceptable.

- Prevent economic fraud – inauthentic ingredients, mislabelling.

  Here human health is not compromised, but the consumer or parties in the supply chain are cheated. Furthermore, such cheaters have an economic advantage over honest merchants and, if not discovered and eliminated, thrive at the expense of others. In view of the complexity of juice and beverage labelling laws, there is a grey area between outright fraud and misstatements. A clever blend of high fructose corn, organic acids, flavours, colours, nutrients, and phytochemicals can possibly match any natural beverage in appeal and health benefit, but to claim it as such is clearly dishonest. Declaring the contents and accurate juice percentage (if any) on a label implying fruit juice content is legal (Figure 2.1).

Table 4.2: Some quality specifications for juice fruit.

Attribute	Rationale
Soluble solids (ºBrix)	Defines juice strength
Titratable acidity and pH	Defines acid balance
Colour	Visual appeal
Freedom from defects – decay, insects/damage, mechanical injury, etc.	Aesthetics, susceptibility to spoilage and contamination
Maturity	Optimum quality
Size, shape and uniformity	Ease of juicing
Flavour	Defines quality
Absence of pathogens, chemicals and extraneous matter	Defines safety
Low microbial load	Quality, shelf life

CHAPTER 5

RAW MATERIAL FOR JUICE

5.1 Initial considerations

As indicated, the sources of fruits that can be made into juices are nearly limitless in plants and the plant parts appropriate for juice. However, the fruit producer and juice processor must adhere to some very important guidelines in fruit selection and juice manufacture.

5.1.1 Fruit cultivar

Human selection of plants for their more desirable features has been practiced for thousands of years, initially by trial and error, more recently by scientific knowledge applied to plant genetics and molecular biology. Thus even within a given fruit there are numerous varieties available including some derived from the wild, others specifically developed by breeders and combinations of both. Recent advances in understanding the molecular basis of plant genetics and how the genes and growing environment influence traits, promises to revolutionize agriculture, once the politics and emotions are resolved.

Fruits originating in the wild have evolved to be reasonably robust and resistant to natural environmental stresses, diseases, insects and other predators. These traits, however, do not necessarily favour concentrated production systems or edibility. The exception is if consumption by wildlife promotes pollination or seed dispersal. Human population pressures further impact upon native plant species, therefore except for exotic plants remote from civilization, most fruits are substantially removed from their origin in time, genetics and location.

Special cultivars, developed with criteria such as yield, location adaptability, resistance to disease, insects, drought tolerance, harvest period, ease of cultivation and harvest, handling and storage durability, processing characteristics and sensory appeal (colour, taste, aroma, texture) are characteristics now determined by commercial breeding practices (Table 5.1). Juice quality considerations are also important in many fruits such as citrus, grape, apple, pineapple and others. Specific cultivars dominate the juice trade, while others are preferred for the fresh market. Some cultivar end uses are dictated by fruit supply, condition and economics and varies by season, location and market depending upon fruit quality.

Nevertheless, all fruit species include cultivars that are highly inappropriate for juice (or consumption for that matter) such as bitter, intensely sour orange rootstock. Bitter watermelon contains cucurbitacum, a very bitter compound. (The selective planting of bitter melons that have no different appearance to normal melons in a commercial field can discourage watermelon theft.). Mango trees are usually grafted and chance seedlings range from those with deliciously sweet, smooth textured flesh to fibrous harsh terpeney fruit. Some fruit species are even toxic and avoided by experience. It is conceivable, even probable, that such inedible or toxic fruits may possess unrecognized nutraceutical value, but safety and palatability are the present criteria.

Table 5.1: Fruit breeding criteria.

Trait	Rationale
Plant hardiness	Survival, resistance to drought, cold, heat, etc
Disease resistance	Plant/fruit survival, reduced pesticide use
Plant morphology	Ease of cultivation/harvest
Fruit morphology	Ease of harvest/processing, high yield
Composition	Quality, economic/nutritive value
Seasonality	Availability, market demand/price
Fruit durability	Marketing/handling/processing
Yield	Economic value
Flavour	Quality, value
Colour	Appeal, value, by-product potential
Texture	Appeal, durability
Nutrients/phytochemicals	Value, appeal, by-product

5.1.2 Cultivation practices

The condition of a fruit tree or plant throughout the season from flowering to fruit maturation can dramatically influence juice quality. Practically all cultivation parameters can influence quality and composition (Table 5.2). Season, location, fertilizer application, form and timing, irrigation, amount of precipitation, temperature, sun exposure, plant spacing and pruning, disease, insect and predator stress influence fruit quality and yield. In the interest of quality, uniformity and yield, horticulturists constantly strive to overcome unfavourable conditions that may be a fresh, unexpected challenge each year. For the commercial grower there is never an “average” season or crop; quality, prices and supply vary accordingly.

Unforeseen, variations in weather can have a significant effect upon fruit quality, quantity and juice characteristics. Unseasonable freezes or hail can decimate a crop or send fruit destined for the fresh market immediately to the juice processor. Insect and disease damage also affects the fresh marketability of fruits and excess or inadequate rainfall influence juice solids, flavour and composition. In contrast to whole fruit quality, juice variability can be somewhat overcome by blending of juice stocks or amelioration, if permitted.

Cultivation practices also affect regulatory matters and labelling. For example, to label the product “organic” certain very specific criteria must be met, some based on perception more than scientific reality, but extremely important to proponents. As with juice purity regulations, organic standards must be rigorously adhered to as a matter of principle. Thus the use of fertilizer, pesticides, and all agricultural inputs, even timing and location relative to standard agricultural enterprises are carefully proscribed (Organic Trade Assoc., 1999; USDA, 2000c).

Table 5.2: Cultivation factors influencing quality.

Factor	Importance
Location	Harvest period, plant survival, market
Cultivar	Yield, desirable juice traits, harvest period
Plant spacing	Yield, ease of cultivation/harvest
Plant care	Yield, ease of harvest, quality
Pruning	Yield, maturation, ease of harvest
Irrigation	Fruit/juice yield, quality
Fertilization	Growth, designation (i.e. organic)
Pesticide use	Fruit quality, designation, regulations
Field protection	Yield, quality (bird, varmint damage)
Field sanitation	Juice safety, quality
Labour training	Fruit quality, cultivation/harvest efficiency

Cultivation also influences food safety, a topic for ongoing emphasis. In the case of fruit production, organic or otherwise, an additional concern is the use of manure as fertilizer. Food poisoning outbreaks involving juices have been traced back to the use of manure. Fruit that has fallen on the ground, becomes contaminated and is later collected and utilized. Even where manure is not used or is properly treated before application, the potential for fruit contamination by insects, wild life or field workers dictates cautious handling and sanitary practices. Good Agricultural Practices (GAPs) are the first line of defense against such dangers (FDA, 1998; FAO, 2000a and c; Rangarajan, *et al.*, 2000).

A further concern may be pesticide residues. A crop can:

- be over tolerance for permitted pesticides,
- treated with a permitted pesticide, but too close to the harvest date,
- possess trace amounts of pesticides permitted in country of origin but banned by importing countries,
- for organically grown produce the situation is critical, since even trivial wind-blown amounts of any pesticide from adjacent fields can negate the organic label.

Table 5.3 lists some potential safety hazards associated with crop cultivation. There have been food poisoning cases attributed to all. Increasingly, fruit producers who cannot demonstrate GAPs to their buyers will be at a competitive disadvantage nationally and internationally. Some governments certify only certain growers to produce crops for export. Implicit throughout the production chain is the importance of a quality labour force. Without trained, adaptable, motivated workers, commercial success is unlikely.

Table 5.3: Juice safety hazards from farm to factory.

Hazard	Effect	Response
Wildlife in field	Contaminated fruit or containers	Minimize contact (difficult with birds and varmints)
Insect abundance	Fruit damage/contamination	Minimize by integrated pest management
Mould growth	Aflatoxin production	Careful field and factory sorting
Water quality	Spray or irrigation contamination	Monitor/treat water source
Manure	Contaminates crop	Discard/treat manure
Pesticides	Unauthorized or over use	Train applicators, minimize/monitor use
Harvest	Poor worker sanitation	Train/motivate/monitor workers
Handling	Unclean containers/equipment	Sanitation programmme
Transport	Unsanitary containers/transporters	Sanitation programmme
All of above	Unsafe fruit	Rigorous GAPs
Receiving	Contamination at factory	Enforce GMPs
Processing	Inadequate procedures	GMPs plus HACCP

5.1.3 Harvest season and maturity

The seasonal availability of fruit is the major determinate for juice manufacturing. Ideally, the maturation of desirable cultivars is either spread over a long period or different fruits can be harvested consecutively so that a juice operation can process for an extended season, if not most of the year. Figure 5.1 indicates the Northern Hemisphere seasons for some major juice crops. Of course, variations in altitude and microclimates can modify or extend the season to some extent. Furthermore, unseasonable and/or variable weather can play havoc with fruit availability and processing schedules. Although the northern and southern hemisphere seasons complement each other (and thus serve global fresh produce demands), the economics of producing juice from ripe fruit precludes such long distance hauling. The operations are best performed reasonably close to production areas. The globalization of the juice trade reflects regional availability.

There is an important distinction between plant maturation and fruit ripening (Kader, 1992). Maturity relates to the full natural development of the plant, whereas, ripeness is the desired stage for consumption or processing. Thus a fruit such as avocado or peach may be mature, fully developed and ready to be harvested, but far from ripe, requiring careful ripening conditions to achieve optimum quality.

Fruit are living structures and undergo complex changes during maturation, ripening and into senescence that influence quality. As fruits mature on the plant or after harvest the composition may change dramatically. Fruits are classified as (1) Climacteric, meaning they have a definite peak in respiratory rate for production of carbon dioxide and ethylene. (2) Nonclimacteric where there is a gradual decrease in respiration and CO_2 release (Wills, *et al.*, 1998). Table 5.4 indicates the parameters affecting fruit ripening and Table 5.5 several distinguishing features of ripening.

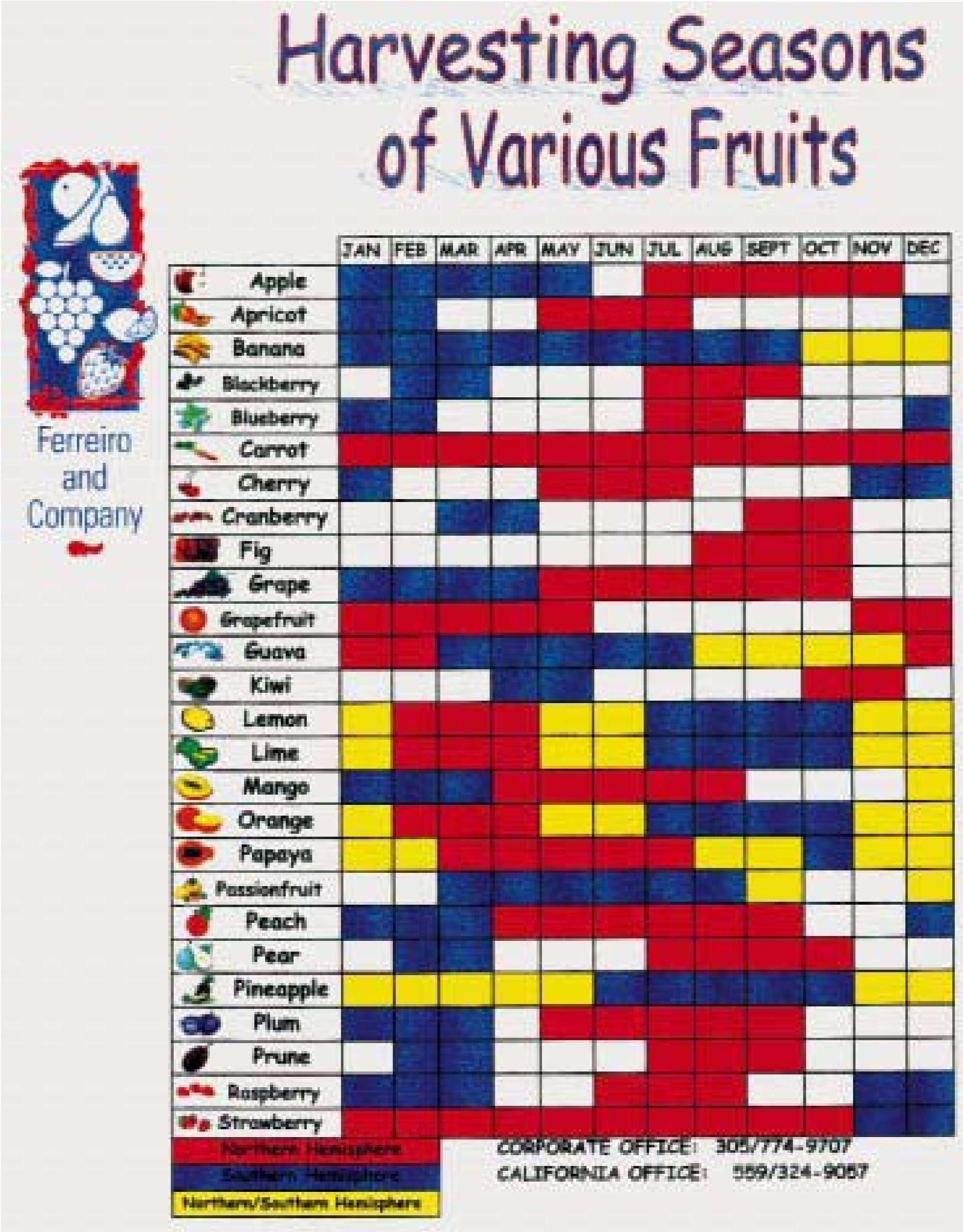


Figure 5.1: Harvest season of various fruits, Northern Hemisphere.
Courtesy Ferreiro and Co. (Brandon and Ferreiro, 1998)

Table 5.4: Factors influencing postharvest fruit ripening.

Factor	Result
Cultivar	Cultivar-specific response to holding conditions
High temperature	Accelerates ripening and microbial growth
Low temperature	Retards ripening, chill injury in some fruits
High oxygen (~21%)	Increased respiration and ripening rates
Low oxygen (<3%)	Promotes anaerobic respiration
High CO_2	Promotes anaerobic respiration
Ethylene	Accelerates ripening of climacteric fruit
Moisture (Rel. Humidity %)	>90%, microbial growth; < ~80%, wilting
Contamination	Losses during ripening
Physical damage	Speeds up ripening, decay

Whether these changes occur on the plant or post-harvest, it is important to understand and control them in order to optimize fruit and juice quality. For example, cold storage extends the shelf life of many fruits, such as apples and oranges, so the colder the better (avoiding freezing). In contrast, tomatoes and banana require storage temperatures above 7ºC. Excessive holding at lower temperatures cause irreversible damage referred to as chill injury (higher temperatures are also detrimental). There are well-understood fruit and cultivar-specific holding and ripening regimens for all major fruit cultivars. With minor or exotic fruits, local knowledge and experience is the best guide; there is continual need for focused cultivar and location-specific ripening/holding research (Mitra, 1997).

In general, fruit destined for juicing should be of good edible quality, full flavoured and substantially more mature than fresh market fruit. This favours softer tissues (more amenable to juice extraction and higher yield), higher sugar content, deeper colour and a lesser amount of acid. However, overripe fruit quality is inappropriate as the flavour and acidity may suffer. Also, the fruit's defence mechanisms are diminishing, so incipient spoilage and microbial loads are apt to be higher. One of the major quality deficiencies in small juice operations is due to the use of under or over mature fruit, a propensity to use drops, culls and salvaged pieces.

5.1.4 Harvest and postharvest handling

At this stage the fruit have reached maturity and subject to a finite "harvest window" during which picking must take place. Cultivation and cultivar, as well as climate and weather affect this window. Heavy rains or extremes in temperature hasten or delay harvest and influence fruit quality. Harvest aids, machines and hand-pickers function better in moderate weather, but this isn't always possible. Delays and improper conditions extract a quality, yield and expense toll. Maturity standards as they influence colour, sugars, acid, fruit damage, etc., may be the basis of payment and dictate the end use, i.e. the fresh market, whole processing, juice, by-products, animal feed, or destruction (at supplier's expense).

Even given an acceptable, gentle, timely harvest, attention must be paid to field handling and transportation. Worker's judgement is critical in optimizing picked fruit quality as determined by size, shape, maturity and free from defects. Improper packing into field containers, rough terrain in transport and delays in transit can equally damage delicate or rugged fruit. A further consideration is the danger of contamination by field workers, containers and equipment. The inclusion of plant debris, mud, dust or soil contacting fruit can greatly complicate subsequent cleaning operations.

The major harvesting and handling factors affecting fruit quality are outlined in Table 5.5. A basic tenant of GAPs is that it is easier and <u>more efficient to prevent</u> field, harvest and handling damage and contamination <u>than it is to correct</u> or decontaminate improperly treated produce later in the production chain.

After cultivation there are many parameters impacting fruit and juice quality and safety. Some of these parameters are obvious, others are subtle while there can be complex interactions between several factors. Under most circumstances a fine balance must be achieved between these factors. It is worth emphasizing that extremes in any parameter are to be avoided. The proverbial "happy medium" is an attainable compromise, albeit species, cultivar, fruit condition and process specific (Table 5.5).

Table 5.5: Influence of fruit harvesting and handling on juice quality.

Procedure	Error	Result
Harvest timing	Too early	Inadequate flavour and colour development, low yield
Harvest timing	Too late	Incipient spoilage, low quality
Rough harvest	Fruit damaged, soiled	Incipient spoilage, contamination
Improper packing	Unsanitary container	Fruit contamination
Transportation	Delayed/hot fruit	Fruit deterioration
Rough transportation	Unprotected fruit	Damaged fruit
Temperature abuse	Too high or low	Rapid quality deterioration
Lengthy holding	Fruit unprotected	Rapid quality deterioration
Rough unloading/conveying	Fruit damaged	Rapid quality deterioration

CHAPTER 6

GENERAL JUICE MANUFACTURE PRINCIPLES

6.1 Unit operations applied to juice

There are a number of unit operations involved in converting whole fruit to the desired juice, puree, or pulp product (Table 6.1). Fruit handling depends upon the process design. If the raw material is destined for multiple uses such as fresh market, whole piece processing, additional products and juice, the flow scheme will differ greatly from one for a juice-only plant. In some circumstances, cleaning, sorting and inspection precede in-plant storage or the operations can be reversed or repeated immediately prior to juicing. As indicated, an ounce of prevention (preventing/removing contaminants from raw material) is worth a pound of cure (trying to clean up contaminated juice).

Table 6.1: Unit operation involved in juice manufacture.

Unit Operation	Result
Mass transfer	Fruit delivered, dry cleaned
Extraction	Washed
Separation	Sized, graded
Separation	Peeled, cored and deseed
Size reduction	Crushed, comminuted
Pressure application	Juice extracted
Separation	Solids screened
Deaeration	Oxygen removed
Centrifugation	Solids separated
Filtration	Clarification
Fluid flow	Juice transferred, pumped
Heat transfer	Enzymes inactivated, juice pasteurized and cooled
Concentration/evaporation	Volume reduction, stability
Mass transfer	Packaging, shipping

Although there are key differences in the handling of each type of fruit destined for juice (Table 6.2) and important varietal and seasonal adjustments, the generalized flow scheme in Figure 6.1 puts the operations in perspective. Normally, juice fruit does not receive the care in packing, transport or postharvest treatment reserved for fresh market and solid pack fruit (Fellows, 1997; Arthey and Ashurst, 1996). Operations such as cooling, washing, sorting and inspecting require attention to mass and heat transfer. Cooling depends upon heat transfer from fruit to air (possibly water). Cooling and cleaning can involve physical removal of surface debris by brushes or air jet separation prior to washing with water. These steps substantially decrease water use and speed up product flow. Efficient equipment minimizes cooling/heating energy and wash water use. When performed improperly the contamination level can actually be increased. Thus equipment and water sanitation is critical with chlorination and recycling usually necessary.

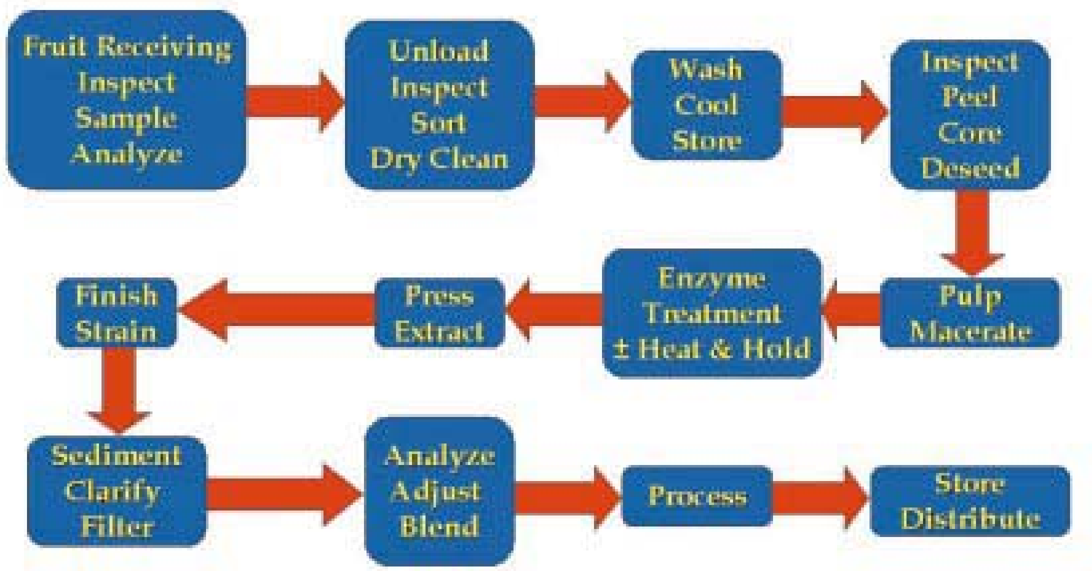


Figure 6.1: Generalized juice flow scheme.

Table 6.2: Fruit characteristics affecting juicing.

Type	Procedure	Example
Soft, all edible	Comminute, grind, press	Berry
Soft, seed inedible	Crush, press	Grape
Firm, seed inedible	Grind coarse, press	Apple
Firm, inedible skin ± seeds	Ream, press flesh	Citrus
Soft inedible skin ± seeds	Pre-peel, gently pulp flesh	Mango
Brittle inedible skin + seeds	Slice, gently press flesh	Passion fruit, lychee
Tough adhering skin, ± seeds	Hand or contour peeling	Guanabana, pineapple
Soft, inedible skin	Roller/squeeze peel	Banana

6.1.1 Pre-process storage

The logistics of production, harvest, transport and ripening dictate that many fruits must be held prior to juicing. The seasonal harvest window may be much shorter than the time required processing the entire annual crop and stabilizing the resulting juice and finished products. As with the aforementioned steps, careful holding is necessary to allow optimum ripening to occur or prevent spoilage and contamination. Producers and processors should have a good understanding of postharvest physiology, particularly as it relates to the species and cultivars in question.

With certain climacteric fruit, ripening and senescence can be controlled (delayed, maintained constant, accelerated, or promoted uniformly) by the judicious use of low temperature, moderate humidity and adjustment of oxygen, carbon dioxide and ethylene levels (Table 5.4). These practices termed controlled or modified atmosphere storage can greatly extend the storage life of some fruits and vegetables (Arthey and Ashurst, 1996).

With other fruit, holding is short term and serves only temporarily to prevent contamination and damage while accommodating processing flow. Some fruit can be frozen and stored for long periods. Freezing is costly, but promotes cellular breakdown and facilitates shipping and juicing. In hot climates where refrigeration or freezing facilities may be neither available nor practical for juice fruit, strategies such as just-in-time harvest, cooler night time harvest operations, rapid transportation and shady, well ventilated storage can help balance the processing load and stave off deterioration for a few critical hours. Many processors are disturbingly unaware of the importance of these procedures; but every little bit helps and the benefits add up.

Packing for transport should be gentle and sanitary. Simply throwing fruit into a bulk container and travel over rough terrain guarantees partial, unacceptable juicing during transit, prior to delivery. Moreover, if the delivery time is lengthy or if the lot must be held for more than a few hours at elevated temperature, incipient fermentation will follow. A major problem in handling and storage of fruit destined for juice is the relatively low value of the crop. Thus all post-harvest operations up to and including juicing often do not receive the attention they merit. Such produce failing to meet GAPs represents a safety as well as a quality hazard and is soon eliminated from trade in all but the poorest markets. Food safety regulations and quality standards continue to eliminate businesses employing such poor agricultural and manufacturing practices.

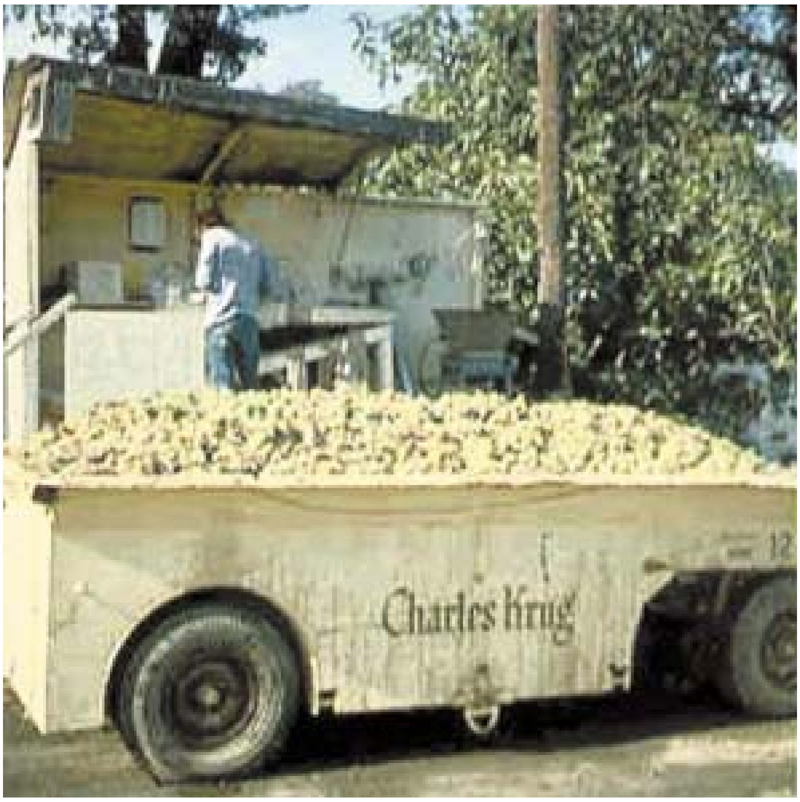
In some regions local processors stated this chauvinistic line, “We’re doing fine, our products are inexpensive and are the consumer’s only alternative.” The result has been responsible for the dramatic increase in alternative beverages such as imported juices, carbonated soft drinks and other beverages. Most seriously, local fruit juices and all locally processed products have received an undeserved poor quality image. Consumers do not make subtle distinctions as an entire industry can be “tarred with the same brush”.

6.1.2 Cleaning, sorting and inspection

If the fruit producer has followed GAPs and the harvest and handling have been accomplished effectively, fruit arriving at the processing plant should be reasonably sanitary and of optimum quality, thus simplifying succeeding operations. Nevertheless, quality cannot be taken for granted. In many cases the basis for payment is the condition of the fruit as received. Hence sampling and analysis for composition and quality are mandatory.

Government norms, an industry association, or agreement between producer and processor in advance of the crop purchase can dictate applicable quality standards. Some agreements are seasonal or even ready before planting or harvest. A representative sample of the shipment may be drawn according to statistical procedures, inspected for visible defects and foreign matter and then analyzed for microbial load, pathogens, pesticide residues, aflatoxin level, colour, sugar, acid, flavour, or other important safety and quality attributes.(Table 6.3). Figure 6.2a and b illustrate raw material delivery inspection procedures for apples and grapes.

a.



b.

Figure 6.2a and b: Delivery inspection of apples and grapes.
Analysis upon delivery is the basis for payment

Table 6.3: Some quality criteria for juicing.

Factor	Criteria	Rationale
Maturity	Ripeness	Optimum quality
Solids	Adequate level	Affects yield, flavour
Acidity	Appropriate pH level	Flavour, sugar/acid ratio
Colour	Fully developed	Juice appearance
Defects	Appropriate level	A few can be tolerated
Size/shape	Uniform	Ease of handling/juicing
Specific chemicals	Past analyses	Reflect handling/quality
Pesticide residues	Regulatory control	Legality of product
Foreign matter	Appropriate level	Reasonable limits
Microbial count	Low total, no or few pathogens	Safety/stability of juice
Aflatoxin level	Below proscribed limits	Juice safety

Rejection at this stage is a serious matter, since considerable time, effort and expense has already been invested in the suspect lot. If the defect is correctable (cleanup, resorting and inspection) a price penalty may be imposed or alternate processing required. However, if the lot cannot be corrected, contamination (microbial or chemical) or far off-standard composition/quality disposal costs and reputation damages, result. In either circumstance process flow is disrupted and plant operations suffer.

Thus for reasons of quality and safety it is important that GAPs be in place before the harvest season, agreed to by all parties, followed strictly and documented throughout the production and delivery chain. At the juice processing facility, the GAPs interface with the processor’s system (GMPs), which should be equally well designed and practiced. It is inefficient and illogical to take fruit that has been well handled up to this point and then subject it to inferior juice manufacture operations. The components of GAP and GMP systems are emphasized throughout this text.

Prior to juicing, the fruit can be washed, thoroughly inspected and sometimes sized (fruit-dependent). Inspection and removal of unsound fruit is very important, more so than in whole fruit processing. In solid packs one bad piece of fruit can cause a defect in one container, but after juicing that same piece of defective fruit can end up contaminating an entire lot of juice. In the same context, a few pieces containing microbial pathogens or toxic chemicals can and do raise havoc when juiced.

Dry pre-cleaning steps and water recycling systems may be required depending upon the availability and sanitary quality of water. GAPs should insure that dirty fruit is not delivered for processing. However, weather and delivery conditions may require the removal of dust, mud or transport-induced foreign matter. Water dumping/transport can serve to gently convey the fruit, but this is a dangerous practice, if dump water is not adequately chlorinated or otherwise treated. Maintenance of water quality is an expensive but essential feature of any quality juice processing facility. A screen shaker in conjunction with air jets and dry brushes can effectively reduce water usage, provided that the fruit can tolerate such mechanical handling.

Inspection can be manual, contingent upon workers observing and removing defects or automatic, effected by computer controlled sensors to detect off colour, shape or size (Figure 6.3). Sophisticated instrumentation operating at high speed is being increasingly employed in modern processing facilities, although the human eye, hand and mind still commonly make the final decision.

6.1.3 Crushing and juicing

There are many fruit-specific ways to extract juice. Some are well-established, large-scale procedures for commercial fruits and will be explained in detailed for those fruits. Operations range from kitchen to industrial scale depending upon volume, end use and raw material. Table 6.2 provides some general guidelines for various fruit types. The goal in juice manufacture is to remove as much of the desirable components from the fruit as possible without also extracting the undesirables. Thorough comminution maximizes the yield, but by so doing extracts substances from everything, i.e. seed, skin, core, etc.

Thus the compromise between juice yield and quality dictates the juicing and subsequent steps. Fruit with unpalatable skin and seeds must be treated more cautiously than one that can be completely pulverized. It is possible to minimize extraction of skin and seed components by a crushing regime that mashes or removes edible flesh, while sparing other portions. However, some fruit must be carefully peeled and deseeded or cored prior to juicing. Hand labour is the current alternative with many minor fruits, although there is an economic incentive to mechanize if possible.

Contour peelers, such as used with apples (Figure 6.4) can be adapted to a range of fruits that are sufficiently firm and uniform to facilitate the rotary peeling action. A battery of analogous units was the precursor of the Ginaca, used successfully for pineapple (Section 15.1). Peeling systems that are effective with some vegetables such as lye, abrasion, enzymatic, explosive, are less satisfactory with delicate fruit flesh. Nevertheless, cleverly designed machinery can greatly facilitate these labour-intensive operations. Under all circumstances, a final human inspection and piece selection/rejection step is mandatory.

Generally a whole fruit is more stable than the juice, unless rapidly preserved after extraction. So fruit should not be committed to juice until the material can rapidly be stabilized or the process go to completion. Attention to quality at the prejuicing step is extremely critical. Otherwise surface debris and portions of skin or seed can easily ruin the

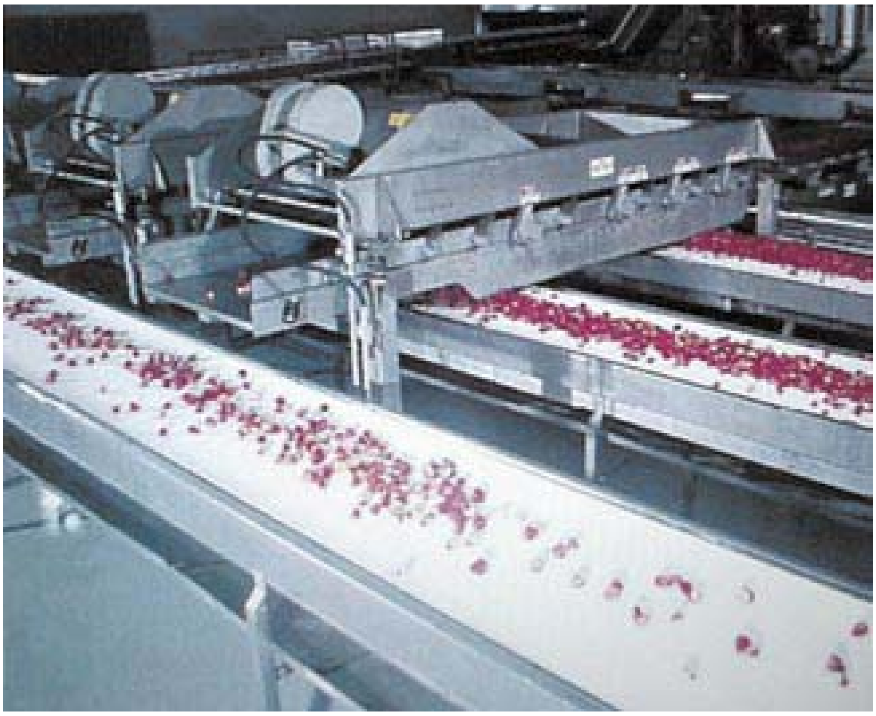


Figure 6.3: Automatic inspection/grading system.
Courtesy Key Technology, Inc. (Key, 2000)

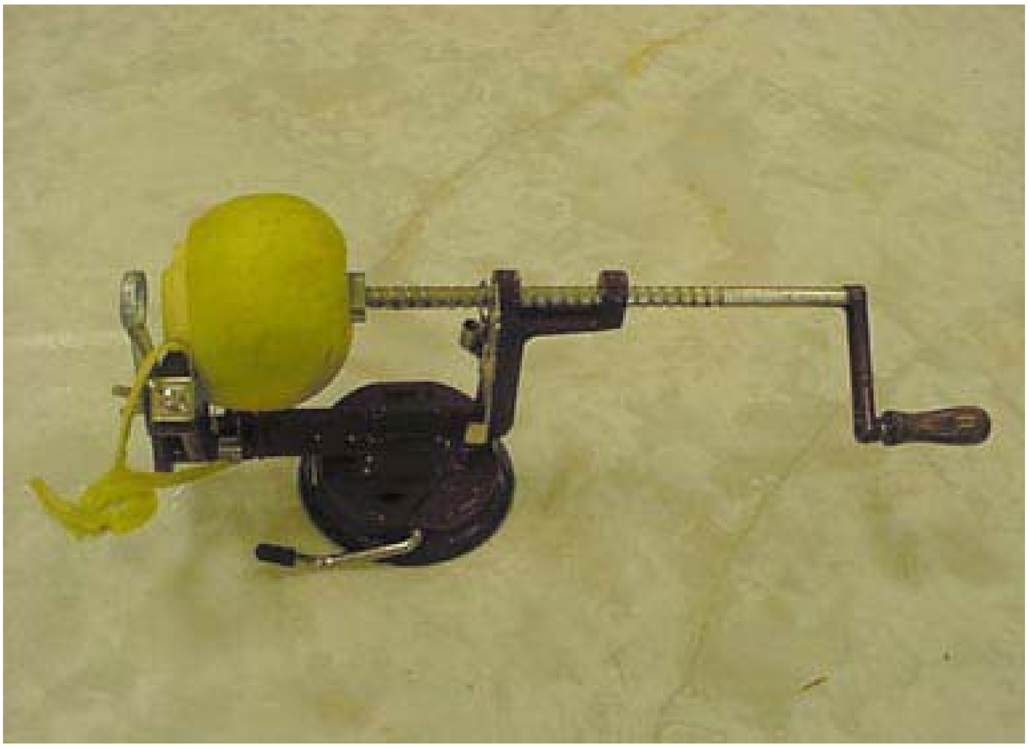


Figure 6.4: Apple peeler/corer.
Courtesy of Basics Products, Inc. (Back to Basics Products, 2000)

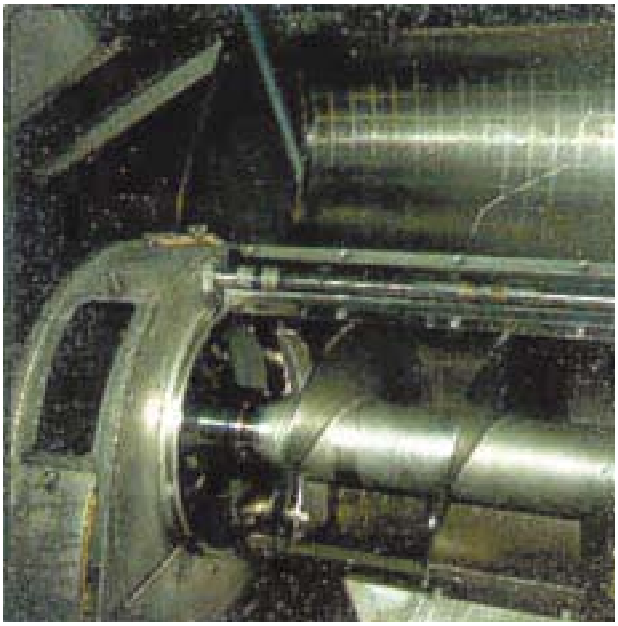
colour or flavour of an entire batch of juice. Of course, in a similar sense, microbial and chemical contaminants at juicing can and have caused disastrous public health consequences.

Juice extraction equipment ranges from hand operated crushers to tonnes/hour mechanical extractors (Figure 6.5). With soft or comminuted fruit a cone screw expresser or paddle pulper fitted with appropriate screens serves to separate the juice from particulate matter (Figure 6.6). Where skin or seed shattering is a problem, brush paddles can replace metal bars. Two pulpers in series with screens of ~1 to 0.2 mm can effectively clean up many juices and often yield a usable thick pulp by-product.

a.

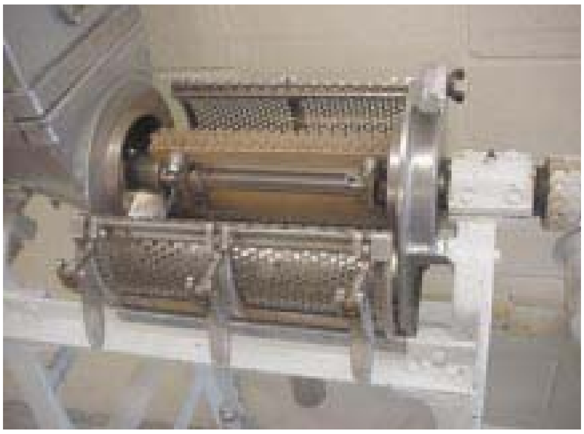
b.

Figures 6.5a and 6.5b: Small and large fruit crushers.
Capacity ~100 kg to 40 MT/hr.



a.

b.



c.

d.

Figure 6.6a. b., c. and d: Fruit pulper screw finisher, paddle pulper, paddle pulper with coarse screen, paddle pulper with brushes for soft fruit.

With thicker purees a pressing step may be needed and several options are available. For refractory material, pretreatment with a macerating enzyme with or without heating to ~60ºC and holding up to ~40 minutes can greatly increase yield and subsequent pressing/clarification steps. Enzyme suppliers have selections of enzyme blends with hydrolytic activity against fibrous plant materials such as pectin, hemicellulose and cellulose to match the composition of most plant material **(**Hohn, Somogyi, *et al.*, 1996).

Even without macerating enzyme addition, heating to ~70ºC softens the fruit, inactivates native enzymes, reduces microbial load and affects an increase in juice yield. However, delicate flavours can be destroyed and unacceptable darkening due to enzymatic and non-enzymatic browning can occur. Rapid heating and cooling prior to juicing can overcome some of these quality problems. Traditionally mashed fruit and purees were batch heated to optimum macerating enzyme temperature (~55 to 60ºC) in open steam-jacketed kettles with stirring. This step and subsequent cooling can be accomplished by swept surface heat exchangers **(**Figure 8.4) or thermal screws (a hollow steam-heated auger in a steam-jacketed trough). Steam or cooling fluid flowing through both auger and trough effectively and continuously heats or cools the material. Pulpy, viscous puree cannot be passed through a plate or tube heat exchanger due to clogging problems, although, after solids reduction, these units are appropriate.

A thermal screw is a continuous system for both transporting and heating or cooling crushed fruit or whole small fruit. In a hot press regimen, the material passes directly from the crusher to the press holding tank via the screw, adjusted to deliver the crush at the proper temperature for enzyme activity, ~60ºC. In continuous pressing, the screw can even be slowed down enough to accomplish the holding time and then feed directly to the press (or to another feed/holding screw). Only reasonably small particles can be so treated and care must be taken to insure even heating and avoid scorching of the crush.

Macerating enzymes also facilitate juice clarification steps. In some cases the naturally present enzymes (primarily pectinases) can be allowed to act at ambient temperature prior to pressing. However lengthy holding may favour spoilage organisms and the natural hydrolytic activity is apt to be slower than with added industrial enzymes. For fruits with delicate flavour or those where colour extraction from seed or skin is not desired, an immediate press at ambient temperature (referred to as a cold press) with or without enzymes is favoured. Juice yield will thereby be lowered; a compromise dictated to avoid undesirable heat-induced darkening.

A word of caution regarding commercial enzymes, enzyme preparations available in powder or liquid form, have a finite shelf life and should be refrigerated, since activity decreases rapidly at ambient temperature. These processing aids are fairly expensive and should be used sparingly. The solutions and powders are warranted only when the value of the additional juice yield and its quality exceeds enzyme cost. Also, they are mixtures containing individual enzymes, some of which may promote undesirable reactions, so consultation with suppliers and pilot testing is advised.

Another means of extracting water-soluble components from fruits and plant material is infusion extraction. The flesh is comminuted with added water to dissolve solids that are then separated from the pulp as described. Multiple extractions with temperature and pH adjustment and enzyme treatment can extract practically all-soluble solids. A counter-current flow where fresh solvent (usually water) contacts the last stage of spent pulp is quite efficient **(**Figure 6.7) and used widely in the Citrus Industry (Section 11.3.4**)**. In this case, subsequent concentration of the extract is necessary to return to the initial fruit ºBrix.

With soft, readily extractable fruits a steam extraction system has promise. An early example is a home extraction unit of Scandinavian origin **(**Figure 6.8). The fruit is in a strainer that drains concentrically away from an inner container with boiling water. Rising steam condenses in the fruit compartment or on the fruit, heating it and leaching out soluble that drain away from the pulp. A larger scale semi-continuous unit of French design is shown in Figure 6.8. Despite the use of high temperature, this system steam inactivates enzymes (blanches) and pasteurizes the fruit and excludes oxygen during extraction. Thus the juice has unusually good colour and flavour retention.

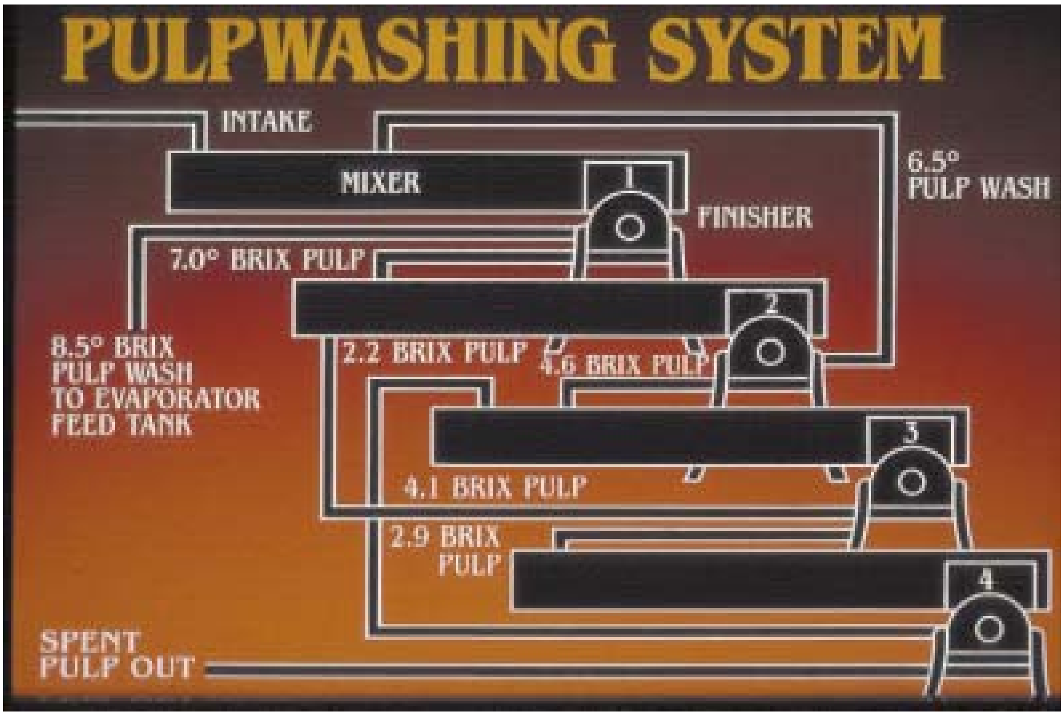


Figure 6.7: Pulp wash extraction schematic.

a. 

b. 

Figure 6.8a. and b: Steam extractors. Kitchen and pilot plant models.

Independent of the system used, if the extract is then concentrated back to the original solids level, it is technically juice. However, labelling as juice depends on specific country regulations. The pulp or press residue of high value fruits can be extracted in this manner with water or other solvents to yield extracts containing pigments, nutrients, nutraceuticals, essences, or other useful by-products.

6.1.4 Pressing

The pressing operation can also range from manual to mechanical **(**Figure 6.9) with complete automated systems common in the juice industry. Kitchen-scale juicers or food processors are effective for small quantities, but for larger multi-kilogram amounts, flow resistance and distance the expressed juice must travel to the press surface complicate pressing. The rack and cloth press increases the surface area to volume ratio and is quite effective, albeit labour intensive. Figure 6.10 shows a simple press based on a hydraulic truck jack developed by Cornell University (Downing, 1972). All supports are wood, including the racks. Tough cottons or synthetic cloths provide an inexpensive, durable batch press, albeit difficult to clean and sanitize.

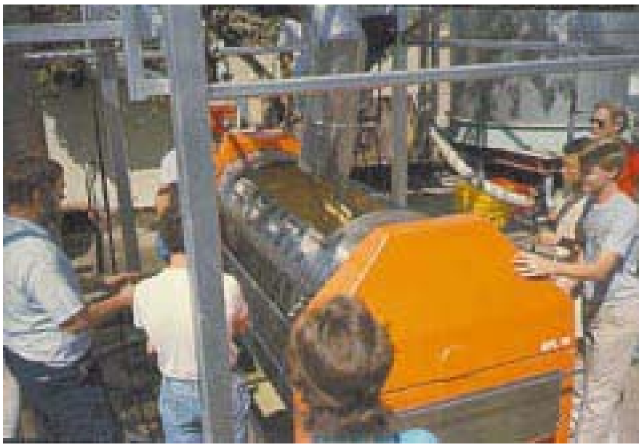


Figure 6.9: Juice presses – hand basket, rack and cloth and pneumatic bladder.

Figure 6.10: Simple hydraulic rack and cloth press.
(Downing, 1972)

Figure 6.11: Bladder press, 100L capacity.

Other batch systems involve hydraulic basket presses where pistons move down into a press sack containing the crush. Better extraction is obtained by mixing the crush between multiple pressings to expose fresh surface near the cloth. This mixing step is accomplished in bladder presses by rotating a horizontal basket fitted with a chain or internal mechanism to redistribute the cake and reinflating the bladder to provide pressure on the crush (Figure 6.11). Vertical bladder presses inflated by air or water pressure are also in use. Periodic deflation of the bladder and manual cake redistribution is necessary to insure a fresh press surface.

At the other extreme are continuous screw presses capable of handling many tonnes/hour of crushed fruit. Care must be taken not to subject the press cake to excessive shear; or else seeds and other solids will contribute undesirable components to the juice. A more expensive continuous yet gentle system is a belt press where the pulp is pressed between porous belts by rollers. In most press configurations, adding several percent of a press aid to the crushed fruit can increase yield. Press aids consist of clean rice hulls or cellulose fibre that provide drain channels for the expressed juice. Multiple pressings or rotations (in bladder presses) further increase yield, but require more time and can extract undesirables if overdone. The press aid also serves to strain out particulates; juice expressed late in the cycle tends to be clearer (and darker, if browning has occurred). However, press aids can present a disposal problem, may be expensive and unless well refined, can contribute off flavours.

With some fruits allowing the crush to settle provides natural drainage. The pulpy fraction either floats or sinks for easy separation and greatly reduces the volume needing pressing. Fining with the use of bentonnesite or highly adsorbtive powder capable of flocculating colloidal material from the juice speeds up settling and is commonly used in wine clarification. Similarly, addition of protein or tannins as fining agents can not only remove suspended solid, but also form complexes with macromolecules that, if not removed, can cause haze formation in finished juice (Chapter 13).

Figure 6.12: Juice sampling after manual crushing through a nylon bag.

Table 6.4: Press factors influencing juice yield and quality.

Factor	Effect
Fruit immature	Resistance to juicing, low yield
Fruit inadequately crushed	Resistance to juicing, low yield
Fruit over mature	Undesirables extracted, poor quality
Fruit over comminuted	Undesirables extracted, poor quality
Excessive pressure	Undesirables extracted, dark juice
Excessive time in press	Dark, over extracted juice
Short press cycle	Low yield, lighter juice character
Long press cycle	Low throughput, over extraction
Cold Press	Lower yield, lighter character
Hot press	Higher yield, stronger, darker character
Enzyme treatment	Higher yield, stronger character
Pressing aid added	Higher yield
Press cake redistributed	Increased yield
Delayed or extended pressing	Dark juice, incipient spoilage

6.1.5 Juice clarification

For more fluid juices where cloud or turbidity is not acceptable primary extracted juice must be treated further. A settling step can help, if the juice can be held refrigerated for a few hours. At ambient tropical temperatures holding is not recommended. Rapid methods such as centrifugation and filtration can produce a clear juice. A continuous or a decanting centrifuge with automatic desludging to produce a clear or nearly clear juice is quite effective. (Juices where a cloud is desired generally do not require filtration; centrifugation is adequate.) The stream should be settled or coarse strained prior to centrifugation in order to reduce the sludge load in the feed going to the centrifuge. A fine mesh shaker screen can further remove particulates (Figure 6.13). A centrifuge is a very costly item; however, it greatly simplifies subsequent filtration steps and is an essential component in many juice processing operations (Figure 6.14).

Figure 6.13a: Shaker separating screen.
Mesh size and vibration frequency can be varied to accommodate feed viscosity

Figure 6.13b: Shaker separating screen used in conjunction with a continuous centrifuge.

Figure 6.13c: Commercial dewaterer/dejuicer.
Courtesy Keys Technology, Inc.

Figure 6.14: Continuous centrifuges.
Commercial ~200-1 000 L/hr, Pilot plant ~ 5 to 20 L/hr

6.1.6 Filtration

As with pre-centrifugation, the juice stream should be cleaned up as much as possible to reduce treated volume and increase throughput. There are many filtration systems well suited to various juices. These range from plate and frame filters, fitted with porous cellulose pads, **(**Figure 6.15**)** to plastic, ceramic, or metal membranes. Diatomaceous earth mixed with the liquid serves to greatly increase the surface area and porosity of the filter bed and hence the particulate absorbing capacity of the filter.

Figure 6.15: Plate and frame and vacuum filter.

In the extreme case a filter can have small enough pores to physically remove microorganisms from the juice (sterile filtration) or even remove macromolecules such as proteins and carbohydrate polymers (ultrafiltration). These processing steps will be considered later. The production of a clear or brilliantly clear juice and the prevention of post filtration turbidity are the normal goals. Membrane clogging is a concern in any filter, so pretreatment to minimize particulates and flow patterns that self clean the membrane are essential.

The system can be made continuous by a rotary vacuum filter **(**Figure 6.15**)**. A vacuum deposits fresh filter aid suspended in the juice on the drum surface. The juice passes into the rotating drum through the filter bed that is constantly renewed by scraping the spent material off the surface after a rotation. Various other filters use durable ceramic or metal porous membranes with backflush capabilities and flow patterns that minimize clogging. These systems operate in parallel to insure continuous operation and can reduce or eliminate the need for filter aid; a purchase and disposal expense.

6.1.7 Deaeration

In the operations described crushing, comminution, pressing, shaker separation, centrifugation and filtration, the fruit and juice are subjected to considerable aeration. The inclusion of oxygen can promote enzymatic browning, destroy nutrients, modify flavour and otherwise damage quality. Therefore, care should be taken to perform these steps rapidly, at low temperature and/or protect the material from oxygen, if possible. Sometimes preheating to inactivate natural and/or added enzymes is useful, provided rapid cooling follows.

Deaeration can be accomplished by either flashing the heated juice into a vacuum chamber or saturating the juice with an inert gas. Nitrogen or carbon dioxide is bubbled through the juice prior to storing under an inert atmosphere. Clearly, once air is removed or replaced by inert gas, the juice must be protected from the atmosphere in all subsequent processing steps. Deaeration, especially flashing off at high temperature, can also remove some desirable volatile aroma, another compromise facing the juice technologist.

6.1.8 A word of caution regarding processing systems

The excellent research reporting juice details - preparation, processing, composition, storage quality, etc. most likely came from academic or institutional research labs working with small, albeit representative samples of fruit. Handling is usually ideal with the major emphases on repeatability, speed and attention to detail. Rarely are the studies concerned with the logistics of handling large, i.e. commercial quantities, under industrial conditions.Thus scale-up and the attendant difficulties are not stressed. Just because a fruit can yield an outstanding juice in the lab doesn't mean it is commercially viable. Equipment from harvest to storage must be developed to efficiently perform the myriad of operations under varying and often vastly different and difficult operating conditions. Furthermore, these operations must match reasonably well the process flow scheme. Incompatibility in throughput, or highly sensitive procedures with excessive down time raise havoc with production flow and cannot be tolerated. Ingenuity and/or technology can eventually overcome these hurdles, but only with considerable patience and time.

Hand labour and care can represent a first step in scale-up and produce juice products for local niche markets. However, this is no substitute for well-designed mechanization, to replace or at least supplement human labour. Thousands of labourers cannot match several high-speed extractors for long. Some fruits mentioned here have superb eating quality, but will have scant juice (or solid pack) potential, until some degree of cost-reducing mechanization is introduced into the system.

Generally it is the inspection, cleaning, sorting peeling/coring/pulping operations that cause the greatest problem. (Once the flesh is isolated in a reasonably clean form, subsequent operations scale up fairly easily.) This is a major challenge for small processors. If they don't continually strive to improve juice manufacture efficiency, somebody else will or the fruit will remain under exploited to the detriment of the growing region and consumers.

Curiously, the awesome ingenuity and craftsmanship demonstrated by third world mechanics in repairing and maintaining complicated machinery and equipment (automotive, refrigeration, electrical) with little training or parts inventory has not been extended to food processing equipment design and development. Of course, all such equipment is kept running long after the anticipated design life, past zero depreciation. New and innovative mechanical solutions to tedious processing steps are either conspicuously absent or not shared within the local food industry. There is a critical need for such innovation, especially since existing (large scale/multinational) equipment manufacturers with the experience and talent view this as a niche market not worthy of the investment. Conversely, if appropriate small/medium scale equipment does exist, it is atrociously expensive and/or complicated to operate and maintain.

CHAPTER 7

GENERAL JUICE PROCESSING PRINCIPLES

7.1 Juice spoilage

Freshly expressed juice, is highly susceptible to spoilage, in fact more so than whole fruit. Unprotected by skin or cell walls, fluid components are thoroughly mixed with air and microorganisms from the environment. Thus, unheated juice is subject to rapid microbial, enzymatic, chemical and physical deterioration. Table 7.1 shows the major categories of juice spoilage. The goal of processing is to minimize these undesirable reactions while still maintaining and in some cases enhancing, the inherent quality of the starting fruit.

Table 7.1: Juice safety and deterioration hazards.

Hazard/Deterioration	Result
Microbial contamination	Survival/growth of pathogens
Microbial contamination	Rapid spoilage
Aflatoxins on fruit	Unsafe/illegal product
Pesticide residues	Unsafe/illegal product
Spurious dissolved matter	Unsafe, off-flavour
Spurious particulates	Unsafe, reduced quality
Enzymatic activity	Browning, consistency/flavour changes
Dissolved oxygen	Browning, nutrient and quality reduced
Metallic cations	Flavour/colour/nutrient losses, unsafe
Maillard reactants	Browning, quality loss
Colloidal instability	Sedimentation/precipitation/haze
Extended holding	Quality deterioration

The major concern must be microbial deterioration. The ubiquitous nature of microbes dictates that no matter how sanitary the raw material, juicing equipment and facilities are, the normal fruit microflora represents inevitable spoilage potential. The low pH of most juices favours yeast that rapidly initiates an incipient fermentation. Most civilizations have mastered this type of spoilage and directed it toward the production of alcoholic beverages. However, left uncontrolled it represents spoilage. Furthermore, the presence of aflatoxin producing mould contamination on the surface of fruits generally ends up in the juice.

Certain aflatoxins are potent liver carcinogens (Ashurst, 1995) and commercial standards dictate parts per billion limits on aflatoxin levels, thus restricting the use of mouldy fruit. This is another valid reason for GAPs, sound harvest selection and inspection practices.

In fact, until recently the uncontrolled fermentation of improperly handled low pH juices was wasteful, but not deemed particularly dangerous. However, over the last decade fresh juice has increasingly been the source of serious food poisoning outbreaks and fatalities. Unpasteurized juice has been implicated in outbreaks of Salmonella and emerging pathogens such as *E. coli* O157 H7 **(**Table 4.1**)**. These incidents have resulted in far stricter sanitary and labelling requirements for commercial fresh juice producers.

There are several reasons for increased fresh juice food poisoning incidents:

- greater use of manure as fertilizer for fruit crops, a particular problem for organically grown produce,

- increased demand for and consumption of fresh juice as compared to pasteurized and frozen concentrates. The “back to nature” movement promotes a strange philosophy regarding common food processing practices,

- a larger number of individuals are immuno-compromised and quite sensitive to low numbers of pathogens. The very young, very old, pregnant women, transplant patients and those with chronic disease conditions are extremely susceptible to food poisoning, compared to healthy individuals. The consequences of infection are correspondingly more serious,

- the pathogens are also becoming more robust and resistant to preservation techniques,

- efficient manufacturing and distribution systems insure widespread, prompt delivery and rapid consumption of juice products, both safe and tainted,

- detection techniques based on molecular biology can now rapidly identify very low numbers and “fingerprint” specific pathogens or their metabolic products,

- the news media is also more efficient in detecting and publicizing food sanitation failures.

Along with safety considerations, quality factors are also important. Sound fruit, reasonably free from microbial contaminants are subject to biochemical deterioration upon juicing. The mixing of fruit enzymes with substrate and air can rapidly initiate enzymatic browning. Plant phenols, polyphenol oxidase and oxygen react to darken many juices. There are many other enzymes active in juice capable of destroying ascorbic acid, modifying pectin and affecting colour, flavour and texture. So rapid processing and the use of heat or enzyme inhibitors are necessary with some juices.

Even barring microbial and enzymatic changes, other chemical reactions involving oxygen, metal cations and other juice constituents can occur to modify sensitive pigment, taste or aroma substances. There are literally hundreds of reactive compounds in the simplest of juices, so the reaction possibilities are enormous (Tables 3.1, 3.2, 7.1).

Another storage limiting factor affecting most juices is the common sugar-amine or Maillard reaction. Reducing sugars and amines, ubiquitous to plant cells and hence juice, slowly go through a series of steps to form brown pigments. In the baking of bread Maillard products are responsible for the desirable crust colour and flavour, but not in juices. Low temperature greatly retards Maillard browning, but does not stop completely these undesirable reactions.

Chemical contamination can also occur from the environment. The unauthorized or excessive use of pesticide chemicals is the most common and avoidable source, readily preventable by GAPs. Such contamination is particularly serious in organic juices where no pesticides are permitted. Even trace amounts of innocuous substances present in soil, water, or wind drift can cause rejection. Although the health hazard is trivial, the analytical sensitivity insures detection. Mistakes anywhere in the food chain are more serious. Unlabeled lethal white powders have been mistaken for food ingredients and added to juice, resulting in fatal poisonings.

The use of nonfood grade equipment in the processing line is a relatively minor safety concern that still impacts juice quality. Metals such as copper, bronze, aluminium, iron, galvanized, steel (except stainless) are easily attacked by fruit acids and, in turn contribute metal ions to the juice. These ions can have pro-oxidant properties and adversely affect flavour, colour, clarity and nutritive value. In addition, flexible connections and all food contacting surfaces should be stainless steel or food grade plastic, since off flavours and unauthorized plasticizers could leach into the juice. Certainly, contact with toxic metals such as lead, mercury, cadmium and zinc must be rigorously avoided. Food grade surfaces are significantly less available and more expensive than easily obtained "hardware store" alternatives, but much more durable, safe and ultimately cost-effective.

Physical changes can also take their toll on juice quality. Separation of dispersed particles can help or hinder appearance. Clear juices can turn cloudy or release an unsightly precipitate. Chemically or freeze-thaw induced colloidal reactions can affect juice viscosity to thicken or thin the consistency and influence the taste. In view of the numerous pathways to juice spoilage and delicate nature of juices, it is an impressive testimony to food science and technologies that juice stabilization techniques work as well as they do. Indeed, through most of history, the controlled spoilage (fermentation) to alcoholic beverages such as wine, was the tenuous but only preservation alternative.

CHAPTER 8

JUICE STABILIZATION AND PRESERVATION

8.1 Preservation

Despite the many pathways to deterioration, there are a number of effective preservation methods that have evolved to combat spoilage. A principle tenant of food preservation is to maintain the quality and nutritional attributes while preventing spoilage. In general, the fresher the juice, the higher the quality, so the standard of excellence is often freshly prepared, unprocessed juice **(**Sizer and Balasubramanian, 1999**)**. As indicated, this is a very transitory product having a limited shelf life of hours or days even under the best of circumstances.

8.1.1 Refrigeration + sanitation

Two practical "processes" capable of extending storage are rigorous attention to good sanitation from production through juice preparation and low temperature holding. Even in the absence of pathogenic microbes, the natural microflora present will be active. The microbial load can be appreciably reduced by good handling and sanitary practices, but not eliminated. A holding temperature as close to the juice freezing point as possible (-1 to -3ºC, depending on soluble solids), combined with efficient preparation and exceptional sanitation in preparation and packaging can extend storage life up to a month. Several accompanying difficulties are the possibility of other quality-reducing reactions comprising enzymatic, oxidative and the challenge of maintaining minimum refrigeration temperature throughout distribution, including in the consumer's refrigerator. Going from an exceptionally low refrigeration temperature to a merely good one (2ºC to 5ºC) can reduce shelf life from greater than a month to less than 3 weeks. One rule of thumb specifies each 10ºC increase in temperature roughly doubles reaction rates.

Refrigeration combined with pasteurization and hermetic packaging can further increase storage life with minimum quality changes, but then the juice cannot be labelled "fresh". Thermal processing does away with the absolute need for refrigeration and inactivates enzymes. But heat-induced reactions change the character of the juice. With many juices heat is tolerable and commercially acceptable packs are available. However, there are some delicate-flavoured juices, most of tropical origin, that cannot tolerate even the most gentle pasteurization step. A major quality defect in pasteurized tropical juices and juice beverages is over heating or holding the product at too high a temperature before or after pasteurization. The resulting scorched flavour and colour does not do justice to the fruit so treated, easily reduces consumer appeal and destroys market potential.

8.1.2 Freezing

All preservation methods that allow juice storage above refrigeration temperatures, greater than about 5ºC, are limited by Maillard browning and other slow but persistent reactions. Thus low temperature during manufacture and storage is a valuable hurdle to deterioration. Single strength juice freezing and storage in a low oxygen environment can maintain fresh character as well or better than any other process. However, it is a costly alternative and appropriate only where product value merits freezing and holding large volumes of single strength juice. Slow deterioration (over months) is exhibited by decline in nutrients , primarily loss of ascorbic acid, enzymatic activity as well as flavour, colour and viscosity changes. For frozen products, the closer to thawing temperature they become, the faster these reactions occur. Although the product cannot be labelled as such, subsequent thawing and proper packaging approximate fresh juice. “Fresh frozen” is the appropriate designation. The thawed juice then has a shelf life limited by sanitary conditions and pre-freezing treatments.

8.1.3 Combined methods

In circumstances where thermal processing is impractical, minimal processing employing hurdles is called for. The hurdle principle is based on the premise that while any single barrier to microbial growth may be inadequate for desired protection, a number of barriers together can enhance product stability (Figure 8.1).

Thus good sanitation is the first barrier to reduce microbial load; low storage temperature further retards growth. An acid environment of pH less than 4.5 (ideally less than 3.5) restricts the growth of many organisms. Fortunately most juices are acid, or amenable to acidification. The exclusion of oxygen is an additional barrier. (Although anaerobic conditions are dangerous with low acid foods and can even set the stage in high acid products for anaerobic spoilage organisms, i.e. yeast, lactic acid bacteria, etc.) Antimicrobial substances, either natural or chemical preservatives, also assist. Proper use of hurdles can appreciably lengthen shelf life of unpasteurized juices without unduly affecting quality.

Minimal processing is the strategy by which a number of hurdles are combined to effect near “fresh” juice characteristics. Although the sensory quality may approximate that of the unprocessed product, the term “fresh” cannot be used. The ubiquitous network of refrigerated and frozen production, storage and transportation facilities, including home units, encourages minimal processed juice products. Thus, even the slightly less fresh flavour exhibited by pasteurized juice is not acceptable to some. In developed countries fresh squeezed, refrigerated juices continue to capture sales from frozen concentrates despite a substantially higher price and shorter shelf life (Table 8.1, Figure 8.2). Convenience and the closer-to-natural image apparently justify the 30 to 50 percent price premium and bulky storage requirements of these ~85 percent water drinks.

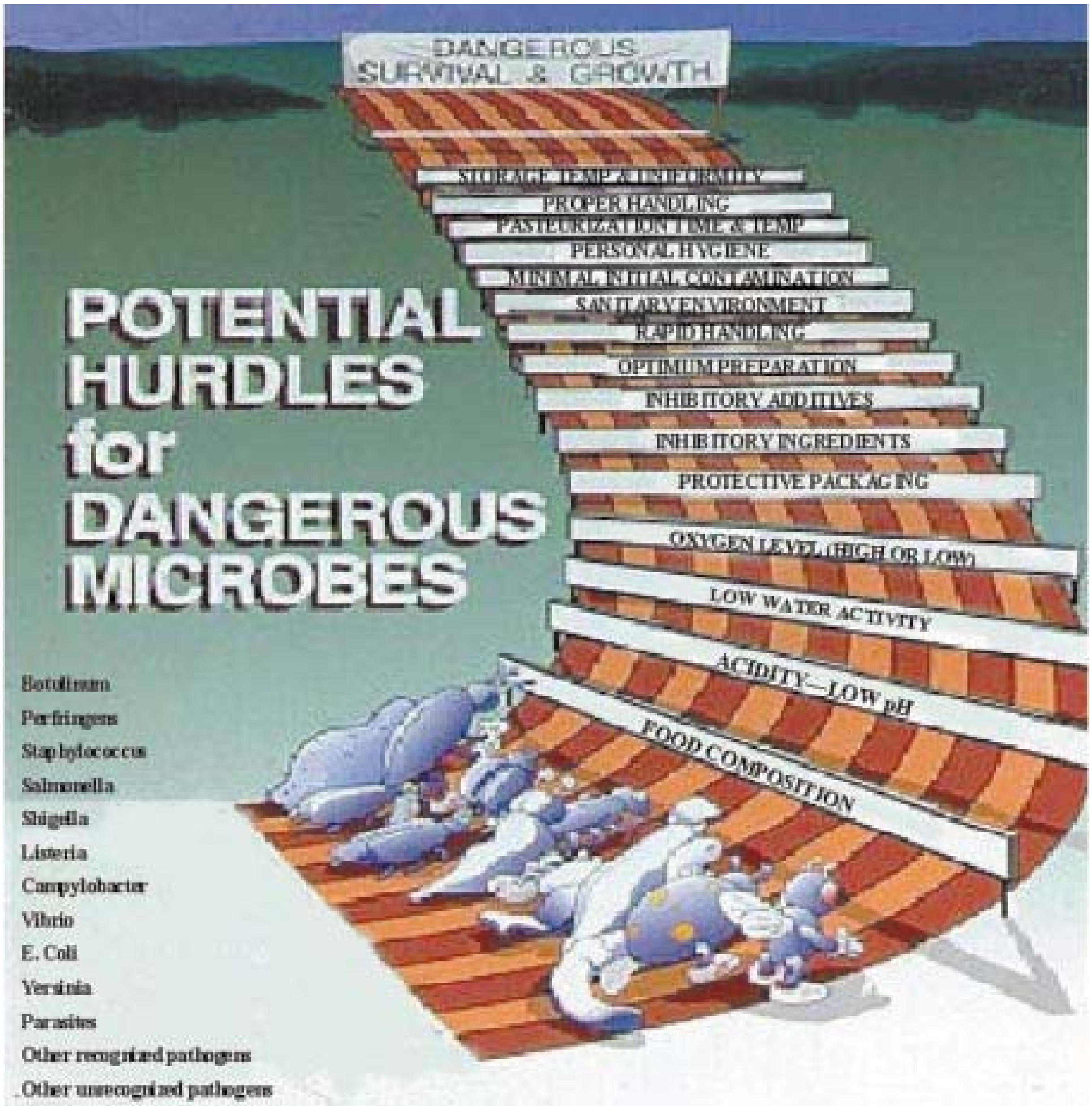


Figure 8.1: Hurdles to microbial growth.

Table 8.1: Advantages and disadvantages of "Fresh" = Minimally processed juice.

Advantages	Disadvantages
To Consumer: Health image	More expensive than processed juice
Fresher sensory appeal - flavour, colour	Shorter shelf life
Closer to self preparation, but convenient	Quality demands proper storage
"Natural" image	
To Marketer: Increased profit	More costly display space
Attractive sales display	Shorter sales life
Promotes fresh produce sales	Handling mistakes costly
High turnover	
To Manufacturer: Simplest process	Higher quality fruit required
Adds value to cull fruit	Dictates very careful handling
All juices pass through this step	Safety responsibility high
High seasonal turnover	

8.1.4 Competitive inhibition

A conceptually appealing process (actually a hurdle) is the inclusion of benign microorganisms into a food. These microbes, designed to grow well under conditions of storage abuse including temperature, oxygen level, pH, water activity, etc., will dominate spoilage and readily signal their presence thus harmlessly causing rejection of the spoiled item. In some cases competitive growth produces substances inhibitory to dangerous organisms, or affects a desirable chance in the food such as cheese ripening, alcohol production and lactic acid and flavour development.

Figure 8.2: Chilled juice aisle.
Single strength beverages requiring refrigeration throughout the distribution chain.

Indeed, the development of these fermented foods served to stabilize and improve the original materials. Taking the concept one step up the food chain suggests that competitive inhibition can be used to combat pathogens in food borne disease vectors i.e. insect droppings, animal manure/intestine and even in the human body. Just as vaccination employing modified pathogens or their derivatives dramatically reduced infectious diseases, genetically modified organisms with tailored growth/inhibition characteristics will eventually protect minimally processed foods.

8.2 Thermal processing

The acid nature of most juices permits pasteurization, defined as the use of temperatures near 100ºC to effect destruction of spoilage organisms. Although spores conceivably can survive at a pH less than 4.6, outgrowth is unlikely. In contrast, at a pH greater than 4.6, spore heat resistance dictates a process temperature of greater than 115ºC for an extended time. Hence pH reduction by acid addition to turn low acid or marginal pH juices into high acid products is widely practiced.

A potentially effective process for fresh juice involves heating clean, well-sorted whole fruit for up to 1 minute at 80ºC. This greatly reduces surface contamination without influencing the underlying flesh that, if juiced in a sanitary manner, has the sensory quality of fresh juice. A great deal of research is underway combining surface heat with other decontamination practices. Whether these treatments will qualify as producing "fresh" juice for labelling purposes remains to be seen.

8.2.1 <u>Canning</u>

Standard canning procedures specify filling cans or jars with hot juice (~70 to 80ºC), sealing and processing at 100 to 105ºC for up to 10 minutes and cooling immediately. This is rarely done in a still (stationary or motionless) retort, since slow heating and cooling would ruin the quality. Instead, a continuous rotary retort provides rapid heating and cooling as a result of the juice being stirred inside the can by the headspace bubble movement during rotation (Figure 8.3). Another rapid system is the spin cooker/cooler where the spinning action provides good internal and external surface contact.

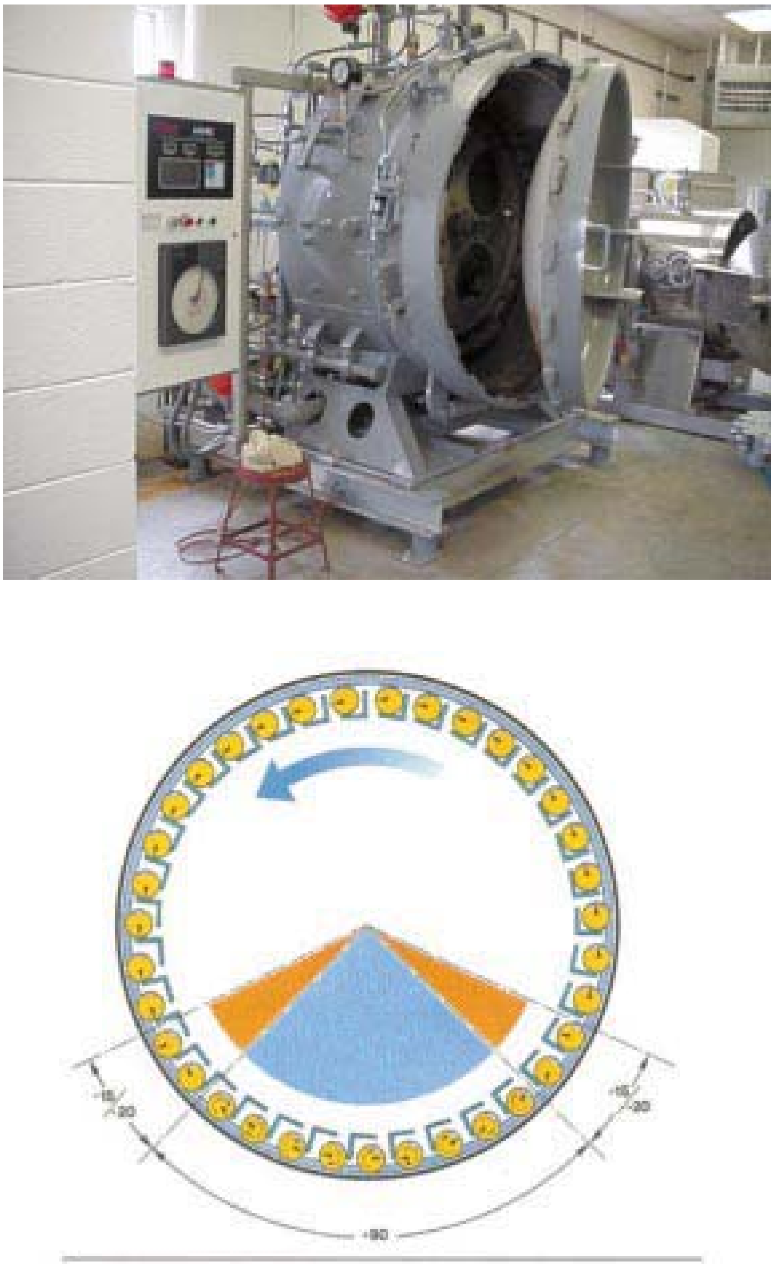


Figure 8.3: Rotary retort and schematic.

~2 to 5 rpm rotation provides in-container mixing

8.2.2 Hot fill

It is fairly easy to hot fill pack juices by rapidly heating the juice in a heat exchanger and filling containers with the hot juice measuring around 95ºC followed by sealing and inverting, thus pasteurizing the container (Section 11.5). Reasonably rapid cooling is accomplished by rotary or spin action. This is known as flash pasteurization and can be achieved almost instantaneously. However, once in a container, cooling cannot be as rapid. The major quality problem is scorching, due to holding the juice hot, either before or after filling.

Many types of heat exchangers are used. The simplest is a coil submerged in boiling water with the juice flow adjusted to the desired pasteurization temperature (Figure 11.14, Chapter 11). For pulp-containing juices or those likely to leave a film on the heating surface, a swept surface unit can continuously heat a juice stream. A plate heat exchanger with a regeneration section by which the cool entering product is preheated by the exiting hot product stream can be quite energy efficient, although the cooled stream must then be handled, filled and sealed in a sterile environment (Figure 8.5 aseptic processing).

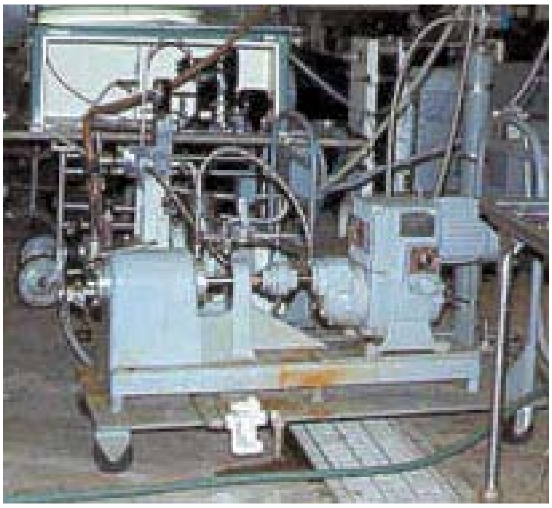


Figure 8.4: Pilot aseptic line.
Swept surface heat exchanger on right.

Figure 8.5: Plate heat exchanger.

Hot fill has the additional advantages of driving air from the juice and ensuring a partial vacuum in the sealed container as vapour condenses upon cooling. Of course, deaeration and use of an inert gas during packaging are also useful. Sanitation is quite critical, since there are acid resistant moulds such as B*ysochalmous fulva* and *Talarmyces flavus* with unusually high temperature tolerance that require temperatures close to 100ºC for up to 60 seconds for adequate pasteurization (Ashurst, 1995; Splittstoeser, Somogyi, *et al.,* 1996a). Such a process could be excessive for some delicate-flavoured juices, thus requiring either gentler processes or exceptionally sanitary preparation. These moulds are not too common, but once established in a processing facility, they are difficult to eliminate.

8.2.3 Aseptic processing

A more elegant aseptic system rapidly heats, holds the hot juice to implement pasteurization and cools the juice before filling into sterile laminated paper/plastic/foil containers which are literally formed around a cylinder of flowing sterile juice **(**Figure 8.6, Tetra Pak, 2000). The rapid heating and cooling of the product guarantees microbial and enzyme destruction. A major advantage of aseptic packs is its adaptability to many size containers from single serving 200 ml portions to thousands of litre bulk packs. It is absolutely essential to pasteurize or in some cases sterilize the product, cool adequately and pack into sterile containers in a sterile environment, since the presence of a single viable organism can spoil an entire lot of juice. The evolution from simple canning to aseptic processing has greatly improved processed juice quality, but at a price. Aseptic systems cost more than US$1 000 000 and require sophisticated control and maintenance.

Figure 8.6: Aseptic package formation and multiple lines.
Courtesy Tetra Pak

8.3 Non thermal and other methods

8.3.1 <u>Sterile filtration</u>

Another gentle and effective preservation method is sterile filtration. Clarified juice can be passed though a membrane filter with uniform pore size of less than 0.2 microns, thereby physically removing all microorganisms and virus (Figure 8.7). Of course, down stream sterility and aseptic packaging are essential and membrane leakage is disastrous. However, such juices have long storage potential provided endogenous enzymes are not active and reasonably low temperature storage is maintained. Juice where a cloud is normal or one that throws down a precipitate or forms a haze after filtration cannot be so treated. Experimental systems that separate the juice into a clear liquid, for sterile filtration and a pasteurized cloud portion then homogenizing and combining the sterile streams can be developed. Similarly, one strategy for juices containing considerable pulp is to separate pulp from fluid juice, process the juice rapidly in a heat exchanger and the pulp by slower means. The two streams are combined with homogenization to stabilize the blend and then packaged, all under aseptic conditions.

Figure 8.7: Pilot scale sterile filtration units.
Carbonation is accomplished in stainless tank, sterilization by white filter, centre

8.3.2 <u>Chemical preservatives</u>

Building on the hurdle principle, antimicrobials can effectively extend shelf life (Table 8.2; Maga and Tu, 1994**)**. Sulphur dioxide is quite effective in inhibiting both microbial growth and enzymatic and non-enzymatic browning and is standard practice in most wine making. A small number of individuals are quite sensitive to $SO_{2,}$ so correct labelling and minimum levels are required. SO_2 is delivered as the gas or in the less noxious and more easily controlled form as potassium metabisulphite with about 60 percent by weight as $SO_{2.}$ Dosage is reasonably self-limiting, since too little is ineffective and too much gives an unpleasant, pungent aroma. The preservative action is due to the undissociated H_2SO_3 molecule (formed when SO_2 or bisulphites are dissolved in water), so lower pH favours its use, as graphically illustrated in Figure 8.8. Levels of 30 to 100 ppms, at a pH below 4.0 are effective. However, some asthmatics are so sensitive that simply being near SO_2 solutions is enough to trigger an adverse reaction, so caution is advised in use and labelling in foods if over 10 ppms is mandatory.

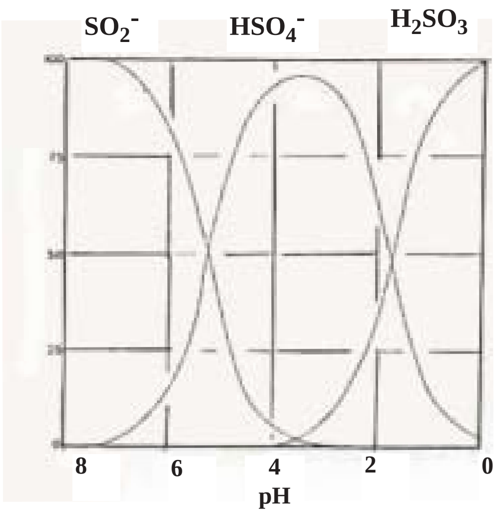


Figure 8.8: Relationship between sulphurous acid ionization and pH.
(Amerine, *et al.,* 1980)

Table 8.2: Common juice preservatives and additives.

Ingredient	Use
Sulphur Dioxide	Retards microbial and enzymatic activity
Benzoates	Antimicrobial @ pH <4.5
Sorbates	Antimicrobial @ pH <6.5
Carbon Dioxide	pH reduction, anaerobic atmosphere
Ascorbic Acid	Retards enzymatic browning
Dimethylpyrocarbonate	Antimicrobial
Gluco Delta Lactonnese? Niacin	

Other preservatives such as benzoic acid, sorbic acid and to a lesser extent, CO_2 can be used individually or synergistically. Sodium benzoate and potassium sorbate are the preferred forms given greater solubility of the salts (Branen, *et al.*, 1989). Both function best below pH 4.0. U.S. Federal regulations limit benzoates to 0.1 percent and they are most effective against yeast and mould. Sorbic acid is effective over a broader range, up to pH 6.5. Benzoates and sorbates are often used together in combination with low temperatures to extend the shelf life of minimally processed juice drinks (Somogyi, *et al.*, 1996a).

Although both sorbates and benzoates exist in nature, these so-called "chemical preservatives" are currently out of favour due to consumer misperceptions regarding their safety and the trend toward selecting "all natural" products. The term "no preservatives added" has the false connotation of improved quality. In reality, proper use of such preservatives can benefit safety and quality and prevent much waste, but is a hard sell in the marketplace.

There continues to be misuse of preservatives by some processors. Benzoates in particular are overused. Some pasteurized juices have a biting aftertaste due to excessive benzoate. The overuse is not harmful, but ironically completely unnecessary in adequately pasteurized juice. The philosophy "if a little is good, more is better" has no place in food processing. Under no circumstances should any preservative be a substitute for sanitary practices. Preservatives are only one of several hurdles that can be used to maintain quality and extend shelf life **(**Figure 8.1).

A preservation method that has been alluded to previously is alcoholic fermentation. This will be dealt with as a by-product, although in most cases it is the primary product. Winemaking is now far removed from simply "letting Nature take its course" by which naturally occurring wild yeast convert fruit sugars to alcohol. Low levels of ethanol represent another hurdle and levels of over 7 to 10 percent by volume partially inhibit other spoilage organisms. The addition of alcohol up to about 18 percent is a reasonably effective antimicrobial preservative, although the character of the juice is dramatically altered. Oxidation and other types of deterioration can still occur.

Weak fruit wine at about 6 percent alcohol is the starting point for the acetic acid fermentation and the manufacture of vinegar, which represents a value-added by-product of fruit juices. Under unsanitary conditions and in the presence of air, spoilt juice or wine can slowly turn to vinegar due to acetobacter contamination. And vinegar itself is a useful pH-reducing hurdle, although associated more with acidified vegetable products than fruits.

However, gross contamination of fruit juice is apt to result in a vile mixed fermentation with moulds growing on the surface, producing visible growth and a range of noxious organic chemicals, perhaps aflatoxins, with alcohol being produced at the bottom. How producers up until a century ago consistently got palatable wine or even vinegar from such natural fermentations is a tribute to their pre technology skills.

8.3.3 Newer methods

Unless fruit juices are handled with extreme care for fresh consumption or gently thermal processed and stored at moderate temperature, flavour suffers. There are a number of evolving preservation methods applicable to juice that do not require heat (Hoover, 1997). For the most part these are experimental with processing details still under investigation. The cost of processing equipment and present engineering limits to continuous, high throughput systems are barriers not yet overcome. Nevertheless, the promise of shelf stable juices with freshly prepared characteristics is adequate incentive, so commercial systems will eventually evolve. A few approaches summarized in Table 8.3 are mentioned here.

Table 8.3: Some newer juice processing methods.

Process	Description	Status
Aseptic	High temperature short time	Widespread commercialization
Hyperbaric Pressure	High MPa pressure	Approaching commercialization
Hyperbaric + CO_2	Combines pressure and low pH	Scale-up evaluations
Pulsed electric field	High KV/cm, Microsec field	Actively being researched
Ultrasonic	High intensity ultrasound	Potential synergistic hurdle
Ohmic heating	Resistance-generated heat	Actively being researched
Membrane	Physical removal of microbes	Effective for clear juices
Pulsed light	High intensity UV to visible	Effective for clear juices
Magnetic field	Low and High frequency/ intensity	Highly experimental
Irradiation	Electrons, gamma or x-rays	Commercially feasible
Nonthermal plasma	Electric discharge into liquids	Highly experimental
Preservatives	“Natural” herbs, spices, etc.	Actively being researched
Hydrodynamic shock	Instant high pressure	Highly experimental

Hyperbaric pressure

Subjecting juice to extremely high pressure in the order of hundreds of megapascals (thousands of atmospheres, 101.3 kPa=1 atmosphere) can destroy vegetative cells and some spores. Enzyme inactivation requires even higher pressures or longer exposure times, but relative stabilization can be achieved. Rapid pressurization cycles demand very rugged, expensive equipment. Although continuous systems for liquids are under development, initial use will be applied to high value products.

High pressure using CO_2 provides the additional stress of reduced pH (by the formation of carbonic acid, which is eliminated by depressurization). In this case, lower pressures (~100 MPa) can accomplish greater microbial destruction and enzyme inactivation than higher pressures alone.

High intensity pulsed electric field

High voltage potential maintained in a flow chamber can pasteurize juice at only moderately elevated temperatures. However, enzyme activity is reduced to a much lesser extent than vegetative cells.

Oscillating magnetic fields

Magnetic fields are somewhat effective against microorganisms and easier to apply to fluids, but these are still in the preliminary experimental phase.

High intensity pulsed light radiation

A thin film of reasonably transparent juice can be subjected to intense light irradiation ranging from ultra-violet through near infrared as a pasteurization step. Such a process is practical only for water and clear juices. Shelf life can be extended provided that flow is uniform, no blocking particles interfere and the product is deaerated prior to treatment and refrigerated rapidly afterward. However, enzyme activity is not affected appreciably.

Irradiation

Ionizing irradiation has long been practical to extend the shelf life of fresh fruits. The process can be applied in juice manufacture by either irradiating the fruit prior to extraction or treating the juice. Although juice enzymes are quite resistant to irradiation, elimination of pathogens is accomplished by reasonably low doses in the order of 0.2 to 0.5 kGy (Thayer and Rajkowski, 1999). Interestingly, irradiation long scorned by technophobes with little understanding of radiation chemistry, is an effective way of safely maintaining fresh juice quality under refrigeration. Although the products must be identified as having been irradiated through the display of the international symbol the Radura, it should be popular as a safe alternative to thermal processing. Irradiation may have the more immediate use as a whole fruit surface pasteurization step prior to juicing. As an insect disinfestation process in whole fruit, it is unparalleled.

8.4 Concentration

There are a number of liquid concentration systems applicable to juice (Table 8.4). Open atmosphere concentration of juices has long been practiced; simply boiling off water is at the expense of product quality due to heat damage. The process that has been most responsible for the wide availability, economy and popularity of fruit juices is vacuum concentration. Post war developments in the United States of America dramatically increased the demand for frozen concentrate, primarily citrus (orange and grapefruit), grape, apple and pineapple. Energy efficient multi-effect systems with essence recovery systems are widespread in major juice processing regions globally (Chapters 11 and 12).

The application of vacuum concentration reduces the boiling point of juice and, when combined with short exposure to high evaporation temperatures, reduces heat damage. Process developments led to multiple effect low temperature evaporators operating at a maximum temperature of 50ºC (vacuum of ~ 40 KPascals, depending upon soluble solids). High thermal efficiency is achieved by using the vapour from the first effect as the heating media in the second effect and so on (Figure 8.9). However, enzyme activity required pasteurization at ~90ºC. The thermally accelerated short time evaporation (TASTE) system that combined enzyme activation at around 100ºC for several seconds improved concentrate quality at high throughput (Chen in Nagy, 1993). Essence recovery from vapour from the first effect further advanced concentrate technology and is found in many industrial units (Figure 8.10).

Table 8.4: Juice concentration systems.

Method	Advantages/Limitations
Open pan boiling	Inexpensive, slow, low quality, energy intensive
Vacuum evaporation (multiple effect)	Good quality, energy efficient, costly equipment
Freeze concentration	High quality, slow, costly equipment, limited solids attainable
Reverse osmosis	High quality, slow, costly equipment, limited solids, clear only
Electrodialysis	High quality, slow, costly equipment, limited solids, clear only

Since vacuum concentration strips the natural aroma from the juice, quality suffered. An initial solution with citrus was to over concentrate the juice to about 55ºBrix and add back about 43 percent of fresh, high quality single strength juice to obtain 42ºBrix and provide aroma. Essence recovery and add back was an improved solution. Although in the absence of recovered essence, juice added back is an effective solution.

Water removal as affected by concentration greatly simplifies juice handling, storage and shipping logistics. Some juices can be concentrated to over 70ºBrix, thereby increasing the juice solid up to 10 fold (Crandall, *et al.,* 1981; Fox, 1994). High Brix is limited by viscosity build up due to the presence of pectin substances and insoluble solids or pulp. In the concentrated and frozen or refrigerated form the juice can be held for extended periods, shipped, or stockpiled for future use. Indeed, the global trade in frozen concentrate has profoundly influenced juice and juice beverage developments, since long term stability and ease of transport make concentrates a readily available commodity. Concentrates must be maintained cool, if not frozen to prevent quality loss primarily Maillard browning type reactions affecting colour and flavour. However, shelf stable concentrates (100 percent juice and ~25 percent juice drinks) of about 50ºBrix are found in retail trade under conditions of good inventory control (Figure 8.10).

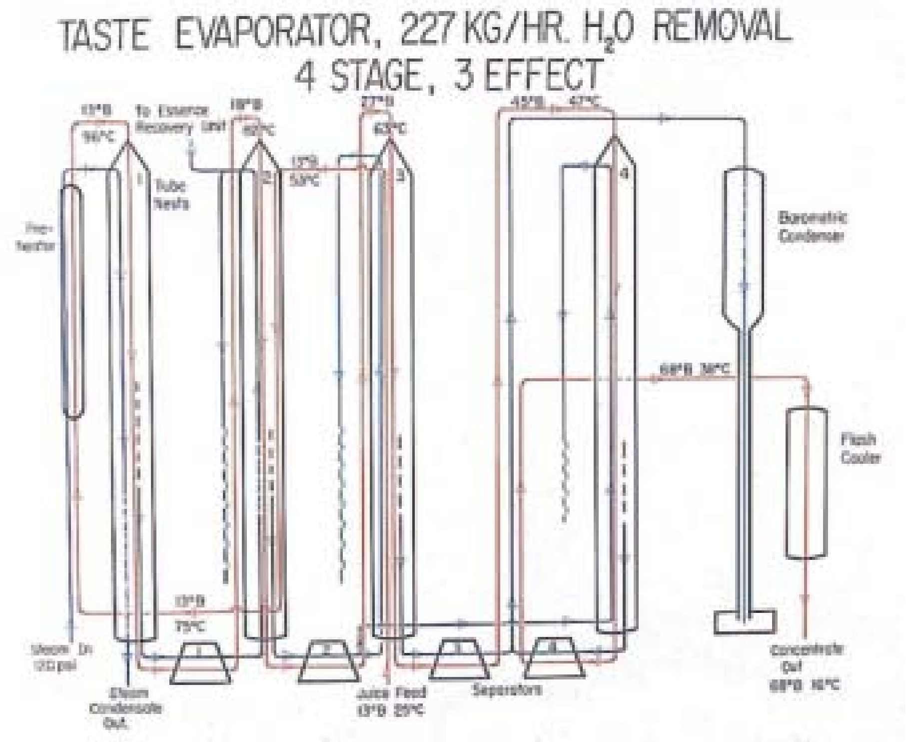


Figure 8.9: Essence recovery system schematic and commercial TASTE evaporator.
Commercial units range to 20kL water/hr.

Figure 8.10: Unfrozen juice concentrates.
Three can volumes of water added for reconstitution.

8.5 Jelly and jam manufacture

A considerable amount of fruit juice, puree, pulps and pieces are devoted to jellies and jams. Standard jelly or jam manufacture requires a minimum of 45 percent by weight fruit juice, pulp or pieces, sufficient pectin to set the gel and acid to reduce the pH to ~3.1. Although traditional jelly making relied on the natural pectin present in fruits, commercially standardized pectin is invariably added in commercial operations. The process is related to concentration, as the juice is partially concentrated and sugar is added to increase the solids level to above 65 percent. Combined with pectin and acid and hot filled, jellies are reasonably shelf stable and, along with the pectin derived from certain fruits can be considered a co-product of juice manufacture (Chapters 11 and 12). As with other concentration methods, the use of vacuum concentration during boil down and rapid filling and cooling, dramatically increases jelly quality. Quality and efficiency considerations now favour vacuum systems in large throughput operations, although open steam kettles suffice in small niche markets. The key to open kettle jelly manufacture is:

- Sanitary processing facility and equipment,
- Trained workers,
- High quality raw material such as fruit, sugar, pectin,
- Rapid, minimum heating to desired ºBrix,
- Immediate hot filling into sanitized jars,
- Rapid cooling to less than 30ºC,
- Low temperature storage, less than 30ºC.

Although the combination of low pH, high solids and hot fill eliminates microbial spoilage, an opened container can be recontaminated by sugar-tolerant mould. Also, high temperatures during preparation or subsequent storage reduced quality. Ultimately Maillard darkening and off flavour development occurred. Very delicate fruits make acceptable jelly, but the flavour is far removed from the fresh or gently processed juice product.

Low calorie jelly is even more difficult to manufacture and store. Low methoxy pectin and calcium salts or other gel systems that are not dependent upon high sugar level provide adequate gel set. However, such systems are more susceptible to post process contamination and require refrigeration after opening.

8.6 Wine

Fruit juice, particularly grape, is closely associated with wine. Indeed, wine was originally spoiled fruit juice that over the millennia was appreciated and perfected long before juices were refined. Actually, the technical and lay literature devoted to wine far exceeds the total treatment of all juices and similar beverages combined. Wine is briefly mentioned here since it represents a high value added product from fruits and also a step in the manufacture of vinegar, a logical by-product of juice manufacture.

Crushed fruit or freshly expressed juice/puree is one step away from wine. The ubiquitous presence of all types of microbes, the sugar and nutrient content of fruits and generally low pH provides an ideal environment for “something” to grow. Airborne, that something will no doubt be mould, with an unsightly mass of mycelia and offensive odours. However, below the surface where oxygen is limited, yeast growth is likely, resulting in the production of ethyl alcohol and carbon dioxide gas. The classic Gay-Lussac equation is an over simplified but stociometrically reasonable depiction of the transformation of fermentable fruit sugars to ethanol and CO_2 (Figure 8.11).

The Gay-Lussac Equation

$$6(CH_2O) \xrightarrow{\text{Yeast, Nutrients, } -O_2} 2(C_2H_5OH) + 2CO_2$$

Fermentable Sugars 180g 100%

Ethanol 92g 51%

88g 49%

+ (~140KCal/Kg) Heat

Figure 8.11: The Gay-Lussac equation.

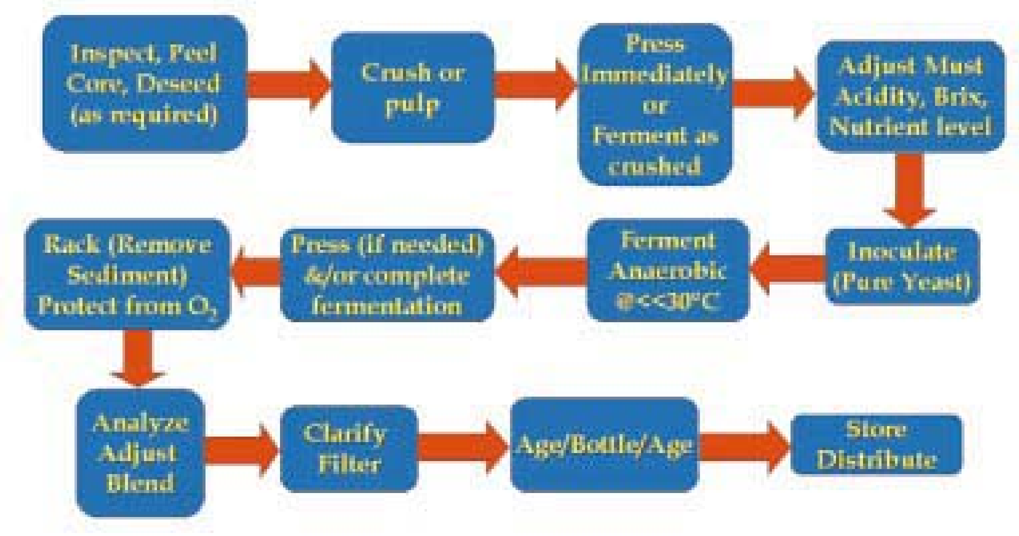


Figure 8.12: Fruit wine flowchart.

Wine manufacture is challenging, relatively straightforward and well treated in classic texts **(**Amerine, *et al.*, 1980; Vine, *et al.*, 1997). Many of the steps inherent in juice production also apply to wine, including selection of fruit and attention to quality and sanitation. Figure 8.12 is a generalized flowchart; important distinctions between juice and wine are noted:

- Fruits do not necessarily have to be peeled, cored, deseeded, pressed, etc., immediately after crushing. Provided that undesirable off flavour/colour substances are not leached out of the crushed fruit, the fermentation can be initiated and allowed to proceed for some time prior to pressing. Light coloured fruits are best pressed soon after crushing and treated with about 100 ppm sulphur dioxide to prevent browning. Even here, clarification is not required until after the fermentation,

- SO_2 also serves to inhibit spurious microbial growth,

- In the case of coloured fruits where pigment extraction into the must (unfermented juice properly adjusted for fermentation) is desired, the initial phase of fermentation serves to extract colour and soften the crushed material (by natural enzyme activity), thus increasing press yield. This is one advantage of wine over juice; by setting the proper conditions and yeast inoculation, fermentation can proceed, thereby preventing microbial spoilage. In addition, the evolving CO_2 serves to exclude oxygen and the alcohol build up further limits competing microbes. The type of yeast is important. Special wine strains selected to resist SO_2 and efficiently product alcohol and desirable flavours are used. Relying upon wild yeast, as was the practice until the research of Pasteur ~1860s, is too unreliable,

- Rarely is the fruit composition ideal for wine. Certain grape cultivars under specific cultivation and climatic conditions are the exception. The crush or must usually requires sugar and/or acidity adjustment with or without added water. As with juice, imbalances in must acid or soluble solids are thereby corrected. A 10 to 13 percent alcohol (by volume, v/v) wine requires about 20 to 23 percent fermentable sugars and a pH of 3 to 4.

The adjustments or amelioration depends upon the specific fruit and wine style,

- In contrast to grape must, many fruits lack the nutrients necessary to sustain yeast growth. Thus yeast nutrients such as yeast extract or diammonium phosphate may be needed up to 0.1 percent. Crushed fruit is apt to have more yeast nutrients than pressed juice, so addition may be unnecessary in the latter,

- A vigorous strain of pure wine yeast at about 0.25 g/l should be added to well aerated must. (Oxygen early in the fermentation promoted yeast growth, later it is detrimental to wine quality.),

- Air exclusion by a fermentation trap serves to prevent contamination and monitor fermentation rate,

- Fermentation temperatures of less than 30ºC, ideally ~15ºC, improve wine quality. Since the fermentation is exothermic, containers larger than 30 L are apt to overheat,

- A completely fermented wine with few fermentable sugars remaining and an alcohol content ~12 percent v/v is much more stable than the initial juice. If protected from contaminants in the environment and air, the wine can be separated from the yeast and pulp containing sediment and held at less than 15ºC for an extended time. Ageing can improve certain wines. Even elevated temperatures greater than 30ºC can improve some dessert wines, if fortified with additional alcohol,

- Regulations dealing with wine and alcoholic beverages are among the most convoluted in existence. Whereas most beverage control relates to matters of food safety and fair trade, alcohol controls also serve to produce considerable tax revenue. In addition, the adverse effects of excessive consumption require special sales and consumption scrutiny. These vary by nation and culture, depending if alcohol is viewed as a curse, source of tax revenue or both,

- There are national standards specifying the amount (if any) of sugar, acid, water permissible. This defines alcohol strength and limits must manipulation more so than with juice beverages, where low juice levels are permissible, if properly labelled,

- Alcohol has some preservative effects by acting as an additional hurdle along with low pH. Stabilization involves the addition of SO_2 and/or sorbic acid. Pasteurization is less common and 60 to 65ºC adequate, depending upon alcohol level,

- The quality of properly made wine when held over time far exceeds juices. The extreme is fine wine, which may be many decades old. Nevertheless, storage at ~13ºC is ideal and most wines, particularly of fruit origin, should be consumed within several years.

- Fruit wines do not share the lofty image of certain fine wine grape cultivars. This is partially due to the several thousand year grape wine tradition, lack of experience with non grape wines and the more difficult manufacturing requirements. Highly acceptable wines can be made from practically all fruits, including exceptional ones in some cases. Indeed, there are some soft fruits from both temperate and tropical regions whose pigment stability and flavour profile match those of any grape wine lacking only intensive research, development and marketing efforts,

- The most common quality defects of fruit wines are excessive sweetness and oxidized flavour and colour. Practice and attention to detail can easily avoid both.

Of course, no food product, including fine aged wine is infinitely stable. Even under ideal storage conditions, deterioration of quality, which is mentioned in Chapter 4, is inevitable. Microbial contamination by lactobacillus can convert malic acid to lactic acid, reducing the acidity and changing the character, sometimes for the better. A more dramatic change is affected by Acetobacter, which can convert wine to vinegar in the presence of air. Fortunately, by excluding oxygen and maintaining low but significant SO_2 levels (~50 ppm), incipient spoilage is easily avoided. In fact, the vinegar fermentation is more difficult to initiate and control than wine making. Both products have their place in adding value to fruits.

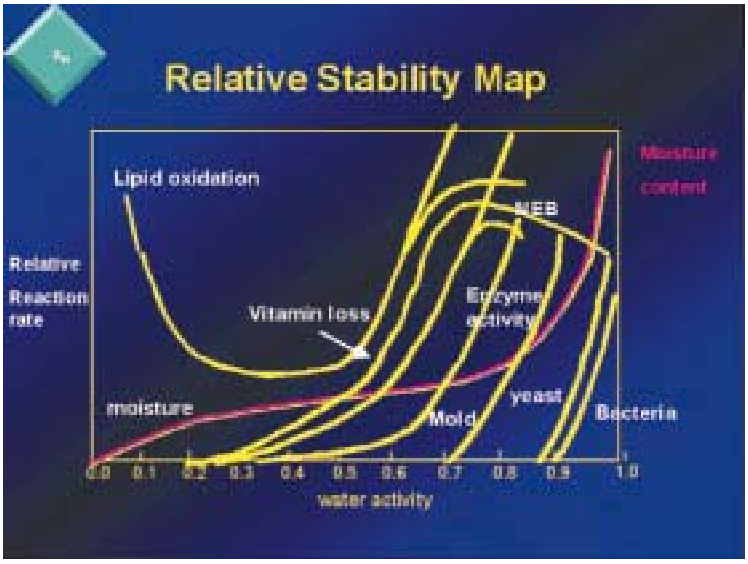


Figure 8.13: Stability diagram.
Courtesy Ted Labuza

8.7 Water removal and water activity

Dehydration and concentration are important juice preservation steps that rely upon the physical state of water in foods. Figure 8.13 is a very useful generalized food stability map. From this diagram the influence of water activity on the various deterioration mechanisms affecting juices is well summarized. Water activity (A_w) is the relative humidity/100 in equilibrium with the food in a close system at a fixed temperature. As seen from the generalized curves:

- Microbial growth occurs only very slowly below 0.7, not at all below 0.6 and no pathogens grow below a water activity of about 0.9,
- Enzymatic activity occurs slowly at low A_w and increases with moisture content,
- Browning (Maillard) reactions require moisture, but in excess water the reactants are diluted,

- Oxidative changes are promoted in the absence of moisture with more reactive sites available for oxygen binding. Additional water molecules protect these sites. At higher moisture levels the above reactions dominate.

For comparative purposes, single strength juices have A_ws around 0.96; 72°Brix concentrates ~ 0.7; and dry, free-flowing juice powders ~ 0.2.

8.8 Dehydration

The next step from concentrated juice is further removal of water to obtain a dry powder of less than 6 percent moisture. In the dry state ambient storage is possible, although low temperature still serves to extend storage life. Water is much easier to remove from fluids that can be pumped and manipulated through heat exchange and vapour removal systems. Mass and heat transfer becomes more of a challenge as the juice loses moisture and fluidity. There are a number of dehydration techniques applicable to juices (Table 8.5). For economic reasons most are based on some degree of juice concentration above single strength, generally as high as practical, given the flow characteristic and mechanical properties of the concentrated juice and design features of the dryer.

Table 8.5: Juice dehydration systems.

Method	Characteristics	Product*
Air	Thin sheets, exposed to air	Fruit rolls or leathers
Foam	Stable foam, porous structure	Powder from foam
Vacuum	Low temperature, may puff	Powder
Spray	Cool dry spray	Powder
Drum	Dries glassy, cool to recover	Powder
Freeze	Gentle conditions, porous structure	High quality powder
Fluidized bed	Analogous to spraying	Powder or aggregate

*All dry products are somewhat hygroscopic; protect from humid conditions.

Fruit juices are not as easy to dry as protein or starch based foods. The high sugar content, consisting primarily of the reducing sugar, glucose and fructose, presents a problem. At low moisture levels the products are quite hygroscopic, readily picking up moisture from the air to become sticky and difficulty to manipulate. Dried fruit products, especially juices must be protected from the atmosphere during and after drying. An ideal drying room is maintained around 10 percent relative humidity. The dry product is then rapidly packed into a hermetically sealed moisture barrier material, either a bulk container or final package.

Juice powder also presents a large surface area and is quite susceptible to oxidation without surface bound water to protect reactive sites (Figure 8.13). Rapid destruction of ascorbic acids and carotenoids occurs, unless oxygen is excluded during packaging. A nitrogen flush may help retain low oxygen conditions in the package, sometimes assisted by an internal oxygen-absorbing sachet or material built into the package inner surface (Section 8.3).

Another difficulty is the sticky point of the dried juices. Even with little remaining moisture at high temperatures (greater than ~ 70ºC), the product will be in a glassy syrupy state and stick to machinery, vastly complicating materials handling. Malto-dextrans or other low dextrose equivalent (DE) corn syrups can reduce the sticky point, but then the juice powder is not pure. Means of overcoming these limitations are described for distinct types of drying. Nevertheless, equipment modifications and more demanding product handling procedures are required to overcome stickiness and the hygroscopic nature of dehydrated juices.

The simplest dry product is fruit leather or fruit rolls, obtained by air drying a thin layer of juice, pulp, or concentrate on a flat surface **(**Figure 8.14**)**. Gentle low temperature drying in a pan yields a plastic, sticky sheet about 1 to 3 mm thick of the original product containing less than 15 percent moisture. Depending upon the sugar profile, temperature and ambient humidity, the leather will range from slightly to moderately sticky to the touch. Sucrose, low dextrose equivalent (DE) corn syrup or other humectants (glycerol and other sugar alcohols) can be added to reduce the hygroscopic nature. Increasing pulp content provides chewiness to the roll. Ideal moisture content is around 12 percent; over 18 percent the sheet can support mould growth and below about 10 percent the sheet is too brittle.

Figure 8.14 Fruit leather from juice puree.

8.9 Vacuum drying

As in evaporation processes, the juices can be dehydrated under vacuum to reduce drying temperature and enhance quality. Continuous and batch systems are in operation. For economy and quality reasons, the juice is usually concentrated prior to vacuum drying. If the consistency is thick enough the concentrate can be puffed by applying rapid vacuum and maintained in this state to produce a puff-dried solid. The puffing produces an expanded surface area that facilitates moisture diffusion.

Foam mat drying accomplishes the same effect without vacuum (Abd-Karim and Chee-Wai, 1999). A foaming agent is added to the concentrate with whipping to produce heat stable foam. Gentle air-drying results in dry foam. A continuous system applying a foam mat and blowing holes in the mat prior to drying has been developed. The puff or foam mat dried material is then ground to a readily reconstitutable powder. Foam drying has the advantage of using simple air drying, but the disadvantage of producing a large volume of foam to obtain a relatively small amount of dried juice powder, requiring protection from ambient humidity.

The more efficient high throughput air dehydration techniques such as spray drying and drum drying are marginally applicable to juices. Aside from adding malto-dextrans, a spray-drying pattern must be designed so that the juice spray dries and is cooled below the sticky point before the particle hits the dryer wall and enter the collection system. A circuitous flow pattern and the introduction of a cooling zone accomplish this. The cool, dry particles do not stick but flow and are packaged as a powder.

Another system employs a high tower in which spray dried material at the top has sufficient time to drift downward and cool before hitting a surface. Drum drying employing a hot roll rotating in the fluid or fed from between rollers. The film adhering to the roller surface is rapidly dried as it rotates out of the feed tank. Although the dried juice is in the glassy, sticky state, cooling and grinding under low humidity produces a juice powder. Vacuum drum drying in which the dryer in enclosed in a vacuum chamber can reduce heat exposure and affect a puffing of the juice on the drum.

The gentlest and most expensive dehydration method is freeze-drying. The juice or concentrate (at about 50 ºBrix, the highest practical to maintain the frozen state) is applied to the belt, the vacuum puffs the juice slightly and it is then frozen and subjected to a vacuum well below the triple point of water, 4.6mm. Heat, applied by conduction from the shelf, infra-red radiation, or even microwave results in sublimation of the water in the frozen juice to vapour which refreezes on a condenser coil in the dryer. Since the juice never thaws, it dries as a porous sheet with minimal exposure to high temperature (Figure 8.15a. and 15b.). If the vacuum is replaced by nitrogen gas and the dried juice layer is ground, transferred and packed hermetically under low humidity and oxygen pressure, optimum quality results.

Foods for astronauts (space food rations, including juices) are often freeze dried to reduce precious weight and volume. The freeze-dried juice is compressed to reduce volume and packaged under inert atmosphere in a pouch that is oxygen and moisture impermeable and designed to facilitate rehydration. The juice is rehydrated by injecting into the pouch water generated from the fuel cell reaction of hydrogen and oxygen, so the water “paid its way” into space (Figure 8.16). Freeze-dried juices are extremely expensive, since water removal costs exceeds US$2/Kg of water removed. The process is quite functional for military, space and backpacking applications where saving weight and space is so critical. With adequate protection from high temperatures, moisture and oxygen reconstituted juice quality is high and a shelf life of several years or more can be accomplished.

a.

b.

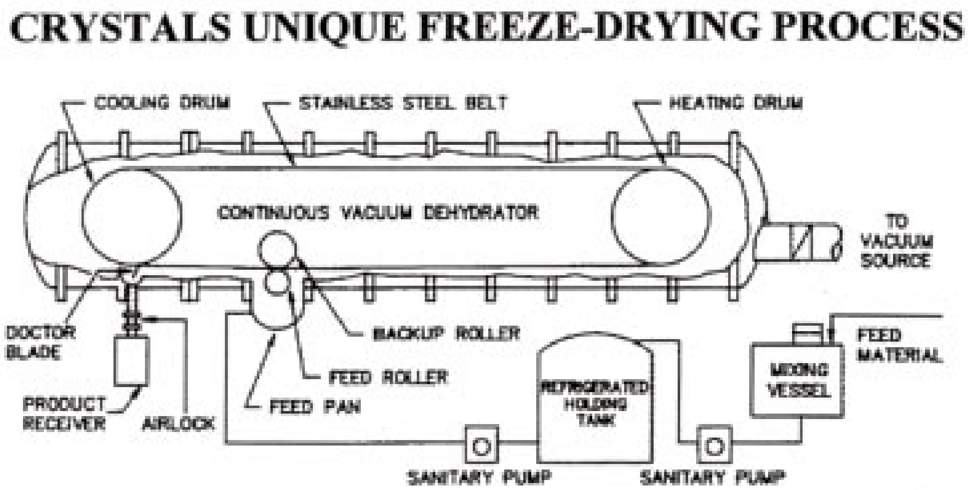


Figure 8.15a and b: Continuous freeze-dryer and flowchart.
Courtesy Crystals International Inc. Plant City, Florida, USA

Figure 8.16: Freeze-dried space foods.
Dehydrated juice in dispensers, lower left and bottom.

8.10 Juice packaging systems

Ever since early humans gathered semi-solid or liquid provisions, the problem of transporting and storing fluids has needed to be addressed. In clever adaptations to environmentally available materials the problem has been solved, first with animal skins/entrails and tightly woven or shaped/carved plant matter, then by industrial manufacture, i.e. pottery, glass, metal (Figure 1.1). Table 8.6 indicates the evolution and characteristics of some juice packaging materials and Table 8.7 the important functions provided.

Parallel with the development of juice processing systems has been accompanying advances in packaging technology. The 3 piece can and glass-canning jar can be replaced in some applications with 2 piece aluminium cans, light weigh shock resistant glass, plastic and laminate materials. All facilitate greater efficiencies such as rapid throughput, product protection, lower cost and consumer convenience. Table 8.8 lists some juice packaging alternatives.

Table 8.6: Juice packaging alternatives.

Material	Characteristics	Limitations
Animal/Plant	Readily available, inexpensive	Short term storage
Pottery - glazed	Local, fairly durable	Sealing difficult
Glass	Impermeable, inert	Brittle, heavy
Metal	Impermeable, rugged	Juice acids corrode
Plastic	Durable, inexpensive	Permeable, heat sensitive
Paperboard laminate	Inert, inexpensive	Heat sensitive, flimsy
Plastic laminate	Inert, impermeable	Costly, flimsy

Table 8.7: The role of food packaging.

Function	Rationale
Protect contents	Reduce mechanical damage and chemical deterioration
Optimize safety and quality	Prevent post process contamination
Extend shelf life	Sealed environment excludes spoilage vectors
Facilitates handling Convenience of use and reuse	Easy to transport and store, open and reseal (Producer, distributor, retailer and consumer)
Provide information (Label and UPC)	Legally required label and use data (Consumer) Product tracking, inventory and sales data (Manufacturer)
Marketing Tool	Promote contents and brand identification

Table 8.8: Juice packaging options.

Container	Comments
Glass	Traditional, inert, visible
Tin Can	Rugged, reasonably inert
Paperboard/plastic laminate	Refrigerated storage, easily resealed
PET	Rugged, reasonably inert, visible
Plastic/metal laminate pouch	Aseptic, inert, light weight
Bulk – plastic, metal	Shipping and long term storage
Paperboard/foil/plastic laminate	Aseptic, inert, light weight

The impermeable and inert nature of glass, combined with transparency makes it the package of choice for sales appeal and upper price beverage packaging **(**Brody and Lord, 2000**)**. Although brittle and relatively heavy, glass containers have visual appeal and reuse potential. Technical innovation has greatly reduced wall thickness, weight and thermal shock susceptibility. Nevertheless, hot filled or processed glass must be carefully cooled to prevent shattering. Brown and green tints limit light sensitive reactions in the product. However, the visual quality of some juices dictates a clear wall, at the expense of light-induced deterioration for shelf stable, pasteurized products.

These same pasteurized juices are found in metal cans. Initially tin plated steel with or without enamel linings was used. In some cases the tin contributed an expected flavour, otherwise, the enamel protected the tin from contacting the juice. Enamels consisting of vinyls and epoxies protected the tin or tin free steel inner surface. Enamel-lined aluminium cans, due to lightweight and ease of manufacture, are replacing tin coatings. Despite rugged enamels, some juices blends and products containing nitrates or SO_2 are highly corrosive, so care must be taken to establish liner/product compatibility under realistic storage conditions. Three-piece tin plate cans from 200 to 1 300 ml are still in use for juices, but increasingly, PET (polyethylene terephalate polyester) bottles predominate in retail markets **(**Figure 8.17**)**. There is currently rough price parity between glass and PET container. Energy costs are higher for glass and raw materials costs more for plastic, although PET has an edge for larger containers. Moreover, recent technological innovations, such as the incorporation of acetylene gas into PET and polyethylene naphthalate (PEN) or PEN-PET blend and copolymers promise enhanced barrier properties, light protection and printability **(**C and E News, 2000**)**.

Figure 8.17: Aisle of "New Age" juice beverage containers.

For processes where the container is not subjected to pasteurizing temperatures, 80 to 95ºC, light weight, durable plastic/paperboard/metal foil laminates are common. Aseptic processing lines literally surround a pasteurized and cooled juice stream with a sterile package and seal the juice in segments of tetrahedral or rectangular shape **(**Figure 8.18, Tetra Pak, 2000**)**. Sterile filtered juice can be handled similarly. Aseptic cartons consist of about 70 percent paper, providing strength and form; 25 percent low density polyethylene, for sealing and moisture barrier; and 5 percent aluminium foil, as the light and oxygen barrier. Container roll stock is sterilized during the forming step by hot hydrogen peroxide **(**Taylor, 1999). Retail packs of 250 ml include a plastic straw and orifice space for puncturing by the straw's point **(**Figure 8.19**)**. (This latter feature is unpopular with parents and school officials, since a full container with straw inserted makes an instant squirt gun for children.) Easy open features are employed in all sizes from 150 ml to multi-litre containers.

Since there are plastic containers capable of withstanding pasteurization temperatures available, hot fill or post fill pasteurization is now common. However, in regions where such technology is impractical, juices are filled into all types of inexpensive plastics, including unpasteurized fresh juice, juice beverages and imitations in polyethylene bags for immediate consumption. When dosed with high levels of benzoates shelf life is extended at the expense of content quality.

Figure 8.18: Juice packaging retail options.
Courtesy Tetra Pak. (Tetra Pak, 2000)

Figure 8.19: Retail aseptic juice packs.

Several characteristics of increasing importance for all packaging material are:

- Ease of recycling - Glass, metal and some plastics have this feature. Indeed, some governments impose a recycling tax on packaging, reflecting the disposal cost of the residual material. Thus some laminates and composites are placed at a disadvantage; durability in service extends to the landfill. Of course, in less industrialized regions used, durable bulk and retail juice containers are held in high regard and find many domestic and industrial uses,

- Uniformity of bulk packaging – In the handling of pallets from shipping to retail the size and shape of over wraps is critical. Some shippers and retailers now demand standardization (moving toward uniform metric dimensions in the United States of America). This facilitates mixed pallet loads, loading and unloading of cartons and display case set up.

8.10.1 Storage requirements

In juices treated by any of the fore mentioned processes that destroy, remove, or inhibit microbes, there is still the potential for deterioration. This can take the form of intrinsic spoilage due to juice constituents or extrinsic induced by the environment. If residual enzyme activity remains (unpasteurized, sterile filtered or preservative treated), colour, flavour and consistency changes can occur.

Extrinsic changes can be minimized, if not prevented by proper packaging. Juice protected from oxygen, heavy metals and light is quite stable, except from the most unavoidable deterioration, a combination of the intrinsic such as juice chemistry, the Maillard reaction and the extrinsic such as elevated storage temperature. Sugar-amine browning accompanied by other degradations occurs slowly at ambient temperatures (20 to 25ºC) but rapidly above ~30ºC. In warm climates or under exposure to improper storage conditions, juices deteriorate within a few days. A closed truck sitting in the sun easily reaches 50ºC, to the detriment of any food material inside.

8.10.2 Active packaging

The incorporation of oxygen absorbing, metal chelating, or antimicrobial agents as an insert or built into the packaging material is an effective strategy (Rooney, 1995; Vermeiren, *et al.*, 1999; Brody, *et al.*, 2001). Although of greatest value in respiring fresh produce, employing "active packaging" can protect food and minimize or retard inevitable deteriorations; another example of the hurdle principle in action.

8.10.3 <u>Product identification</u>

One important role of packaging is to provide information (Table 8.7). Traditionally a label was required for the consumer, but the manufacturer and all others in the distribution chain, including retail sales need now identifying data. The introduction of the Universal Product Code (UPC), those small bar code strips **(**Figure 8.20) affixed to most retail (and many wholesale) items from food to machine screws and laser scanned at checkout counters, has revolutionized marketing.

Figure 8.20: Beverage labels and bar codes for laser scanning.

Along with price identification, UPC provided almost instantaneous information on sales location and volume, inventory and details relating to promotion, pricing and competitive products. The next generation promises even more information-rich devices and ease of use. Smart Packaging (e-PC) employs a packaging tag either emitting a radio frequency or having an electromagnetic charge for remote sensing, with orders of magnitude more information storage capacity of value to all in the juice distribution chain from fruit grower to juice consumer and even beyond to the package recycler.

8.10.4 <u>Bulk storage</u>

Juice manufacture and utilization logistics dictate that vast quantities of juices must often be seasonally held and/or transported long distances. The product must be completely stabilized for such handling. In the case of single strength or low Brix concentrates capable of tolerating thermal processing, aseptic processing is one alternative. Under aseptic high temperature-short time (HTST) processing conditions heat damage is minimum. Provided that the system down stream from the pasteurizer is sterile, including cooler, filler and container, many hundreds to thousands of litres can be processed, transported and held effectively (Figures 8.6, 8.19 and 8.21).

Figure 8.21: Citrus tanker and tank farm.
The ultimate bulk packages.

Under reasonable sanitary conditions, for instance low microbial load, juices can be maintained at low temperature in a carbon dioxide atmosphere (Konja and Lovric, *Nagy, et al.*, 1993). High CO_2 pressure is more effective, but required reinforced storage tanks.

For more delicate products, single strength juice can be frozen practically unchanged, except for the expense and efforts required to freeze, store and eventually thaw large volumes of juice. Deaeration and rapid handling minimize enzymatic deterioration. (Although careful freezing, holding and thawing essentially maintain fresh juice character, it cannot be labelled “fresh” but can be “not from concentrate”.) Frozen concentrate at 68 to 72 ºBrix held at less than -20ºC is widely practiced. The product can be warmed slightly for pumping and has a lengthy storage life. Freezing and storage requirements are proportionately less than for single strength or low Brix concentrates. Since bulk storage at cool temperature is costly, inventory control and utilization scheduling are important to minimize holding time. However, bulk storage can be a useful hedge against crop shortages and/or fruit price fluctuations (Figure 8.21).

CHAPTER 9

JUICE AND BEVERAGE BLENDS

9.1 Rationale

Despite the strong appeal and tradition that many pure fruit juices have, there are logical reason for producing single fruit and mixed pure juice blends and juice products containing less than 100 percent juice. These are:

- Maintaining a single juice's uniformity within and between seasons by blending multiple cultivars to insure a consistent product,
- Blending of different juices to overcome the high cost of some juices (exotic fruits),
- Overcoming scarcity and/or seasonal availability of certain juice components,
- Balancing out excessively strong flavours, primarily high acidity, astringency, or bitterness,
- Correcting low soluble solids level,
- Balancing juices with weak or bland flavour, but possessing other positive attributes,
- Improving poor colour or colour stability, of otherwise desirable juices attributes,
- Balancing extremely good, stable colour, with other positive attributes,
- Emphasizing unique nutritional or phytochemical properties,
- Overcoming undesirable single strength juice consistency.

Blending offers the opportunity to adjust sugar/acid ratios and compensate for other imbalances in juice from a single harvest or cultivar, since many factors influence the composition and quality of juice (Table 3.1). These differences can be dramatic and complicate the task of a manufacturer committed to a uniform product with established standards. Fortunately, by blending several batches of juice with complementary compositions a uniform, standard juice is practical. Adjusting 100 percent juices is much more of a challenge than manipulating acid and sugar in juice beverage blends.

In a similar sense defects in many juice quality or nutritional attributes can be overcome by proper combination of juices. Further adjustments call for additional ingredients. Extremely acidic and/or strong flavoured juices completely mask more subtle juices. In which case, non-juice sweeteners can greatly extend the juice, although labelling regulations must be precisely followed.

9.1.1 <u>Blending strategies</u>

One of the primary considerations in choosing individual components and preparing juice blends is ºBrix/Acid ratio (°B/A). Depending upon the juices involved this ratio determines the sugar acid balance and influences the perception of each. For example, a 10 percent solution of sucrose is moderately sweet. Adding 1 percent citric acid for a °Brix/A of

10 produces an intensely sour sensation. This solution requires a few percent more sugar before the sensation of sweetness is once again dominant. Certainly, juices are much more complex but °Brix/A remains an important factor.

The °Brix/A of some common juices are listed in Table 9.1 It should be emphasized that these figures are quite general, since there are wide ranges among a single species. Even at optimum maturity, ºBrix and acid can vary appreciably. Recent cultivar selection and breeding efforts have decreased acid levels and increased solids (sugars) in some fruits to facilitate fresh eating and juicing. In addition, there are consumer preferences to consider. Orange juice at a °Brix/A of 12 is standard in North America, while in the tropics 15 or more is deemed acceptable. Although a given °Brix/A can be obtained by modifying either Brix or acid (or both) juice blends or beverages with less than about 7ºBrix are deemed weak and watery. Those containing more than ~1.2 percent acid are sour, independent of °Brix/A.

Table 9.1: ºBrix/Acid ratios of some common fruit juices.

Fruit	ºBrix/Acid	Remarks
Orange	10-14	~12 ideal
Grapefruit	8-12	Often sweetened to ~14
Lemon	3-6	Sweetened and diluted
Apple	10-18	~15 ideal
Banana puree	40-60	Acidified or blended
Cranberry	4-6	Sweetened and blended
Blackberry	8-12	~12 ideal
Guava	5-12	~15 ideal
Grape	18-30	~21 ideal
Mango	30-50	Often acidified
Papaya	40-70	Often acidified
Passion fruit	8-15	Sweetened and diluted
Pineapple	10-16	~16 ideal
Strawberry	7-10	Often sweetened to ~12
Watermelon	10-20	~12 ideal

Added sweetener may include cane or beet sugar (sucrose), high dextrose equivalent corn syrup, or high fructose corn syrup. The syrups have a cost advantage over sugar in the United States of America. Non or low caloric sweeteners also have a place in juice blending. In this case the °Brix/A is inappropriate and the perceived sweetness must be balanced by trial and error, since the artificial sweeteners contribute little soluble solids and have varying characteristics depending upon the juice mix.

An additional concern is the organic acid used to adjust the °Brix/A. Normally the predominant acid naturally present is the best choice, i.e. citric for citrus, malic for apples, tartaric and/or malic for grape. Acetic and lactic which are characteristically associated with fermented vegetable products are rarely used exclusively, although the former along with minor acids such as adipic, succinic, shikimik may contribute to an acid blend.

At one time inexpensive bulk juices were deacidified by ion exchange with the colour and flavour removed by activated charcoal. The treated juices were concentrated (removing any surviving aroma) and added simply as sweetener, proclaiming the product as pure 100 percent juice. However, since the treatment essentially removed all original juice character, such material now cannot be labelled as juice, only as natural fruit sugars. These are suitable in "all natural" blends. An ion exchanged "reduced acid" orange juice has recently been introduced to the US market and bears the label '100 percent juice'.

Aside from adjusting flavour, colour, viscosity defects and correcting juice composition, blending can employ juice as the vehicle for delivery of important nutrients and phytochemicals. Pure juices or blends are routinely fortified with vitamin C and more recently calcium. In view of nutrition surveys indicating low calcium levels in the US diet, there has been a proliferation of calcium addition to foods and beverages (Figure 9.1). (Whether this trend will be followed by an increase in hypercalcification health problems in the populace remains to be seen.)

Figure 9.1: Calcium fortified chilled orange juice.

In Japan foods for special health use (FOSHU) are an established category and the 1994 United States Dietary Supplement Health and Education Act (DSHEA) opened the door to dietary supplements (Office of Dietary Supplements, 2000). Juices and juice beverages are ideal and popular carriers for both recognized and fringe supplements. In fact, many natural components of juice are now recognized as having phytochemical value and are aggressively promoted in their own right.

Blending procedures require careful economic considerations. Depending upon year, location, weather and other factors, juice prices (usually valued as concentrate) can vary by a factor of 2 to 3 over a season. The more desirable and relatively scarce juices such as cranberry, raspberry, blueberry and lesser-known tropicals always have a high price, sometimes up to 100 times more than common juices. Bulk concentrate supplies of generic apple, pear, grape, orange and pineapples are usually readily available in the global market and relatively inexpensive (although premium cultivars demand higher prices). Such juices can serve as a logical blending base for other juices and added ingredients, for example sweeteners, acids, nutrients, preservatives, flavours, colours, etc. It is then up to the juice technologist to creatively blend in more costly juices to achieve the required quality and image. The regulatory aspects are quite important, since all ingredients must be properly identified on the label, along with the total juice percent quantified on a single strength basis (Table 2.2, Figure 2.1). Additionally, there is legislative pressure in some industrialized countries with strong domestic agricultural interests to demand "country of origin" labelling of fresh produce and ingredients, including juice.

The economic incentives for blending are persuasive and require careful label reading as well as understanding by the consumer. This is not easy, since juice percentage declarations are inconspicuously printed, compared to promotional material (Figure 9.2). There is no question when a beverage is 100 percent juice as that fact is conspicuously displayed on the label **(**Figure 2.1**)**. Also, a beverage can have juice as the first ingredient (present in greatest amount) on a single strength basis and still not be the major ingredient on a solids basis. High fructose corn syrup or other added sugars are reported on a concentrated syrup or dry weight basis, thus representing considerably more solids than the juice. Even orange juice with 5 percent sugar added (a common practice in some countries) is actually diluted ~30 percent on a solids basis (12ºBrix from juice and 5ºBrix from sugar).

Figure 9.2: Chilled juice beverage label.

An average supermarket carries several dozen juices and juice beverages in many sizes, shapes and forms including frozen, refrigerated, shelf stable single strength, concentrate and dried powder (Figures 1.2, 8.2, 8.18 and 17.5**)**. Items range from 100 percent juice to completely artificial, perhaps with some added natural flavourings and colours. The price, single strength equivalent, can vary over 5 fold. Not surprisingly, “100 percent Natural” or “100 percent+” (of specified nutrients) on the label can contain little, if any juice.

Nevertheless, there is a certain health and image aura about 100 percent juice products that can be maintained and encouraged by judicious blending of complementary juices and accompanying marketing skills. “Natural” is an effective sales tool, even when the juice technologist can and does improve upon Nature.

CHAPTER 10

COMPLEMENTARY PRODUCTS AND BY-PRODUCTS

10.1 Trends

A commendable trend in fruit processing has been the increased attention to waste reduction, resource conservation and by-product utilization. Driven by environmental regulations, economic incentives and the cost of energy and waste disposal, all food producers must now pay more attention to by-products. Moreover, many juicing operations evolved from the need to dispose of materials generated during fresh market and solid pack fruit processing accompanied by the realization that fruit residuals had juice potential.

In addition, the current emphasis on “natural” products is having a profound effect on the demand for fruit ingredients. Although often more costly, difficult to isolate and less functional (in stability, potency and activity), natural ingredients have a much greater market appeal than commonly used (functional and safe) synthetic analogs that are now considered “artificial” and “unnatural”.

10.1.1 Pectin

Citrus, apple and a number of other fruits have sufficient pectin to merit recovery from the by-products of juicing operations. Section 11.3 and 12 deal with pectin recovery while Section 12.8 addresses pectin utilization. In view of the wide occurrence of pectin in fruits, it is unfortunate that small-scale, economically feasible means of extracting pectinaceous materials from local citrus and other crops have not been developed.

10.1.2 Essential oils and essences

The taste and aroma appeal of most fruits is readily obtained in concentrated form by various extraction and/or distillation techniques from peel, flesh, juice, concentrate or combinations. The classic example is citrus **(**Section 11.3**)**.

10.1.3 Pigments

The natural pigments in fruits are also in demand and highly pigmented fruit cultivars are the focus of breeding efforts. Table 10.1 lists some of the more common pigments of fruits. Natural pigments are far less stable than synthetic colourants. Anthocyanin colour is highly pH-dependent as some range from bright red, pH less than 3.0 to green at pH greater than 5.0. Carotenoids are susceptible to oxidation, particularly in dry juice powders.

Table 10.1: Natural colours

Courtesy Overseal Colour Inc.

Colour Selection Guide

Colour	Pigment	Source	CFR	Light	Heat	Comments
Yellow	Curcumin	Turmeric	73.615	Poor	Good	√ Curcumin is the yellow pigment in the Turmeric spice √ Formulations are available giving bright lemon yellow shades, ***mi***Chroma® suspensions with enhanced light stability are also available in water & oil
Yellow to Orange	Natural Mixed Carotenes	Algal	73.95	Good	Good	√ A naturally oil soluble pigment although sensitive to oxidation. √ Water dispersible ***Em-Seal®*** emulsions are available with enhanced oxidative stability, which provide golden yellow to orange shades depending on inclusion level.
Orange	Norbixin/ Bixin	Annatto	73.30	Fairly Good	Good	√ Bixin is oil soluble, Norbixin is water soluble. √ Oil and water dispersible products are available giving orange shades. In low pH applications an
Orange	Capsanthin/ Capsorubin	Paprika	73.345	Fairly Good	Good	√ Paprika is a natural oil soluble extract. √ Oil and ***Em-Seal®*** water dispersible products are available offering orange shades in application.
Orange/ Red	Carminic Acid/ Carmine	Cochineal	73.100	Excellent	Excellent	√ Carminic Acid is a water soluble extract with excellent stability exhibiting orange to red colours. √ Carmine is an insoluble lake. Water dispersible forms are available giving pink/red shades. May
Pink/ Red	Anthocyanin	Grapeskin	73.170	Good	Good	√ Water soluble pigments exhibiting red shades in acidic conditions, Where they are most stable, becoming bluer as pH increases.
Pink/	Anthocyanin	Red Fruits	73.250	Good	Good	√ Water soluble extract from red fruits such as elderberries, blackcurrants, cherries and blueberries.
Pink/	Betanin	Beetroot	73.260	Poor	Poor	√ Water soluble pigments which give pink/red shades. Has limited heat stability so is most suited to
Pink/ Red	Anthocyanin	*Caratho®* Black Carrots	73.260	Excellent	Excellent	√ Water soluble extract from black carrots. √ Exhibits strawberry red shades at low pH values and mauve/purple shades in neutral applications.
Pink/ Red	Anthocyanin	*Magents™* Red Cabbage	73.260	Excellent	Excellent	√ Water soluble extract from red cabbage. Declared as vegetable juice colour. √ Exhibits pink/raspberry shades at low pH values and mauve/purple shades in neutral applications.
Brown	Melanoidin	Sugar	73.85	Good	Good	√ Water soluble pigments giving golden brown shades in application.
White	Titanium Dioxide	Anatase	73.575	Excellent	Excellent	√ ***mi***Chroma® white formulations are available as a pure free flowing powder and water dispersible suspensions. √ Can be used to add whiteness and brightness to a range of applications as well as creaminess to

The matrix gives an overview of the natural permitted pigments available. Formulations are available in liquid and powder form, both oil and water dispersible. Various strengths and customized blends of pigments are also available for specific colour shade or application.

10.2 Phytochemicals

The last decade has seen an amazing paradigm shift during which the potential health value of food components, beyond common nutrients is emphasized (Section 3.2). These substances, termed nutraceuticals in plant foods and phytochemicals, are the focus of a whole new industry (Table 3.3). Fortuitously, fruits and fruit juices play a major role both as dietary sources and carriers of nutraceuticals. Actually, the field is in its infancy. Probably a number of hitherto unrecognized valuable substances could very well be discovered in juices and fruit extracts.

Without a doubt, the reverse applies for potentially dangerous substances, excess amounts of beneficial components or hazardous interactions are likewise possible, even probable. Nevertheless, increased research on the health value of juices promises to enhance the appeal and value of traditional and exotic juice products plus by-products.

Fruit by-products have long had economic value (Table 10.2). Improved recovery technology, recognition of valuable components combined with stringent disposal regulations (and cost) provides the economic incentive to make a valuable resource from waste. In this regard, comparatively unknown tropical plants have an intriguing future, hopefully exploited by and in the countries of origin.

Table 10.2: By-product utilization.

Fruit By-product	Use
Peels	Pectin, flavours, essences
Cores	Animal feed
Culls	Natural colours and flavours
Seeds	Oil, animal feed, fuel
Pulp	Confectionery products
Wash water	Irrigation
Solid waste	Fertilizer, fuel
All plant parts	Enzymes, phytochemicals
Evaporated volatiles	Essence
Rejects (all)	Fuel, feed, fertilizer

PART 2 SPECIFIC JUICE PRODUCTS

INTRODUCTION

Topics mentioned in the previous chapters have applied primarily to basic principles. We will now turn to specific juice manufacture procedures, starting with the major, commercially important crops. The scale of operation can be enormous, yet an insight into such procedures is of significance to even small cottage industry if only as examples of good manufacturing practices (GMPs) and sanitary/quality norms. Large scale production also offers a reminder of the intensely competitive nature of the international juice business. A large, modern citrus plant can process a million tonnes (~10^9 kg) of fruit annually. This is over 1 percent of the total 1999 world orange production and consists of ~ 50 000 trailer loads, each containing over 18 000 kg of fruit. On the contrary, one trailer load would be a season's challenge for a small, village scale processor.

There are opportunities at both extremes, although logistics and markets favour juice operations somewhere in between. The wine industry is a relevant example. While the majority of grape wine worldwide is produced in large (greater than 10^6 L/yr) wineries, often in multiple facilities, there are small vintage wineries (less than 10^5 L/yr production) with outstanding reputations and comparable consumer demand at premium prices. The "romance of the vine" may not extend to juices. Still, niche markets exist and can be developed and maintained, in the face of global competition.

CHAPTER 11

PRACTICAL ASPECTS OF CITRUS JUICE PROCESSING

11.1 What is citrus and where is it grown?

Figure 11.1: Colonial Florida orange planting.

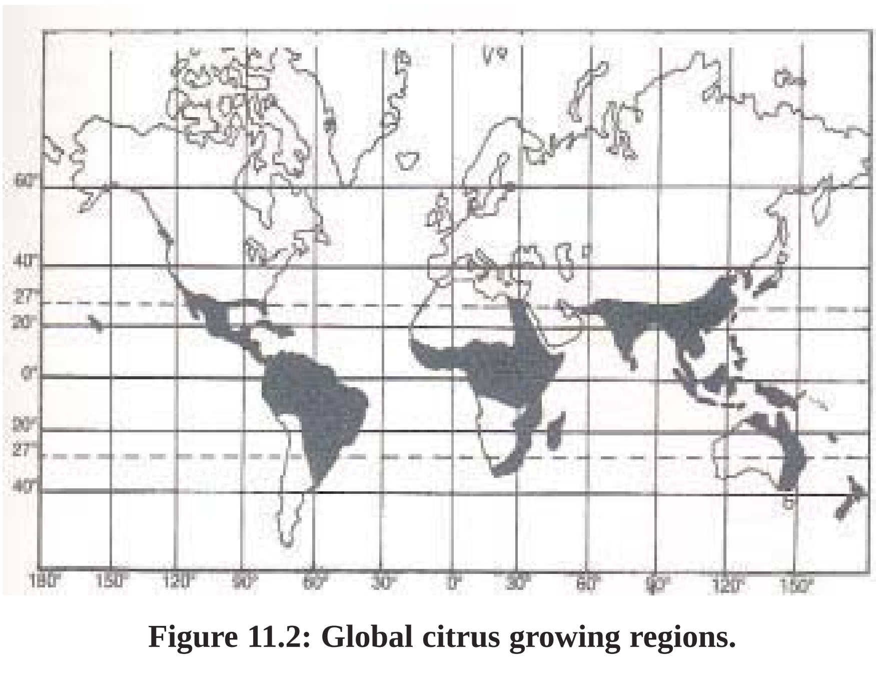


Figure 11.2: Global citrus growing regions.

Citrus is the largest fruit crop in the world with about 60 000 000 MT (1 MT = 1 000kg) grown, slightly exceeding grape production (FAO, 1999). Citrus is grown in two belts on both sides of the equator from about 20 to 40 degrees of latitude (Figure 11.2**)**. All citrus is thought to originate in the Himalayan region of southwestern China and northern India. Columbus brought citrus seeds to the western hemisphere in 1493 and planted them first on the island of Hispaniola, now called Haiti (Figure 11.1). Citrus became commercialized in the Americas in the late 1800s. In the early to mid 1900s the principal producing states were Florida, Texas and California in the United States **(**Figure 11.3). Following a devastating freeze in Florida in 1962, a group of Florida businessmen began to establish citrus groves and later a processing industry around Sao Paulo, Brazil. This industry grew rapidly and after being sold to the Brazilians, it soon surpassed Florida in production by the mid-1980s. Brazil has become the dominant market leader in citrus concentrate. Orange production far outstrips the production of all other citrus (see Table 11.1). Brazil leads the world's orange production with 19 million MT in 1996 to 97. Argentina produces about one-fourth of the world's lemons at 800 000 MT.

Figure 11.3: Citrus grove, Central Florida.

Table 11.1: Citrus fruit production in specific countries (1 000 metric tonnes).

Orange	**1994-95**	**1995-96**	**1996-97**	**Grapefruit**	**1994-95**	**1995-96**	**1996-97**
Brazil	16 520	16 450	19 054	USA	2 642	2 502	2 620
USA	10 641	10 747	11 734	Israel	415	395	405
Mexico	3 500	2 600	3 500	Cuba	230	250	230
Spain	2 644	2 440	2 145	Mexico	136	120	230
China	1 633	1 725	1 850	Argentina	208	190	200
World*	53 904	57 244	59 558	World*	4 694	5 116	5 004
Lemon	**1994-95**	**1995-96**	**1996-97**	**Tangerine**	**1994-95**	**1995-96**	**1996-97**
Argentina	741	700	800	China	4 423	4 667	5 730
USA	831	896	779	Japan	1 539	1 696	1 428
Italy	565	680	714	Spain	1 751	1 566	1 420
Spain	571	443	448	Brazil	560	535	590
Turkey	470	440	380	USA	378	412	540
World**	3 586	3 571	3 550	World*	14 595	15 676	15 954

FAO Production Yearbook, 1999, ** USDA, 2000D

Citrus is botanically a large family whose dominant members are the sweet orange (*Citrus sinensis)*, mandarin or tangerine orange (*Citrus reticulata)*, grapefruit (*Citrus paradisi)*, lemon (*Citrus limon)* and lime (*Citrus aurantifolia)*. Because most citrus are propagated vegetatively by bud wood cuttings, all the millions of trees around the world that are called "Valencia orange" are in fact clones, essentially the same plant genetically. The benefits of this vegetative propagation are that all of the trees of a single cultivar in a grove are genetically identical and will react in the same way to their environment. Their fruit will become ripe and can be harvested at the same time, the oil and speciality products will be of similar composition and juice processors can schedule the timing of the harvest to keep their plants operating at full capacity. Citrus fruit typically store well on the tree. On the other hand, these genetically identical trees are very susceptible to the same diseases and physiological disorders. Nevertheless, all commercial groves that are being established are vegetatively propagated to produce uniform high quality fruit.

In commercial citrus nurseries the bud wood, called the scion, is the top portion of the new tree that controls the type of fruit (Figure 11.4). The scion is grafted on a different rootstock than the bud wood used for the scion. Valencia bud wood could be grafted on to different rootstocks where the rootstocks were known to impart disease resistance or drought resistance. For example, seedling trees or citrus trees grown from seeds typically have extensive root systems and are utilized by budding or top working with good commercial scion wood.

Figure 11. 4: Vitrus scion and rootstock.

Ripe citrus fruit are utilized either as fresh fruit or processed into juice and speciality products. Citrus grown for fresh market requires more extensive inputs in production and harvesting than citrus grown for processing. Typically prices paid for fresh market fruit are higher than fruit grown for processing. As is true for most agricultural commodities, the lowest price paid for fresh fruit is when all of the fruit in a region of a country is ripe simultaneously. Processing gives the citrus grower the business opportunity to shift the sale of a portion of his oranges several months to a time of higher prices due to a scarcity of fruit. Processing citrus provides an economical way to store and transport citrus from regions of production to distant markets. Processing allows small and medium sized businesses to create jobs in growing, processing, marketing and to contribute to the economic growth of a region.

Florida is the principle citrus growing state in the United States of America. In recent years about 90 percent of Florida's oranges have been processed into one of three basic types of orange juice: (1) frozen concentrated orange juice (FCOJ) (2) chilled orange juice (COJ) or (3) canned single strength orange juice called hot pack juice. Both the Brazilian and Florida processing industries have been built around producing and shipping FCOJ. In recent years there has been a trend in consumer preference to not-from-concentrate, chilled orange juice (COJ) that is preferred as a ready-to-serve product. However, the cost is prohibitive to ship all of the water in single strength juice for very long distances. There is also a small amount of "fresh squeezed Florida orange juice", (FSFOJ) that is not pasteurized by heat to reduce the enzyme activity and viable microorganisms. However, there are increasing food safety concerns with food borne illness like *Salmonella* outbreaks from citrus juices that are not pasteurized.

Citrus juice may be hot packed in regions of countries without refrigeration or freezing facilities. Hot packing involves heating the citrus juice to at least 90°C and putting it in clean glass bottles and capping the bottle while the juice is still hot. Entrepreneurs can blend citrus with other juices, or add spices or sugar to this juice prior to heating to make a beverage to meet local preferences in taste. More details on the hot pack process will be presented later in this publication.

11.2 Nutritional benefits from consuming citrus

Citrus fruits and juices are excellent sources of vitamin C containing more than the minimum daily requirement of 60 mg of vitamin C in 240 ml of juice. Citrus fruit are also a good source of folic acid, vitamin B_1 thiamine and potassium (Nagy, *et al.*, 1993; Brown, 2000; USDA, 2000a).

New opportunities to produce "healthful beverages" are now available on a small scale. Some of the current beverage categories are:

- Sport or isotonnesic
- Energy
- Nutraceutical
- Herbal
- Smart
- Fun.

Each of these beverage types needs to be adapted to consumers' taste preferences, bottled attractively and priced competitively with beer or Coca-Cola on the local market. Several of these beverages taste very good and compete effectively with carbonated beverages on the local markets. In the recipe or formulation of these beverages it is critical to try the addition of several food grade ingredients and let potential customers tell you what they like or don't like about a particular beverage. It is absolutely necessary that any ingredients that are used in this beverage are food grade and be approved for use in foods in your country.

It is relatively easy to start developing new beverages by making small batches, pasteurizing and hot packing the beverage. Hot packing the beverage provides a margin of safety against food borne diseases or food poisoning. Details on small-scale beverage manufacturing are covered in the next section of this text. Most of the beverages have a juice base that will provide acidity, a pH less than 4.0, cloudy appearance, typically recognized flavours and juice gives a general basis of consumer acceptance. Typically the more juice that is used in a beverage the more difficult it is to control settling of the particulates to the bottom of the bottle and the more difficult to produce a consistently high quality beverage.

11.2.1 Sport or isotonnesic beverages

These products are designed to replace fluids and electrolytes and provide extra energy during periods of intense exercise. Typically they have a low content juice base of 5 to 10 percent juice, added levels of sucrose, glucose (less sweet) or maltodextrin and elevated levels of electrolytes potassium and sodium in the forms of monopotassium phosphate, potassium chloride, sodium chloride (table salt) and sodium citrate. Workouts lasting less than one hour typically do not benefit from elevated carbohydrates (Brown, 2000). However, many consumers of Sport Beverages enjoy the taste and associate them with the good feelings that come about from strenuous exercise.

11.2.2 Energy beverages

These are designed to increase the consumers' perception they have more energy either by increasing the levels of sugars in the beverage or providing a stimulant like caffeine. Caffeine is a bitter tasting white powder that can have its taste masked in an orange beverage. These can be marketed to office workers in cities who want an afternoon "pick-me-up" or to labourers who need additional energy during a long day.

11.2.3 Nutraceutical beverages

This category is designed to provide healthful benefits beyond the calories they contain and are aimed at reducing the risk of chronic diseases like cancer. These beverages can contain vitamin C from citrus, vitamin A from fruits or vegetable juices rich in carotene and a mixture of plant extracts that are believed by local consumers to promote good health.

11.2.4 Herbal beverages

Can be similar to Nutraceutical drinks, but are made by adding herbs to a beverage. Examples of herbs that can be added are ginseng (believed to boost energy), ginkgo (believed to sharpen the mind), Echinacea (believed to increase the immune system), kava (believed to help relieve stress) and St. John's Wort (believed to be an antidepressant) (Brown, 2000). Caution, while many of these herbs are safe at low levels of consumption they can become toxic at higher levels. Check local regulations before formulating these beverages. Two minerals, selenium and chromium, that may be present are toxic at higher levels.

11.2.5 Smart beverages

This popular group is believed to increase mental capacities on a short-term basis. Some of these drinks contain carbohydrates, such as glucose or galactose, that are readily absorbed and converted into glycogen in the liver then transported by the blood stream for fuel for the brain. Other Smart beverages may contain herbs like ginkgo or stimulants like caffeine discussed above. There is little research evidence that compounds such as amino acids: choline, L-cysteine, taurine or phenylalanine boost mental powers. Still, some of the beneficial effects may be only in the perception of the consumer, termed the placebo or sugar pill effect, that can never the less have a positive effect and be demanded by consumers.

11.2.6 Fun beverages

This category of products are designed to have a maximum eye appeal and must taste very good. Some of these have suspended coloured particles or have weird names that appeal to kids. Typically Fun beverages contain a minimal amount of juice, but a maximum amount of advertising and label hype.

11.3 Economically feasible by-products from citrus and an idea of volumes

By-products, sometimes called speciality products, are those saleable products made from fruit besides juice. One of the opportunities of starting a new citrus processing operation is the unique opportunity to tailor the citrus processing plant's production of speciality products to the customer's needs. This needs to be done early in the design phase so the plant can be specially designed for the production of multiple products. We will give the reader an overview of speciality products currently produced by large citrus operations to give an idea of what additional products can be produced.

Over 400 speciality products can be made from citrus in addition to juice. (Figure 11.5) Many of these products are only research realities that have lacked either the backing or timing to be made profitably.

Figure 11.5: Some of the many citrus by-products.

Many similar by-products can be made from the residue of juice operations from other fruits. It is vital before engaging in a fruit juice operation to make plans on how to economically dispose of the peel and other solid wastes from the operations. Often small quantities of peel that is still wet can be fed to cattle. Larger quantities of peel will ferment before they are eaten, attract flies and become nuisances. The proper disposal of wastewater from a citrus processing operation must be planned for in accordance with local regulations. However, there are probably 6 to 12 citrus speciality products that have established markets. These are:

- Pectin
- Pectin pomace and dietary fibre
- Dried citrus peel
- Pulp wash
- Juice sacks and whole juice vesicles
- Beverage bases and clouding agents
- Healthful, nutraceutical citrus beverages
- Fractionated citrus oils and D-limonene
- Citrus molasses and beverage alcohol base
- Flavonids and limonin.

11.3.1 Pectin

Pectin has been manufactured from citrus peel for more than 50 years. All citrus contains pectin and the richest sources are limes, lemons, oranges and grapefruit in decreasing importance. The soft, white spongy layer called the albedo, just under the coloured portion of the peel is the principle source of pectin. Figure 11.6 shows a cross section of an orange that describes these portions. Pectin manufacture involves leaching to remove sugars and acid from the fresh peel, an acid extraction, precipitation, purification and standardization. Liquid pectin is less expensive to manufacture for use in a local market area. Citrus peel is extensively leached with water and this leach water has the potential for large pollution problems. Pectin plants are capital and energy intensive operations that require sophisticated operation and control. Tropical developing countries may have a locally owned pectin manufacturing operation, but it is typically hard pressed to compete with imported pectin unless the native operation is given governmental protection. Typically pectin operations are co-located with large-scale juice operations that run at least 30 000 MT per year of fruit. A handful of manufacturers make the majority of pectin. Curiously, all of the pectin used in the United States of America is imported, principally from Europe, Central and South America.

11.3.2 Pectin pomace and dietary fibre

Leached, dried citrus peel mainly lime and lemon, is termed pectin pomace. Because of its high pectin content, pectin pomace is shipped from production facilities in Central and South America to Europe for pectin extraction. Pectin manufacturers must run their operations 7 days a week, 24 hours per day so having a stable source of raw materials like pectin pomace is essential to an economical operation.

In addition, leached citrus peel can be treated to make either a moist or dry peel fibre. This dietary fibre contains both soluble and insoluble fibre sources. Dietary fibre is becoming more popular as a healthful way to lower total cholesterol. Several sources of citrus dietary fibre have been shown to be useful food ingredients in meat emulsions, possessing excellent water and fat binding properties.

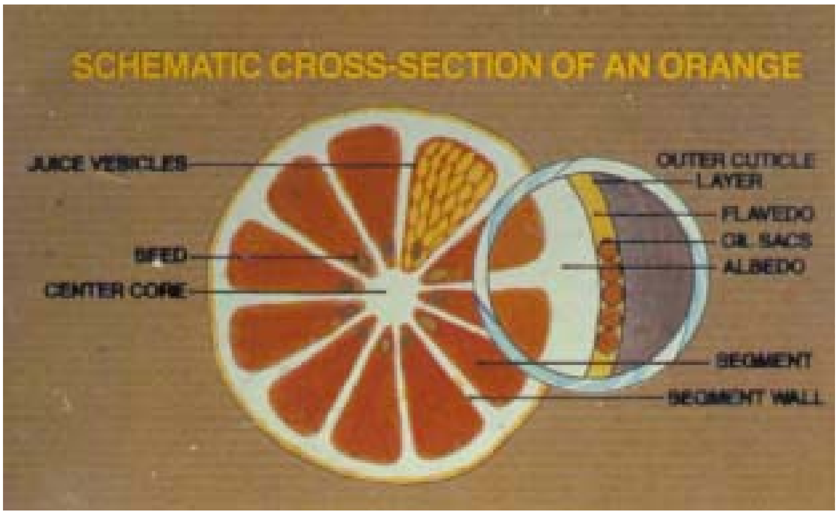


Figure 11.6: Citrus cross-section.

11.3.3 <u>Dried citrus peel</u>

Orange peel, from the extractors in large-scale citrus processing operations, contains about 80 percent water. These large volumes of peel are treated with hydrated lime $Ca(OH)_2$ to release the water and some of the sugars. The treated peel is then pressed and dried in direct-fired rotary dryers. The partially dried peel is pelletized before being stored and transported in bulk. Dried, pelletized, citrus peel at about 10 percent moisture is shipped to Europe as a source of carbohydrate used principally in dairy cattle rations. Citrus peel from small and medium scale processing operations can be treated by: drying in the sun (weather permitting) or soaking the peel with a 1 percent $Ca\ (OH)_2$ solution prior to pressing. This will reduce the water content of the peel that must be transported. Figure 11.7a. and b. gives a material balance for the weights of speciality products and juice that can be manufactured from 1 MT of Valencia oranges **(**Kesterson, *et al.*, 1978).

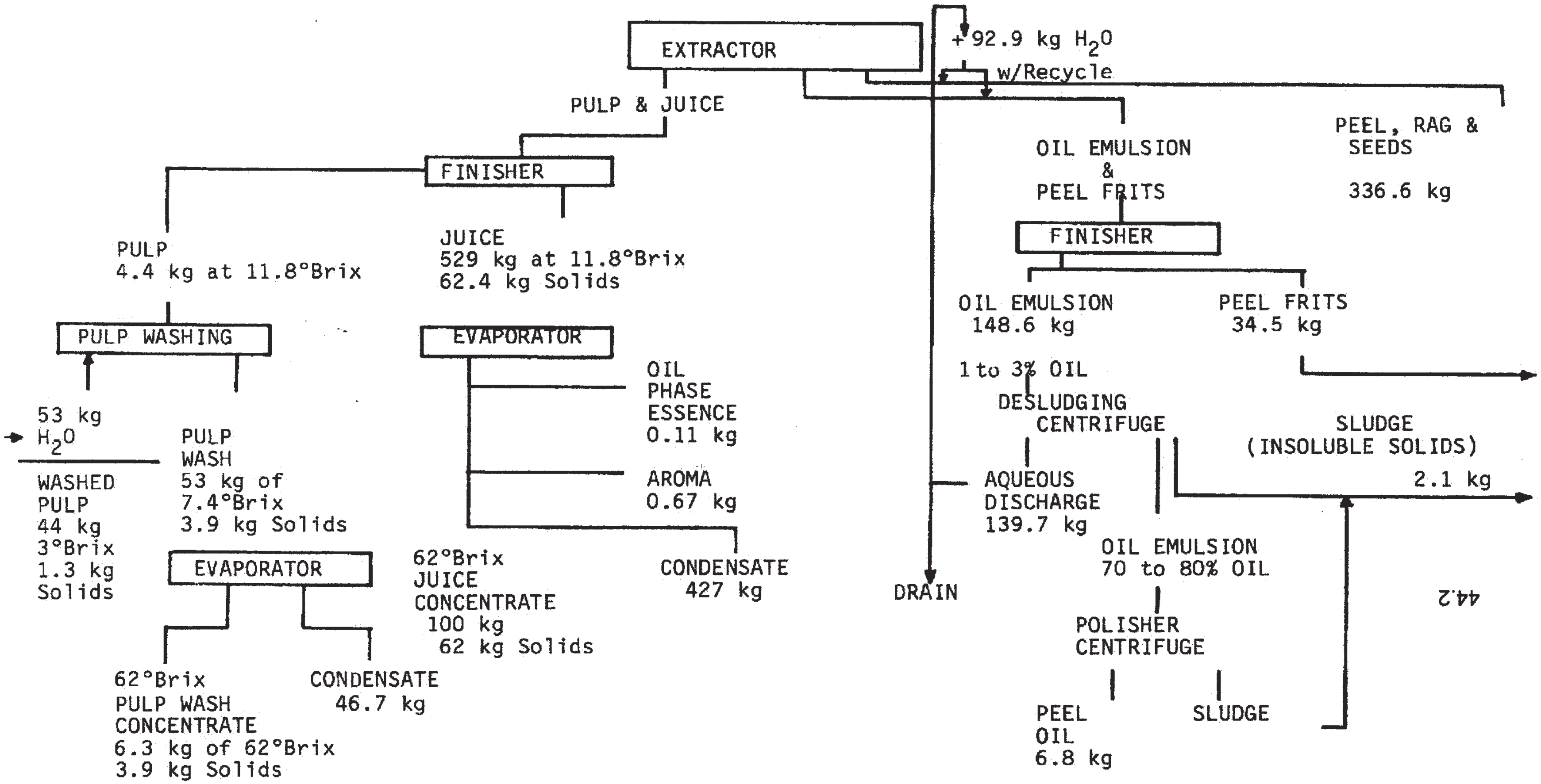


Figure 11.7a: Material balance on citrus processing.

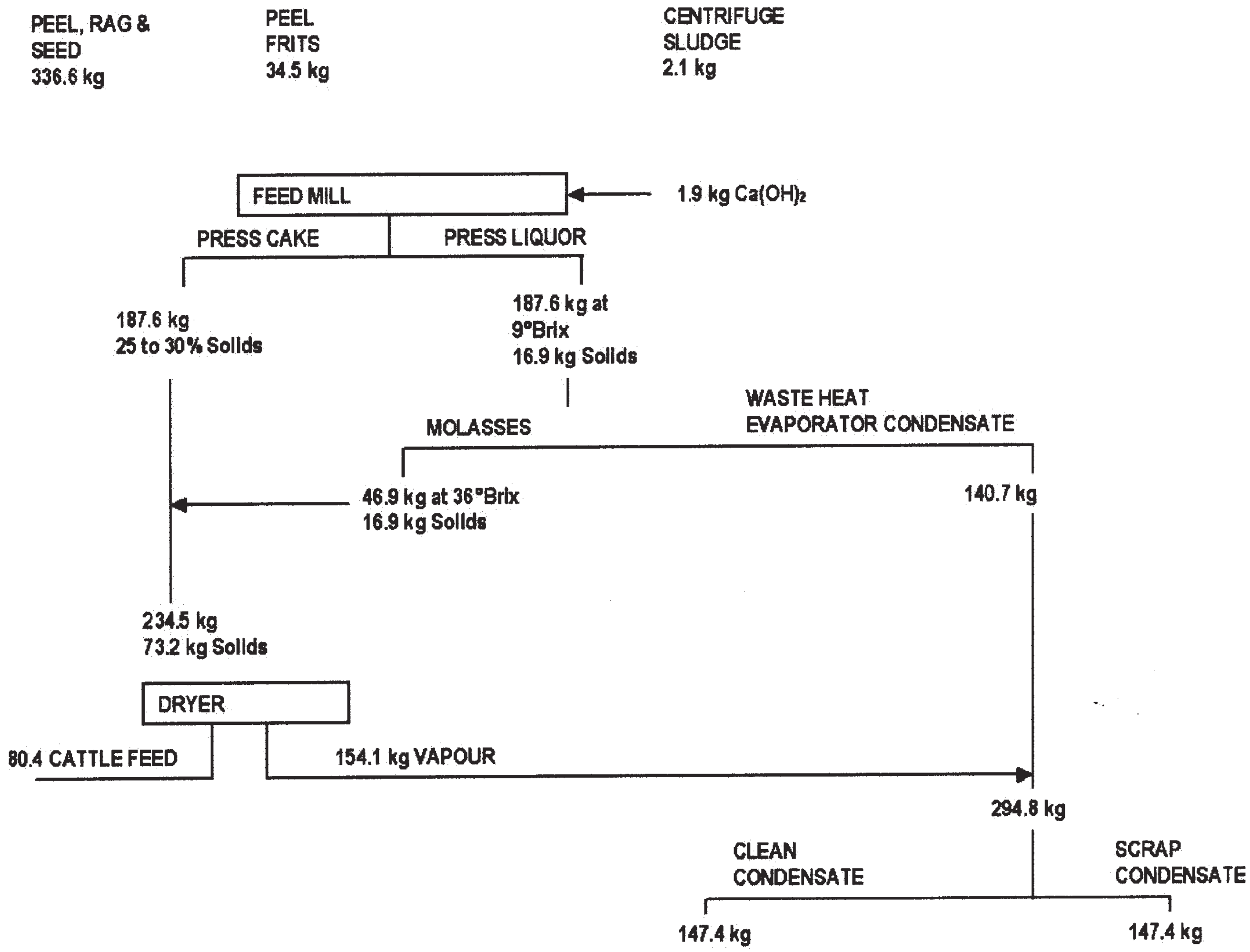


Figure 11.7b: Material balance on citrus processing.

1.3.4 Pulp wash

About 5 percent of the weight of an orange are made up of juice sacs or juice vesicles. Juice vesicles contain orange juice that is about 12ºBrix. After the juice is extracted, the juice vesicles still contain a considerable amount of 12ºBrix juice that can be recovered. The juice vesicles can be taken into a multiple-stage finisher and counter current water washing operation that recovers about 90 percent of these juice solids (Figure 6.7). These solids may have pectic enzymes added to reduce their viscosity and then combined with the juice from the extractors to increase the primary juice yields or sold separately as beverage bases. Pulp wash provides an opaque appearance called cloud to a beverage and is a source of less expensive fruit solids than regular juice for label declarations.

11.3.5 Juice sacs and whole juice vesicles

Juice sacs from the extractors can be pasteurized, dried and then sold. Washed juice sacs from the pulp washing operation described above contain less than 2 percent juice and can be dried. However, drying juice sacs that have not been washed with water produces a dark brown, unappealing product. These juice sacks full of juice can be frozen for storage. Juice sacs can be added back to frozen concentrated orange juice or sold to beverage manufacturers to give eye appeal for beverages containing low levels of juice solids and improve the mouth feel.

Whole, turgid citrus juice vesicles are very popular in Japan where they are added to beverages and yoghurt. These turgid juice vesicles are removed from intact fruit by the judicious use of heat or enzymes. In a very sweet beverage these vesicles, full of juice, provide a turgid squirt of citric acid when crushed between the teeth. This is like getting to drink and eat an orange simultaneously.

11.3.6 Beverage bases and clouding agents

Citrus peel, core and juice vesicles all contain vitamin C sugar solids and natural clouding agents. Processes have been developed to water leach citrus peel so that the leached peel can later be used for pectin manufacturing and concentrate the leach water for an inexpensive beverage base as discussed earlier (Crandall, *et al.*, 1983).

Natural beverage clouding agents are used as a healthful replacement for typical clouding agents made of brominated vegetable oils or glycerol esters of wood rosins. A number of new products can be developed using all natural citrus-based clouding agents especially for overseas markets.

11.3.7 Healthful, nutraceutical citrus beverages

Citrus has long been regarded as one of the most healthful sources of vitamin C. Only recently have other health benefits from consuming citrus come to light. There is an increase in the introduction of new juice products fortified with vitamins and minerals due to an increase in health awareness and lower costs. Drink manufacturers can blend beverages with sugar solids, flavours and essences, pectin and vitamins. Besides vitamin C, both folic acid and carotenoids are found in appreciable quantities. This provides an additional source of income and new products for a citrus processing plant.

11.3.8 <u>Fractionated citrus oils and D-limonene</u>

Within a citrus fruit there are two principle locations of flavouring oils, the peel and within the juice **(**Figure 11.6)**.** The extraction of peel oil by hand or with small-scale extractors will be discussed later in this text. This oil may be further fractionated to yield aldehydes, alcohols and esters used to flavour citrus beverages. During juice concentration the oils in the juice are evaporated off and can be condensed using refrigerated condensers on the evaporator. During the concentration or 'folding' of these oils unwanted flavours can be removed and additional speciality products called orange essences manufactured for sale. These essences contain the characteristic flowery or fruity aromas of the orange and are used to provide flavour to the juice. For a medium sized citrus processing operation it may be well worth the efforts to plan to capture these oils. For citrus fruits like lemons and limes the oils are sometimes worth 20 times the value of the juice. Citrus terpenes, principally d-limonene, are removed from the peel oil during folding under vacuum. D-limonene can be sold for hand cleaners, thinner or as an industrial feed stock.

11.3.9 <u>Citrus molasses and beverage alcohol base</u>

After citrus peel has been limed and pressed many of the sugar solids are removed from the liquid called press liquor. It is routinely evaporated to about 50°Brix molasses. This molasses is either added back on the peel before drying to increase the solids sold, or sold separately. Molasses can be used as an industrial fermentation feedstock for manufacturing beverage alcohol because it meets the definition of alcohol fermented from fruit juices. The alcohol can be used in a range of beverages or subsequently fermented to vinegar (acetic acid). Amino acids can also be manufactured from the fermentation of citrus molasses.

11.3.10 <u>Flavonoids and limonin</u>

The flavonoids, narigin and hesperidin, are found mainly in the peel. Hot water or treatment with base can remove these. These flavonoids are reported to have therapeutic benefits in treating capillary diseases and as anti-carcinogens.

11.3.11 <u>Conclusions</u>

This is a quick overview of the economically viable speciality products that can be made from oranges. The specifics on the yield of product like pectin need to be assayed on the particular orange cultivar that will be used in any project.

11.4 Overview of large scale citrus processing operation

Before going into the appropriate size equipment for small and medium sized fruit juice operations it is important for the reader to understand some of the current concepts being utilized in present day fruit juicing operations. We have chosen to use citrus processing operations in Florida as an example, but most of the concepts discussed can be adapted to other fruit. It is important that the reader realize that a modern citrus processing plant has a tremendous amount of infrastructure and specialization to keep the plant operating at near full capacity 6 or 7 days a week for as long as 200 days a year. A single modern citrus juice extractor will extract about 10 MT of oranges per hour. This is equivalent to almost 5 000 oranges per hour! A modern citrus plant is comprised of three rows of 8 to 10 extractors in each row and each row is fed carefully sized oranges **(**Figure 11.8**)**. This gives the plant the capacity of 300 to 400 MT / hour with the largest plants in Brazil able to run more than 1 000 MT/hour.

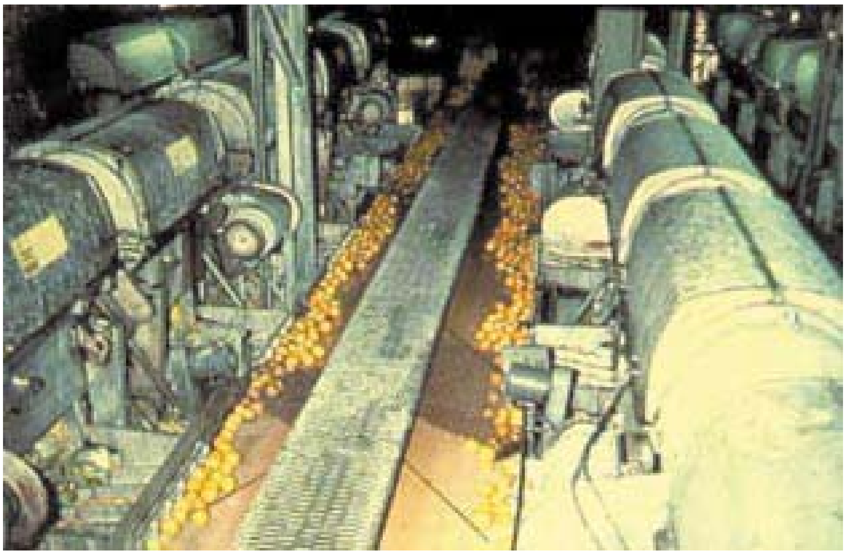


Figure 11.8: Sizing conveyor feeding citrus extractors.

Fruit processing can only preserve the raw product quality, not greatly improve it. To produce consistently high quality juices and beverages it is important to start with the very highest quality fruit. First, look at options then decide on how to best motivate growers to produce the highest quality fruit. One of the best, long-term options is to enter into mutually beneficial relationships with your growers. In years of excess supply, the processors help the growers by paying a fair price for the excess fruit. When there are years of tight supply growers agree to take a little less than the market demand so that fruit processors can fulfil their obligations and contracts. This becomes a mutually beneficial relationship whereby both growers and processors are able to benefit from a long-term, loyal relationship.

11.4.1 <u>Harvesting and transporting oranges into the processing plant</u>

Manual (hand harvesting) is used to harvest 99.9 percent of Florida's orange crop **(**Figure 11.9**)**. Picked fruit, called grove run, moves directly from the grove to the processing plants without ever being graded in a packinghouse. Hand harvested fruit is hand picked into harvesting sacks that are manually dumped into 400 kg bins in the grove. These bins are lifted by small trucks and taken to the edge of the grove where the bin is dumped into a semi-trailer. Each semi-trailer hauls about 22 MT of fruit to the processing plant that can be many kilometres away. The time from harvest to processing is only one or two days because harvesting of the fruit is paced to keep the processing plant running at near capacity seven days a week. Figure 11.10 illustrates typical processing operations.

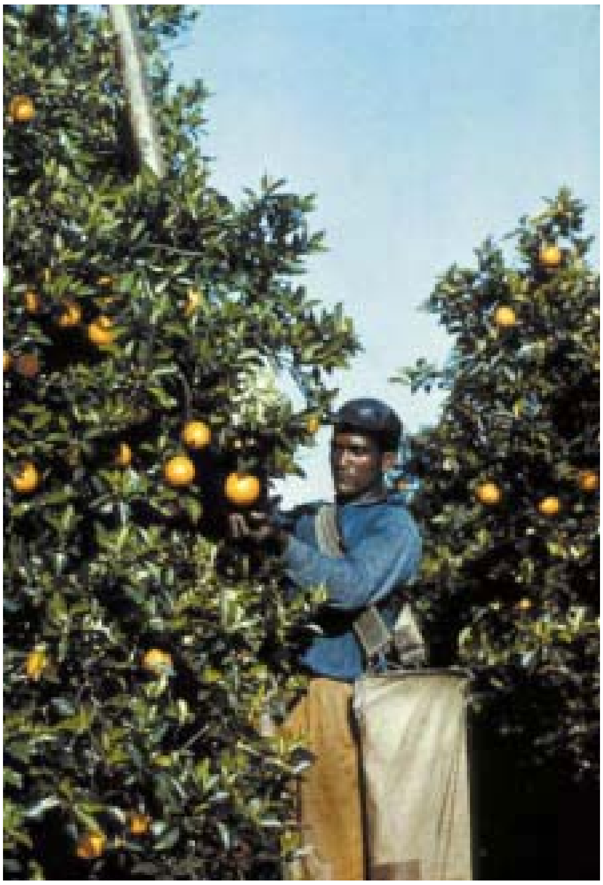


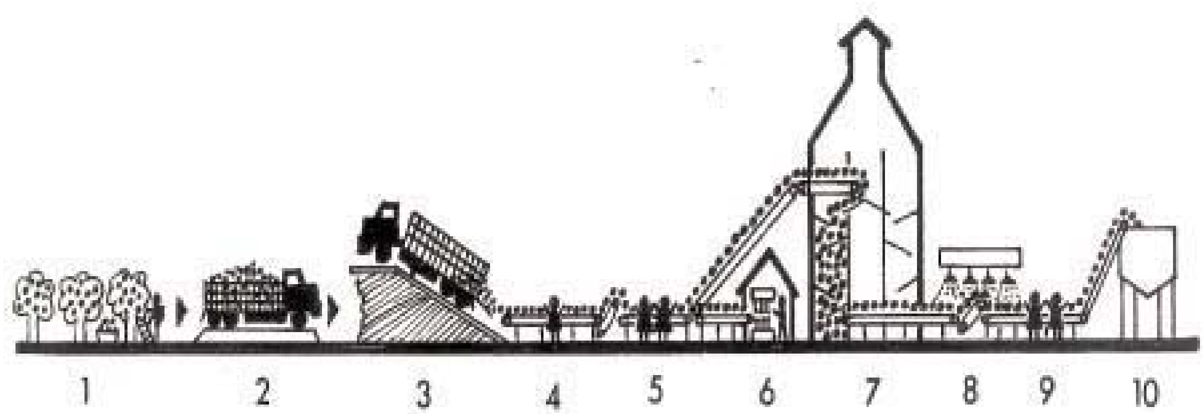
Figure 11.9: Citrus hand harvesting.

In Japan and many other citrus growing regions all of the fruit is picked and taken into fresh fruit packinghouses where it is washed and graded and only the fruit eliminations are sent on to the processing plant. Typically fresh fruit packinghouses pay more for fresh citrus, but the fruit going to the processor is several days old and can be of lower quality than grove run fruit. A new processing operation may want to plan to operate on both sources of fruit in order to get sufficient volume to efficiently operate the plant.

In Florida, a single over-the-road-trailer load of grove run fruit usually represents one grower's fruit and is driven onto a scale where the gross weight is recorded. Elevating the entire truck hydraulically after opening the end gate unloads the fruit. It only takes about 15 minutes to unload about 22 MT, the capacity of the trailer (Figure 11.11). Next, the empty truck and trailer are re-weighed to determine the net fruit weight. In Brazil fruit is received from the grove in bulk containers and in Australia the fruit is unloaded from the side of the trailer. After the fruit is unloaded, leaves, stems and other debris are removed and unwholesome fruit is removed either mechanically or by hand grading.

In Florida, a statistically representative sample of citrus, about 20 kg is removed from each trailer load and graded and tested to insure the fruit meets standards for quality. A government inspector, an impartial third party, uses a special extractor to remove some juice, which is weighed and the sugar solids are measured. The amount of sugar as soluble solids are calculated for the entire trailer load based on the sample of fruit and this is the basis of the processor's payment to the grower. This method of payment encourages the grower to produce fruit with a high juice and high solids yield. Additional payments can be made to the grower on the basis of profits from the by-products like peel oil or dried peel sold as cattle feed. These agreements are typically called “participation plans” and are used by grower’s cooperatives that own the citrus processing plant. In all other countries growers are paid strictly on MT of fruit. Paying growers strictly on the weight of fruit is counterproductive and encourages growers to grow as much fruit as possible regardless of the sugar solids content; and quality can suffer.

Fruit is pulled out of the bin and the individual grower’s load of fruit is blended with other loads of fruit to achieve the desired Brix and sugar/acid ratio of the final extracted juice. The oranges are washed with detergents, brushed and rinsed with clean water before being carefully sized for each row of extractors.



1. Fruit production
2. Load weighing and recording
3. Fruit unloading
4. Rough grading, debris removal
5. Grading and cull removal
6. Yield and quality sampling
7. Segregated storage
8. Fruit washing
9. Final grading and sizing
10. Extractor surge bin

Figure 11.10: Citrus processing operations flowchart.

11.4.2 Citrus juice extraction systems

Several extraction systems are used worldwide, FMC, Brown, Indelicato Speciale/Bertuzzi and Pelatriche/Sfmatrice/Torchi. The FMC or Brown systems are used primarily in Brazil, the United States, Australia, Japan and Israel. Due to space limitations we will only discuss the FMC system (FMC, 2000). FMC extractors are rented rather than owned by the juice processor. The rental fee for most extractors is based on the volume of juice extracted. This arrangement gives the maintenance and updating responsibilities to FMC.

After the fruit is graded to eliminate unsound fruit, it is washed; it is sized for each extractor to obtain a maximum yield of good quality juice. There are three basic models of FMC extractors: the Model 291 for small oranges, lemons or limes, the Model 391 for large oranges and small grapefruit and Model 491 for large grapefruit. The Model 291 with 5 cups extracts about 5.3 MT per hour and the Model 391 with 5 cups for larger fruit extracts about

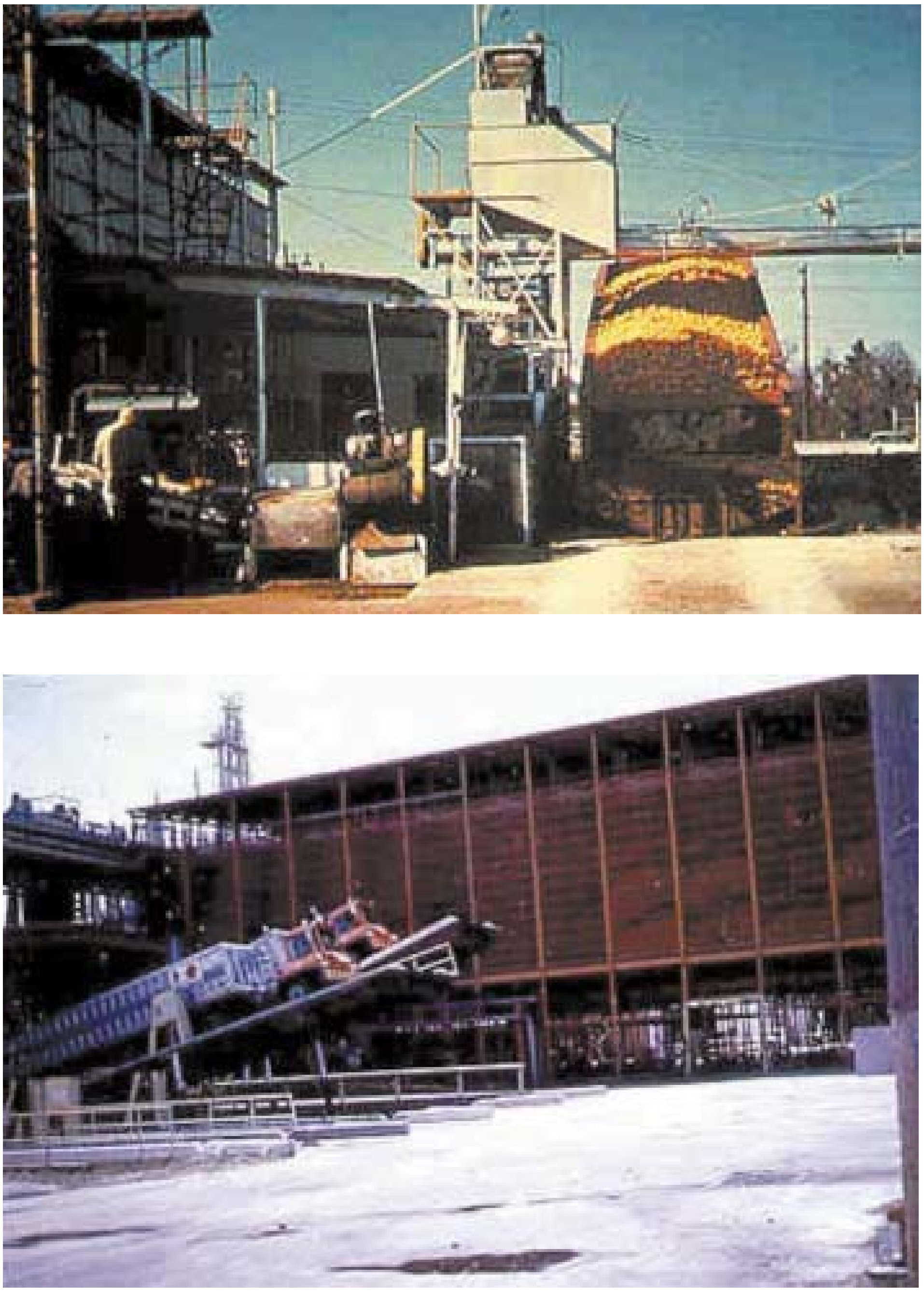


Figure 11.11: Citrus delivered for processing.

4.7 MT per hour. Figure 11.12 gives an overview of the FMC extraction process. A plug is cut in the centre of the fruit and a strainer pushed up inside the orange. A mechanical hand presses the juice and pulp against this strainer keeping the juice away from the exterior of the fruit and strongly flavoured peel oils. The juice exits out the bottom of the FMC Extractor after being separated from the pulp and the peel is pushed up and out the front. At the precise moment the peel is being put under pressure a fine mist of water is sprayed on the peel making an emulsion of the peel oil that is being forced from the peel. Thus in one stroke five oranges are separated into juice, pulp, peel, peel oil, seeds and rag.

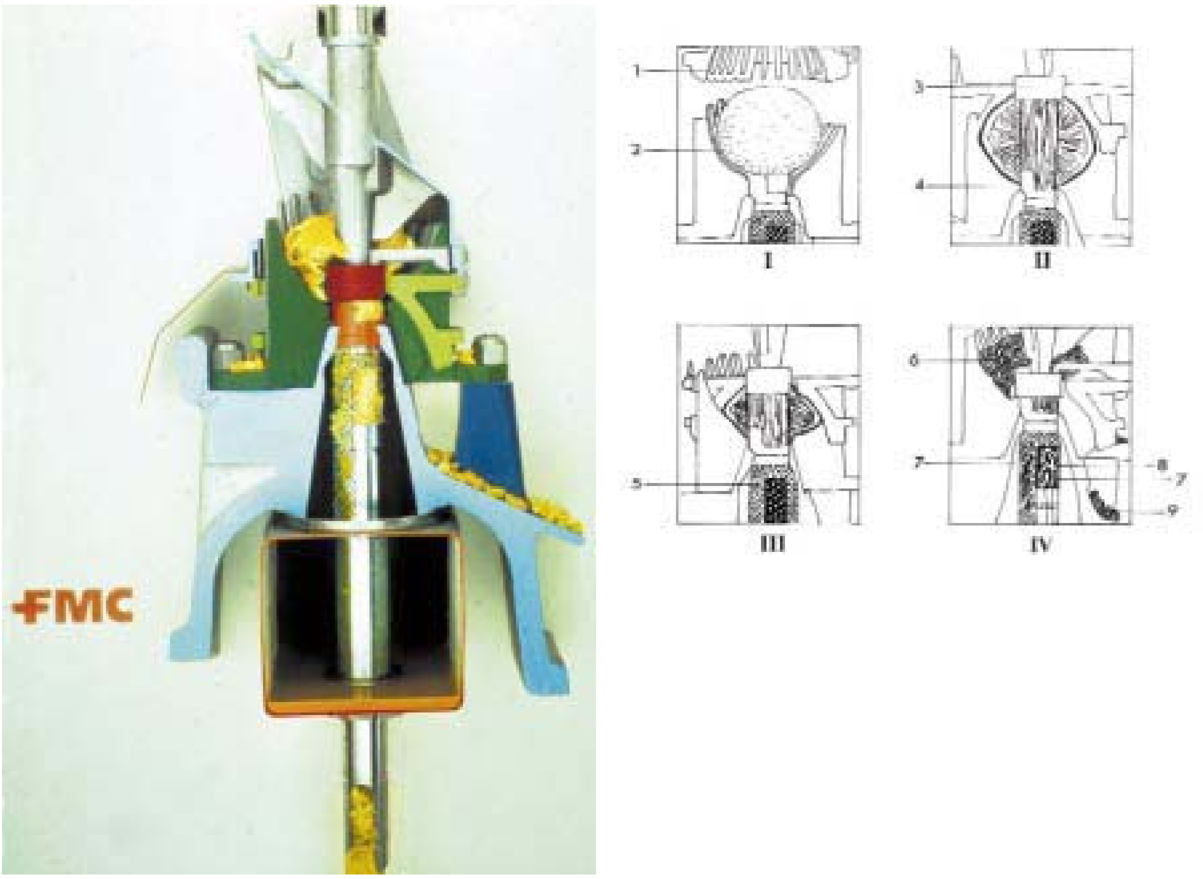


Figure 11.12: Citrus extractor diagram.
(Courtesy FMC, FMC, 2000)

The juice and any remaining pulp are sent to specially designed finishers to remove any small seeds, bits of peel and excessive pulp from the juice prior to evaporation. FMC personnel work closely with plant personnel to insure the highest yield of good quality juice is being maintained.

11.4.3 <u>Manufacture of peel oil</u>

Oil glands are located in the flavedo, the coloured portion of an orange peel (Figure 11.6). When an FMC extractor puts pressure on the peel, the oil in the oil glands is forced out and is mixed with water to form an emulsion. This emulsion goes to a special finisher then to a self-cleaning, de-sludging centrifuge and the final separation is made in a high-speed centrifuge called a polishing centrifuge. Polished oil is stored in the cold to precipitate waxes. Cold-pressed oil gets its name from the original process where peel was mixed with water then pressed in a screw-press with only a small increase in temperature. Even though oil still retains the cold pressed name; the cold press process is no longer used. Table 11.2 gives a yield of cold pressed oil from various citrus cultivars (Kesterson, *et al.*, 1978). Citrus oils are used as flavour and fragrance enhances in beverages, foods and household cleaning supplies.

Table 11.2: Yield of oil from citrus fruit (Kg oil/tonnes fruit).

Citrus Fruit	Maximum	Minimum	Average
Orange			
Hamlin	4.2	3.5	3.9
Parson Brown	6.2	4.5	5.3
Pineapple	7.0	3.7	4.8
Valencia	8.1	5.2	6.7
Temple	4.5	3.4	3.9
Grapefruit			
Duncan	3.4	2.4	2.8
Marsh	3.6	2.7	3.1
Ruby Red	3.9	2.5	3.2
Speciality Fruit			
Dancy Tangerine	8.7	6.7	7.7
Orlando Tangelo	6.3	4.8	5.6
Persische Limette	4.6	3.6	4.0
Zitrone	9.6	5.9	7.5

11.4.4 Evaporation, concentration of the juice, storage and transportation

After the juice is removed from the fruit and has gone through the finisher it is sent to an evaporator feed tank. Almost all orange juice is concentrated on Thermally Accelerated Short Time Evaporators, TASTE (Figures 8.9 and 8.10). These multi-stage, forward feed evaporators take juice that is 10 to 12 percent solids or ºBrix and remove the water to concentrate the juice to 62º to 65°Brix. This concentrate is mixed with a small amount of oil and stored in enormous 500 000 to 18 000 000 L bulk storage tanks. Bulk storage tanks represent significant savings, about 20 percent, over storing concentrate in barrels.

Citrus processors in Brazil pioneered the use of large bulk, refrigerated ships carrying more than 11 000 MT from the Port of Santos in Brazil to Florida, New Jersey or Rotterdam (Figure 8.23). Substantial quantities of orange concentrate are shipped from Mexico in semi-trailer tankers holding about 16 000 litres or in square 1 100 litre bag-in-box containers. Citrus oils, d-limonene and citrus essences may also be transported in bulk.

11.4.5 Saving money by manufacturing 72ºBrix concentrate

Citrus concentrate is shipped around the world at about 62ºBrix, which means that 38 percent of all the storage capacity and transportation costs are due to transporting water. Tank farm and transportation storage capacity could be increased by 14 percent by increasing the concentration from 62ºBrix to 72ºBrix. This more highly concentrated orange juice is less susceptible to attack by microorganisms and may be kept at refrigerated rather than frozen conditions for periods of time, which further increases the energy savings. The 72ºBrix concentrate is more viscous and can require a new operation to be designed to handle this higher concentration. Initially there were concerns that concentrating the reactants could increase chemical degradation reactions such as the Maillard reactions. However, research later showed that this was not the case and the 72ºBrix concentrate was stable for extended periods of storage. There are several methods of manufacturing 72ºBrix, depending on the customer's specifications **(**Crandall, *et al.*, 1981; Crandall, *et al.*, 1987, Fox, 1994). The 72ºBrix concentrate may be a very viable alternative for a new citrus processing operation needing to transport citrus concentrate long distances.

11.5 Principal pieces of citrus extraction equipment for use at an appropriate scale

We will discuss appropriate equipment for use in small and medium size fruit juicing operations. We will start with citrus extraction and pasteurization equipment that is appropriate in size for a village group of about three dozen persons extracting up to $^1/_2$ MT of citrus per hour. Then we will move to the next scale of purchasing extractors and finishers for plants wanting to process 3 to 10 MT per hour. The modern citrus processing equipment just discussed is for operations wanting to process multiples of 10 MT of fruit / hour.

11.5.1 Small village-scale harvesting

The villagers and their neighbours typically grow fruit for small-scale operations. As with most fruit, all of the fruit in a region becomes ripe at the same time and must be processed, sold at the lowest prices of the year or left to rot. Villagers can collect the fruit they want to harvest and collect the glass containers for the finished juice. They must decide whether to process 100 percent full strength juice or blend the citrus juice with other locally available juices or flavourings for a juice based beverage.

11.5.2 Washing and storing fruit

Citrus stores very well on the tree so the rate of harvesting must be controlled so only a one or two-day supply of fruit is on hand at the processing operation. Freshly harvested fruit should be stored dry in the shade. The first Critical Control Point is to juice fruit only after the rotten and diseased fruit has been removed and fruit has been washed to remove soil and dirt from the grove. These operations should be performed just prior to processing. Once citrus is washed it is more likely to decay if held at ambient temperatures. Before processing, stems and leaves need to be removed from the fruit and the fruit needs to be washed and rinsed in clean water. Washing will help minimize the amount of microorganisms getting into the juice. Glass bottles and bottle caps such as used soda or beer bottles need to be collected and washed out with hot water with soap and rinsed in clean water and turned upside down to dry. The hot juice filled into the bottles will kill many microorganisms but this hot pack treatment is not sufficient to kill very large concentrations of microorganisms found in dirty bottles. Bottle caps that can be reused need to be free from rust and reshaped to be flat across the top and have the flanges bent slightly outward. Reshaping the metal caps can be done with a wooden dowel placed inside the cap and striking the dowel with a hammer. The caps then can be clean by rinsing in very hot water.

It is envisioned that the next two pieces of portable processing equipment would be brought to the village by a circulating processing expert after the villagers have their fruit and bottles ready. The person knowledgeable in the fruit processing operation could be an entrepreneur or governmental employee. They could be paid in bottles of juice at an amount agreed to before beginning the processing. The equipment is portable and designed to fit on the back of a man or on a single bicycle. This bicycle can also be used to provide power for the fruit extractor. However, in less remote situations small electric or diesel motors can replace the labour of several persons and can be paid for by the sale of the bottled juice. Details on the construction of the bicycle powered citrus reamer and portable fruit juice pasteurizer are contained in Annex A.

11.5.3 <u>Small-scale citrus</u>

The bicycle or small engine powered reamer uses two standard juice reamers. Alternative fruit grinders for different types of fruit could be powered by a similar system. This extractor uses 5 or 6 people and will extract about 70 kg of citrus per hour. This will give a juice yield of about 30 L/ hour which is only 1/3 as fast as the flow rate of the tubular pasteurizer at 90 L/hour. Three sets of bicycle reamers will keep one tubular pasteurizer operating on 100 percent juice or the extraction can start and get 40 to 50 L of juice ready before pasteurizing starts. Alternatively other juice and flavourings can be used to increase the volume of juice going to the pasteurizer. The whole rear bicycle axle, tire, rim and chain drive sprockets are first removed. An 18-cm threaded shaft with a toothed rear wheel-driving sprocket, two reamers and a bearing are used to replace the rear bicycle axle. The bicycle chain is placed around the threaded shaft, fitted to the driving sprocket and tightened in the rear wheel axle mounting brackets in the bicycle frame. Metal or plastic troughs are constructed to protect the bearing from the acid fruit juice and to direct the extracted juice into a collection bucket. A stand made from old bicycle handlebars is used to elevate and stabilize the reamers. Figure 11.13 illustrates a bicycle-powered reamer in operation and a close up of the reamer.

11.5.4 <u>Small-scale citrus extraction</u>

After the citrus has been thoroughly cleaned, one person cuts the fruit in half between the stem and blossom ends. A second person rides the bicycle or operates a small engine powering a drive chain providing power to vertical mounted reamers. A third and fourth person press the cut cup halves against the reamer and collect the juice in a bucket. A fifth person presses the juice through a metal colander, a perforated metal cone with a wooded dasher; to remove the excess pulp and seeds that would plug the pasteurizer coils (Figure 11.14). This juice is now ready to be pasteurized or can be blended with other juices and flavourings to make a citrus beverage. Citrus juice contains enzymes and microorganisms that can destroy the quality so the juice needs to be run through the colander and to be heated within 30 minutes of the time it is extracted.

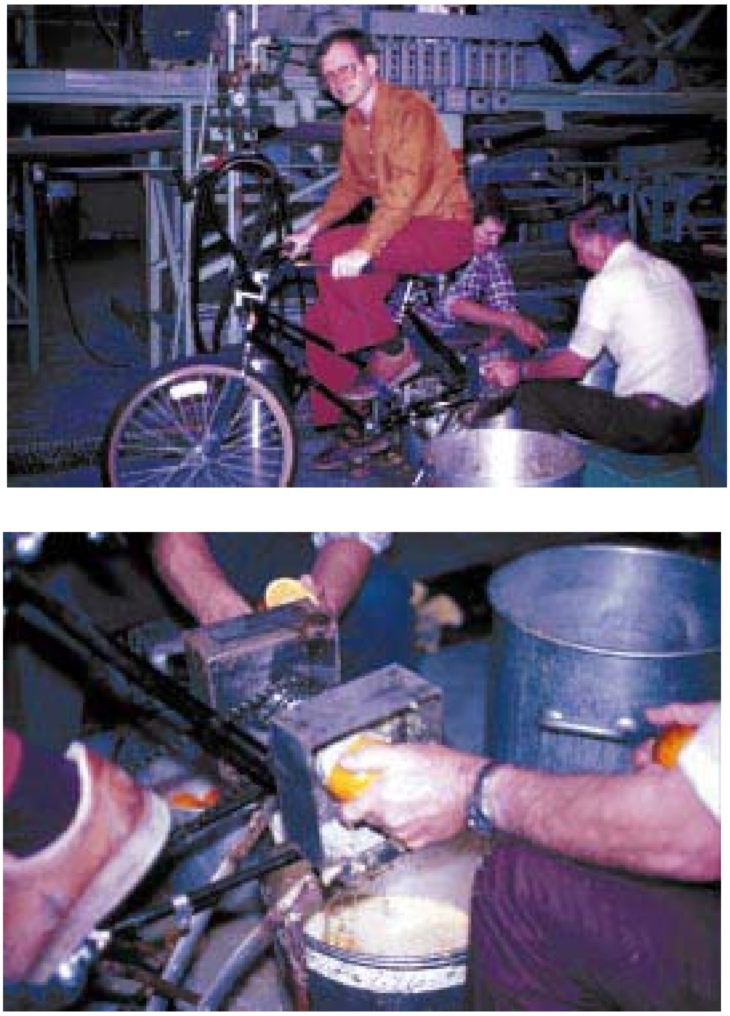


Figure 11.13: Bicycle powered citrus extraction.

11.5.5 Small-scale citrus juice pasteurization

The second Critical Control Point is to check the pH of the fruit juice or beverage to be pasteurized. The pH is a measure of the amount of acid in the juice and the pH absolutely must be below 4.5, but it is much better to have the pH below 4.0 to have a safety margin. The spores of *Clostridium botulinium* are prevalent in most soils and contaminate many types of fruit**.** These spores require a pH above 4.5 and almost no oxygen conditions to grow and produce their toxins. Washing the fruit will minimize the number of spores in the juice and adding an acid juice like lemon or lime juice to reduce the pH of some beverages is required. Pasteurization of fresh citrus juice requires that it be heated to at least 90°C to inactivate the heat stable pectinesterase enzyme that causes the juice to clarify. This can be accomplished by pouring the juice through a stainless steel coil suspended in a boiling water bath.

Figure 11.14: Juice strainer and pasteurization coil.

Figure 11.15 shows the construction of a heating oven, the placement of any type of metal container to hold the boiling water, the coil placed in the boiling water, the placement of the funnel to control the rate of juice flow and measuring the outlet juice temperature. The third Critical Control Point is to make sure the temperature of the juice exiting the pasteurization coil is at least 90°C going into the cleaned glass bottles. Initially the funnel where the fresh juice was poured in is placed 1 metre above the outlet of the juice tubing (Figure 11.16). If the temperature is less than 90°C the juice is running through the coil too fast and the height of the funnel, the hydrostatic head must be reduced. If the juice gets close to 100°C exiting the pasteurizer it may boil inside the tube creating steam that can cause the juice to flash out and can cause serious burns. That is why one person who understands what is needed must keep the temperature of the juice leaving the coil just slightly above 90°C.

Figure 11.15: Pasteurizer coil heater.

Figure 11.16: Pasteurizer feeding and bottle filling.

The pasteurization coil is made from a 5.3-metre length of stainless steel tubing, 9.5 mm outside diameter and 7.7 mm inside diameter. The stainless steel grade is 316. Copper, brass or lead metal tubing must *not* be used to make this pasteurization tube because these metals are soluble in the acid juice and can make the juice toxic.

The 90ºC juice is hot filled into cleaned glass bottles almost to the top of the bottle. The cap is crimped on the bottle with a bottle-capping machine (Figure 11.17) and the bottles laid on their sides for at least 3 minutes to allow the hot juice to sterilize the cap. Then the bottles are cooled in running water to preserve the flavour. Whenever the juice supply is running low the coil can be filled with clean water and pulled out of the boiling water bath until there is sufficient juice ahead to resume pasteurizing. Be sure to flush the water from the coil and insure the exiting juice temperature is at least 90ºC before resuming filling the glass bottles. Immediately after finishing running all of the juice for the day, remove the coil from the boiling water; flush the coil with large amounts of water to remove any traces of juice. Then flush the coil with 1 percent NaOH, a strong base, to remove any scale that may have formed inside the coil. Then this base needs to be washed from inside the coil with a large amount of water. The remaining water is poured from the coil and the coil allowed to dry. This extraction, pasteurization and bottling system can now be transported to the next village. Additional details are contained in Annex B.

11.6 Overview of small scale fruit processing equipment with references on how to make equipment

This equipment is designed for fruit juicing operations wanting to process 3 to 10 MT per hour and to operate in regions where there is electricity or diesel fuel to power generators (Annex C). The fruit supply needs to be available for a long enough period of time within reasonable transportation distances to the plant. It is vital to the success of any new fruit juice processing operation that the supply and cost of fruit be secured before beginning each season.

11.7 Sanitation and good manufacturing practices

Fruit entering a processing operation is sorted to remove damaged fruit, diseased or rotten fruit. Fruit is stored for as short as time as is possible to keep the processing operation running efficiently. Fruits are washed to remove any soil, disease or mould. It is important not to include the white, albedo and portion of citrus by over extracting the juice. While the peel contains vitamin C and bioflavonoids it also contains a number of very bitter compounds and the highest concentrations of pesticides that have been sprayed on the fruit during production and should not be included in the juice.

Most food safety recommendations call for fruit juice to be pasteurized. Pasteurization is a heat treatment that kills the bacteria *Escherichia coli* O157:H7 that is a public health hazard. Most juice manufacturers are no longer willing to accept the liability risk of producing fruit juice that has not been pasteurized. Acid juices like citrus containing pH levels less than 4.0 can be pasteurized by heating the juice to 90°C for a few seconds (Somogyi, 1996; Ashurst, 1995; 1998).

11.7.1 <u>International</u>

There are several approaches that may be taken to comply with Good Manufacturing Practices, food laws and regulations. The suggested approach is to first determine where you want to sell the processed fruit juice or beverages. If you ever expect to export your fruit juice products to another country it will be important to evaluate the FAO Codex regulations for the products you want to manufacture. There is a worldwide effort to make these regulations the same or harmonize the regulations for a region producing similar products. Many national and local regulations use international regulations like Codex as the basis for their regulations. A complete list of FAO Codex regulations pertaining to fruit and vegetable juice and beverage regulations can be found in FAO, 1992 and at FAO 2000a. and c.

11.7.2 <u>National and local regulations</u>

It is not possible to go into detail about food safety regulation for each of the 180+ countries where FAO has contacts. However, we have accumulated some advice and references where more information on each of these subjects may be found.

Growing fruits or vegetables for distribution only within a country or exporting to another country may have different requirements. However, the export requirements to grow under Good Agricultural Practices (GAPs) means that the fresh produce coming into a processing plant will be of the highest quality. Information on GAPs can be found in Sections 4.1 to 4.3.

11.8 Processing citrus other than oranges

There is a great variety of the citrus species: tangerines, grapefruit, lemons, limes and exotic citrus. Most of the processing operations describe above will apply to extracting juice and making by-products from these other species.

11.8.1 Tangerine

Tangerines or Mandarin or Zipper-skin easy to peel oranges are the exceptions. There are many types of tangerines grown around the world because they are delicious when eaten out-of-hand and they have different disease susceptibility than sweet oranges. However, most tangerines and navel orange juice contains a bitter lactonnese structured compound in the juice that reacts closes the ring and forms a very bitter compound when the juice is stored or heated. This makes most tangerine juice a poor choice for beverages that contain more than 10 to 15 percent juice because the juice will become too bitter. However, using small concentrations of tangerine juice together with sweet orange juice can impart a richer, more orange colour to some pale coloured sweet orange juices. Certain types of tangerines may be difficult to juice on a reamer and may need to be peeled then the juice pressed out. Tangerine oil can command a high price but should not be used to flavour orange beverages because it can develop off flavours during storage.

11.8.2 Grapefruit

This fruit was so named because of the tendency to grow in clusters like large grapes. Duncan, a seedy variety, came to Florida in the early 1800s. Marsh, a seedless variety and several pink fleshed varieties are thought to be spontaneous mutations. As with all fruit it is important to process high quality, fully mature fruit. This is especially true of grapefruit. Immature grapefruit juice contains excessive amounts of naringin and limonin that impart an extremely bitter flavour to the juice. Grapefruit juice is considered as an excellent candidate for small-scale juice processing operations because it is the easiest to process and maintains its flavour better during pasteurization and storage. Grapefruit juice extraction requires larger diameter reamers. Before starting on a grapefruit processing operation it is vital that a determination be made that there are sufficient numbers of customers who prefer grapefruit to other types of juice.

11.8.3 Lemon and lime

These are separate species of citrus. Limes are typically grown in humid tropical climates and lemons in the subtropical regions. Both came into cultivation in Europe from Southeast Asia during the crusades. Lemon juice was probably the first commercially processed fruit juice in the early 16th century when it was bottled as a medicinal to prevent scurvy on British navy ships. Lemon juice is used for its acid content, typically above 4.5 percent by weight. Limes have thinner skin and are processed in a manner similar to the one just described. Entrepreneurs planning on processing either lemons or limes need to make provision to extract the oil from the peel. Lemon and lime oil is valued at many times the value of the juice. There are special hand oil extracting techniques if there is a market for this very fine oil. The peel from both of these fruit are leached with water and dried for pectin pomace.

11.8.4 Exotic fruits

In some regions there is grown an orange with a blood red coloured juice. The pulp from this blood orange contains red pigments, anthocyanins, which develop an undesirable muddy colour upon processing so this fruit should be used only as fresh fruit and for fresh juice products. (In contrast, pink grapefruit contain the carotenoid pigment, lycopene).

Kumquats (*Fortunella margarita)* and sour orange contain naringin that can impart an undesirable bitter taste to the juice. Often these small fruit are ground whole and used as a base for manufacture of marmalades.

11.8.5 Conclusion

Citrus is by far the most technologically developed juice industry. Yet we see that operations can range in size and technology from the immense and global to small and village. Mid-size citrus processors can borrow ideas from both extremes and processors of other fruits should adapt (and improve upon) the best (location- and circumstance-appropriate) citrus practices **(**Crandall and Hendrix, 2001**)**. In addition, citrus equipment manufacturers and suppliers have experience and insights into other fruits well worth exploiting. Citrus is, therefore, a good (but not exclusive) model on which to plan and develop a juice processing operation.

CHAPTER 12

GRAPE JUICE

12.1 Importance

The United States of America is the largest user of grape juice and grape juice concentrate. About 25 percent of the 1999 crush was channelled into juice concentrate. From 1998 to 1999 the quantity of imported grape juice rose a whopping 50 percent and greatly exceeded exported juice. Imported grape juice and concentrate is on the rise. Thirteen nations combined to import grape juice and concentrate into the United States of America, Argentina having 70.3 percent share in 1999. Grape juice and concentrate accounted for 9.5 percent of the value of all 1999 imports of fruit juices and concentrates and is increasing. For comparison, orange juice market makes up 37 percent, apple 28 percent followed by pineapple and grape **(**Larsen, 2000**)**.

The volume of grapes processed for beverage use worldwide (including wine and beverage alcohol) exceeds any other individual fruit. Indeed, many of the grape selection and juice preparation steps are common to both even to the extent that fruit not meeting juice standards can be used for wine and ultimately beverage alcohol. In contrast, grapes not meeting wine quality standards would rarely end up as juice. (Curiously, premium “world class” wine grapes make mediocre juice.) An appreciable amount of the fresh market seedless grapes, especially ‘Thompson seedless’, end up as concentrate juice, primarily for blending purposes. However, for juice and juice beverages where grape character is important, other species and cultivars are most prominent.

The first grape juice processed in the United States of America was used as the sacrament on the communion table of the Vineland, New Jersey, Methodist Church. Dr. Thomas B. Welch, a dentist, processed the juice, derived from Concord grapes *(Vitis labruscana L.*). Concord juice and Concord blends have become the standard for quality red grape juice around the world. For white juice, Niagara along with Delaware and Catawba and various labrusca blends are gaining in popularity.

Nevertheless, any grape cultivar with acceptable fresh eating quality can be used for juice. With creative blending (Chapter 9) even those of marginal juice quality can be utilized, providing the grapes are not spoiled or otherwise contaminated.

12.2 Grape juice composition

The composition of grape juice is similar to that of whole grapes except that crude fibre and oils, which are primarily present in the seed, are removed. Sugars, acids, methyl anthranilate (in *Vitis labruscana*), volatile esters, alcohols and aldehydes are major flavour constituents. Glucose and fructose are the major sugars present in grape juice. The quality of grape juice largely depends upon sugar level, acid content and flavour constituents such as methyl anthranilate and other volatiles, tannins and colour substances. Changes that occur in grapes during growth and maturation determine quality of the juice.

The principal acids of grape juice are tartaric, malic and citric, but small quantities of other acids are present. Flavour and aroma develop during the ripening process. Colour in grape juice is largely the result of anthocyanin pigments located in and near the skin. Moreover, the types and quantities of anthocyanin pigments are different among grape species. The differences in the types of anthocyanin help to explain why some grapes have better colour stability and are more suitable for juice processing than others.

The specific composition of juice from any grape species can never be assumed since composition varies from year to year and changes continually during ripening (De Golier, 1978). Likewise, the composition of a given species and cultivar will vary from area to area depending upon soil, location and climatic conditions. In general, as fruit matures, the sugar and colour increase and the pH and titratable acidity decrease.

The Concord grape juice industry has determined that the best objective index to determine optimum maturity is percent soluble solids. It has been reported, for instance, that around Lake Erie ideal flavour, acid and colour levels occur in grapes when the soluble solids value is between 16 and 17 percent (Morris and Striegler, Somogyi, *et al.*, 1996b). The juice industry determined that as the percent soluble solids of Concord grapes increased above 18 percent, flavour and acid decreased; consequently, quality decreased. Concord grapes that are harvested in the range of 14 to 15 percent soluble solids have excess acidity and inadequate flavour-aroma components and may have insufficient colour. The Concord juice industry usually uses 15 percent soluble solids as the lower level of acceptable quality and pays a premium for grapes based on each increase in percentage soluble solids up to 18 percent. However, most cultivars of Vitis vinifera, the major wine grape throughout the world, produce grapes that are much higher in percent soluble solids, but lower in acid at harvest. It is not uncommon for these grapes to produce juice that is 22 to 25 percent soluble solids.

Because of the industry emphasis on the importance of the value of percentage soluble solids to quality, most of the literature dealing with the effects of pre-harvest variables on fruit and juice quality has used percentage soluble solids as the major index for quality. However, this is not the best method of predicting quality. To properly evaluate juice quality, it is important to consider all major quality attributes such as flavour, pH, acidity, colour along with percentage of soluble solids.

12.3 Pre-harvest factors influencing grape juice quality

Among major pre-harvest conditions that influence quality of grape juice are climate, soil, cultivar, vineyard management and maturity. Each of these factors exerts its own influence, but complex interactions among these factors must be kept in mind.

12.3.1 Climate

The maximum, minimum and average temperatures as well as the daily pattern of heat accumulation and solar energy level have to be considered in looking at the overall site (Somogyi, *et al.*, 1996b). Rainfall, clouds and fog and their distribution through the season are important along with other water and solar factors.

12.3.2 Soil

Loose soils with moderate fertility and excellent drainage characteristics are best. This ideal situation and all conditions that vary from the ideal require different vineyard management systems to obtain maximum juice quality.

12.3.3 Cultivar

Concord is the grape cultivar most widely used for juice production and the United States accounts for the vast majority of the world's Concord production. It is a rare grape cultivar that can produce juice with a balance of sugars, acids, flavouring substances, astringent characteristics and aroma as palatable and as well recognized by the consumer as Concord juice (Morris, 1985). Also, the highly flavoured Concord grape juice imparts a rich flavour after dilution and sweetening.

Other cultivars for dark juice are Fredonia, Van Buren, Sheridan, Ives and Clintonnes. Sunbelt is a new cultivar released from the Arkansas Agricultural Experiment Station. It has proven to be an outstanding juice grape cultivar in southern or warm production regions. Among white grapes, Niagara has become the standard for juice because of its unique aroma and flavour. Commercially, Niagara is usually blended with the less expensive and neutral Thompson Seedless juice from California. Cold-pressed Catawba, Isabella, Ontario and Seneca have been used for white juices, usually blended. California has greatly increased their production of grape juice concentrate, a great deal of it being the Vitis vinifera type. Vitis vinifera grapes are the most widely planted grape cultivars in the world.

The juice of muscadine grapes (Muscadinia rotundifolia) has a unique bouquet. It is appreciated by people in the Southern part of the United States of America, where it is native and its flavour is well known by the consumer. Cultivars vary in colour from almost white to pink, red, blue, purple and nearly black. Blends have a beautiful colour and a refreshing taste (Bates and Sims, 2001; Morris and Blevins, 2001).

12.3.4 Vineyard management

Pruning and training systems, fertilization, irrigation, application of growth regulators and pest control measures are vineyard management operations that can influence juice quality. Maintaining an adequate and balanced mineral nutrition program is a major factor in producing high fruit yields and quality grapes. It is not uncommon to create fruit quality problems with excessive nitrogen fertilization that results in excessive vigour and subsequent fruit shading. Also, excessive potassium (K) can result in quality problems. Excessive K levels in the juice were detrimental to fresh juice colour quality and stored juice colour stability, making a balanced K fertilization program highly important in vineyard management of grapes.

12.4 Harvest and postharvest factors influencing grape juice quality

Morris (1985) found that in harvest maturity, the flavour and sugar/acid ratio of Concord juice was directly related to maturity, making harvest dates crucial determiners of juice quality. Most grapes used for juice are mechanically harvested. It was shown that mechanically harvested grapes are of better quality than hand-harvested grapes. Effects on the quality of machine-harvested grapes can be altered or influenced by six major factors:

- Type of machine
- Cultivar
- Production system
- Harvest temperature
- Interval between harvesting and processing
- Postharvest handling system.

Muscadine grapes present a major problem for once-over machine harvesting, since, unlike other commercial Vitis species, many cultivars of muscadine do not ripen uniformly. The presence of immature fruit in an once-over harvest is undesirable, since it lowers the quality of the processed product. Lanier and Morris (1979) developed a system for sorting machine-harvested muscadine grapes into maturity classes using a density sorting system. It provided a rapid and inexpensive way of removing fruit of undesirable maturity. The ease of berry detachment from clusters, spherical shape of the muscadine berry and relatively small variation in fruit size characterizes it as ideal for mass density sorting.

12.5 Juice production

Figure 12.1 illustrates a generalized flowchart for grape juice production. There are several options for juice extraction and subsequent treatment. Methods for commercial preparation of grape juice have undergone continuous change. In most commercial operations, the continuous pressing method is used. Hot pressing is appropriate for deeply pigmented grapes where maximum colour extraction is desired. Whereas, the immediate or cold press procedure is necessary to maintain the initial colour of light coloured grapes.

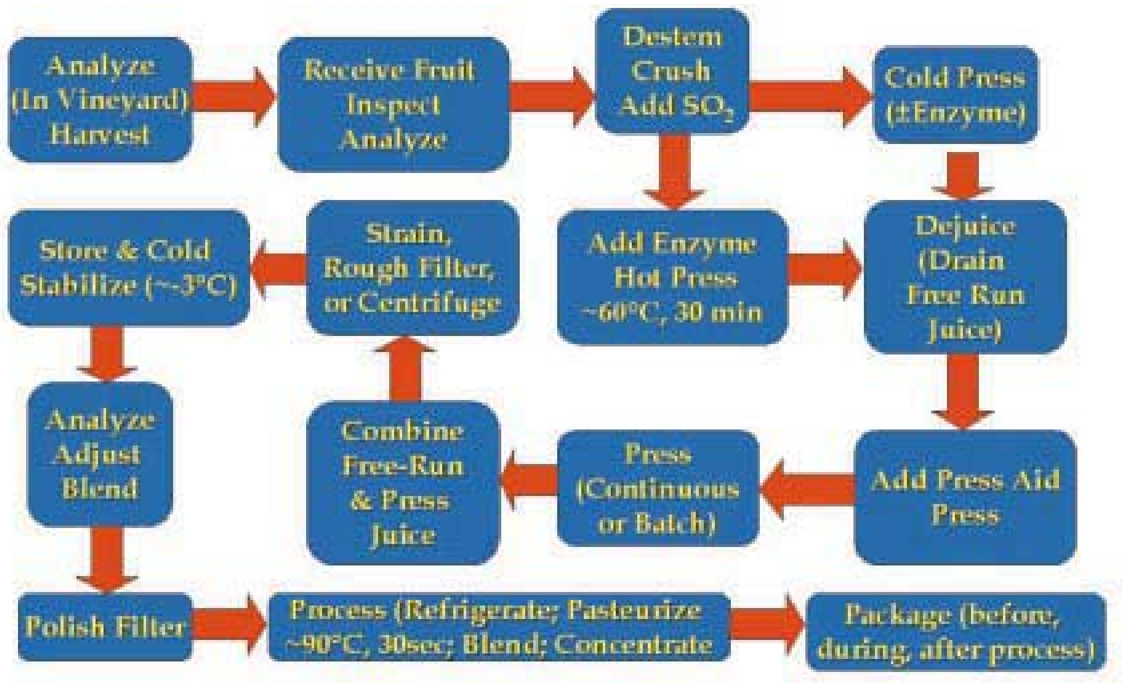


Figure 12.1: Grape juice manufacture flowchart.

Figure 12.2: Hot press enzyme treatment.
Prior to rice hull addition (bucket on left)

12.5.1 <u>Hot press</u>

Hot-press juice production involves the addition of a pectolytic enzyme to break down naturally occurring pectins and it uses paper pulp or rice hulls as press aids to facilitate extraction of juice (Figure 12.2). A hot-press method yields more juice that contains higher total solids, more non-sugar solids, tannins, pigments and other substances than a cold-press juice operation. When hot pressing, the temperature and time in processing can be varied within a range to produce juice with uniform colour from grapes harvested throughout the season. Excessive extraction temperatures (exceeding 65°C or 150°F) must be avoided to preserve juice quality.

Figure 12.3:. Grape stemmer/crusher.
Rice hulls added, auger feeds press

Following the schematic in Figure 12.3, harvested grapes are dumped into a hopper and transported by augers or pumps to a rotary stemmer-crusher that separates the fruit from the stem. The crushed berries are pumped through a steam-jacketed, vacuum preheater in which the pulp is heated to 60 to 63°C and passed into holding tanks. At this point, slow-moving agitators mix pectolytic enzyme and ~7 Kg of purified paper pulp (as a press aid) into each 1 000 Kg (metric tonnes, MT) of grapes. It takes between 30 and 60 minutes for the enzyme to break down the pectin to make the grape pulp ready for pressing. This part of the process helps to extract colour from the skins into the juice **(**Tressler and Joslyn, 1971).

Next, a dejuicer removes 30 to 35 percent of the free-run juice through a 40-mesh screen. The remaining pulp empties into a continuous screw press. The free-run juice may have as much as 20 to 40 percent suspended solids and is combined with the pressed juice that may have only 5 to 6 percent. The combined juices have most of the soluble solids removed by rotary vacuum filtration, pressure leaf filtration or centrifugation (Figures 6.14, 6.15 and 6.16). This process yields approximately 820 L of juice per MT of grapes. An additional 40 L of juice (after the juice and water have been concentrated) may be obtained by breaking up the press cake, spraying it with hot water and re-pressing. (This operation involving the addition of water to extract additional soluble solids is not permitted in table wine manufacture).

Grapes are unique from other fruits in that after juice extraction, the argols (potassium bitartrate, tartar in crude form) and tartrates must be precipitated. Otherwise, the argols will settle out upon cooling or even when filtered juice is refrigerated. These crystals, although harmless, are aesthetically unpleasant and can be mistaken for glass fragments. Thus to accomplish detartration (cold stabilization), the filtered juice is flash-heated at 80 to 85°C in a tubular or plate-type heat exchanger, rapidly cooled in another heat exchanger to -2.2°C and placed in tanks for rapid settling of argols. Seeding with bitartrate crystals and ion exchange methods exist to accelerate the cold stabilization step. The final processing into a single-strength juice or concentrate can occur once the argols have settled and the juice is racked off. The sediment can be filtered, resterilized and stored to allow the argols to settle again for optimal recovery of juice. The juice is now passed through a heat exchanger (heating it to 77°C) into an automatic filler and then into preheated bottles. The bottles are capped, pasteurized at 85°C for 3 minutes, cooled and labelled. In newer operations hot fill into plastic or aseptic packing are increasingly the methods of choice in grape juice processing **(**Chapter 8), although glass bottles still present a quality image.

12.5.2 Cold-press

The major difference between this method of juice production and the hot-press methods are the steps that allow for heating of the crushed berries to 60 to 63°C and holding in tanks with pectolytic enzymes. Without these steps, the dark colour from the dark-skinned grapes is not adequately extracted and the juice is a lighter colour. However, light coloured grape cultivars, lacking skin pigment and yielding a light green to yellow juice, cannot be hot pressed. Enzymes may be added to the cold-press juice to facilitate the clarification and filtration process following cold stabilization. However, extended contact time or high temperatures must be avoided to minimize enzymatic browning and undesirable colour extraction. Also, about 100 ppm of SO_2 should be added to minimize browning. Juice yields from this method of processing may be only 710 L/MT, depending on the cultivar and pressing efficiency. In view of the tough skin and pulp, bronze muscadine grapes may only yield about 560 L/MT when processed using the cold press method.

12.6 Processing factors that influence quality

Colour is one of the most important qualities of grape products. A typical purple-red is associated with high quality ‘Concord’ grape juice or other red grape juice, but changes in colour from purple-red to brown during processing and storage cause a drastic decline in quality. This is true of all cultivars and species of grapes. The red muscadine grape anthocyanin pigments are extremely unstable under conventional warehouse storage temperatures (Bates and Sims, 2001).

The increase in soluble solids of ‘Concord’ grapes from 14 to 18ºBrix during maturity usually corresponds to an increase in colour. After grapes reach 18ºBrix, colour quality may decrease. With Vitis vinifera cultivars, the colour will continue to increase up to 22 to 26 ºBrix. This condition is cultivar-dependent. The development of the typical purple-red colour in ‘Concord’ grapes begins at veraison (time at which berries commence to ripen) and

(Morris and Striegler, Somogyi, *et al.*, 1996b). However, as the pH of 'Concord' grapes gets to 3.7 to 3.8 or higher, a change in the pigment occurs which results in a colour shift from purple-red to blue. Therefore, it is important to harvest at a low pH (3.3 to 3.4) to maintain stable colour in processed juice

Extraction temperature influences juice colour by affecting the activity of polyphenoloxidase (PPO), which accelerates the rate of degradation of anthocyanins (colour ingredient) in crushed grapes. Inactivation of PPO by heat prior to depectination prevents loss of anthocyanins during extraction and subsequent storage. Storage temperature and time are primary factors for stability of colour in long-term storage. Research studies have shown that maturity, total acidity and juice storage time affect the amount of tartrates or argols in grape juice. The percentage of total phenols was increased in less-mature grapes and at high extraction temperatures (King, *et al.*, 1988).

Increased storage time is detrimental to juice quality. Studies showed similar results for 'Concord' and muscadine grape juice (Morris, 1985**)**. Juice from mature grapes had better quality initially than juice from less mature grapes but declined in quality more rapidly during storage. Storage at 35°C resulted in a more rapid loss of quality than storage at 24°C.

Many studies and trials have been conducted to develop and determine the acceptance of grape juices and grape juice blends from new cultivars. King, *et al.*, (1988) studied the effect of maturity and carbonation on muscadine grape juice. A sensory panel preferred the late maturing juices with high muscadine character and low phenolic and acid levels. Carbonated juices were lighter in colour but preferred equally to non-carbonated juices. Muscadine juices have been mixed with other popular grape juices, cranberry juice and apple juice for unique blends (Sistrunk and Morris, 1985). The dark juices were highly acceptable and retained their colour and flavour quality during a 12-month storage period. The lightest combinations (lighter muscadine with apple and 'Niagara' grape juice) were rated highest and remained stable during storage.

One study investigated the effects of amelioration and carbonation on five wine grape cultivars processed for juice (Rathburn and Morris, 1989). The juices with adjusted sugar and/or acid rated higher in flavour than those without the adjustment. Carbonation improved the ratings of the unadjusted juices but generally had no effect on adjusted ones. Two wine grape cultivars, Aurore and Verdelet, produced juices that rated comparable in flavour to 'Niagara', the white juice industry standard.

Later studies evaluated consumer preference tests on blueberry juice blended with water and with three different grape juices. On the hedonic scale used, a majority of the panel members ranked the flavour and colour of all four blends in one of the "like" rankings. The Blueberry-Concord blend had the highest ranking for flavour. Blueberry juice blends have been formulated and marketed as a result of this study. There is an excellent market for juice blends that use grape juice as a major ingredient.

12.7 Grape juice concentrate

Grape juice concentrated to 55, 65 or 68°Brix minimizes transportation and storage costs. This concentrate is diluted for use in single strength grape juice or multi-fruit and sparkling juice. Fruit concentrate is used full strength to sweeten jams, jellies, yoghurt, frozen fruit deserts, cereals, cookies and other bakery products. Many consumers perceive fruit concentrates to be a healthy replacement to table sugar and corn sweetener.

Concentration of juice is a vital operation of the juice processing industry. Juice may be concentrated by evaporation or freeze concentration. Historically, evaporation has been the most widely used concentration process for grape juice (Figure 12.4). Although many types of evaporators are available, all have essentially the same components (Hartel, 1992). Evaporators generally include a heat transfer surface, a feed distribution device, a liquid-vapour separator and a condenser. It is best to heat grape juice for as short a time as possible and to rapidly cool the product. Reduced exposure to heat minimizes the effect on flavour, aroma and sugar components. The following sections describe juice processing systems that are often coupled with essence recovery systems. The recovery systems are generally activated carbon columns that adsorb flavour and aroma compounds. Steam stripping can then be used to selectively remove these compounds for later addition to the concentrate or for other uses.

Figure 12.4: Grape juice concentrate plant, California.

12.7.1 <u>Rising film evaporator</u>

Rising film or long-tube vertical evaporators are sometimes used for juice processing. These evaporators have the advantage of short evaporation times due to high heat transfer rates through thin films at high temperature differentials. The evaporator consists of bundled tubes inside a steam chest. The feed stream is heated and introduced into the bottom of the tubes where some of the product is vaporized. The concentrated fluid rises under vacuum in a thin film along the tubes. The tubes empty into a vapour/liquid separator. The vapour is diverted into a condenser to be liquified or is passed through a carbon column

12.7.2 <u>Falling film evaporator</u>

A falling film is almost identical to a rising film evaporator except that fluid is pumped over the top of the tube bundle. This evaporator is the most popular type because it can handle more viscous fluids than the rising film evaporator is and can be operated at lower temperature differentials.

12.7.3 Plate evaporators

Plate evaporators operate similarly to plate heat exchangers. The fluid to be condensed passes on one side of a plate and steam flows on the other side. The superheated fluid then passes into a flash chamber. The vapour flashes off and the product and vapour are separated. High viscosity fluids can be efficiently concentrated in these evaporators possibly to concentrations above 60°Brix.

12.7.4 Centrifugal or conical evaporators

These relatively new evaporators produce a thin film using centrifugal force in single or nested cones. The cones have steam on the alternate side to provide a heat transfer surface. The systems operate under vacuum and allow the total time on the juice transfer surface to be as little as 0.5 seconds with only a small increase in product temperature. They are good for use with extremely heat sensitive and/or high viscosity products. Two major drawbacks are low capacity and high capital cost. However, these evaporators can also be used to distill, degas and deodorize liquids that have high heat sensitivity.

12.7.5 Freeze concentration

This process is based on the physical phenomenon of freezing point depression. Pure water freezes at a temperature of 0°C, but if a solid is dissolved in the water the freezing point temperature is lower. At a specific critical temperature, pure ice water crystals will form leaving a more concentrated liquid in solution. In freeze concentration, three fundamental elements are employed: 1) a freezer or crystallizer produces a slurry of ice crystals, 2) a centrifuge, wash column, or filter press separates the ice crystals from the slurry and 3) a refrigeration unit reduces the heat from fusion and the heat generated by friction from hydraulic flow, wall scraping and agitation of the slurry. Freeze concentration avoids the difficulties associated with heat-based evaporation methods. It is capable of concentrating most fruit juices to 50°Brix without appreciable loss of taste, aroma, colour, or nutritive value. Even so, freeze concentration has not achieved widespread commercial acceptance due to relatively high capital costs and low throughput.

12.8 Grape spreads

The process of making grape jelly, jam, preserves, butter or marmalade consists mainly of cooking the grapes and/or their juice in combination with sweeteners and pectins. United States federal standards dictate the ingredients, their proportions and the final concentration of soluble solids level. The ratio of minimum total soluble solids to fruit sweetener as required by the FDA is shown in Table 12.1.

Table 12.1: FDA minima for grape jelly, jam preserves and fruit butter.

Finished Product	Soluble Solids	Parts by weight Fruit	Parts by weight Sweetener
Grape Butter	43% minimum	5	2
Grape Jelly	65% minimum	45	55
Grape preserves/Jam	68% minimum	45	55

Jam, preserves and grape butter are made from whole or crushed grapes. The fruit pieces in preserves are usually larger than in jams. Grape butter is made from screened grapes and differs from jam in the final solids concentration and in the ratio of fruit to sweetener.

12.8.1 Sweeteners

The recognition by the jam and jelly industry that liquid sweeteners or syrups offer ease of handling and blending has greatly increased the popularity of corn sweeteners. Syrup from cornstarch may be produced in virtually any combination of viscosity and sweetness with other functional specifications.

Corn syrups are widely used by manufacturers of quality jellies, jams, preserves and butters. United States federal standards have authorized the replacement of up to 25 percent of total sweeteners with corn syrups for these products and up to 50 percent in marmalades. The use of corn syrups is economical and offers these quality improvements:

- Prevents sugar crystallization,
- Provides a pleasing level of sweetness,
- Improves texture and smoothness,
- Allows better colour retention.

It is not difficult to substitute corn syrup in any preserve recipe or formula: 0.57 kg of corn syrup is used for every 0.45 kg of sugar replaced. Therefore, 0.57 kg of corn syrup provides 0.454 kg) of solids and replaces the sugar on a solids basis.

A satisfactory gel must be formed to produce a spreadable product. Gel formation requires that the concentration of the water-sweetener-acid-pectin mixture be in the proper proportions. If the grape juice or fruit does not provide sufficient quantities of acid and/or pectin to form a good gel, then it is permissible under Federal standards to add pectin and/or acid in a quantity that “reasonably compensates for any deficiency.” Since Federal regulations fix the proportions of the grape juice or fruit, the relative amounts of sweetener, acids and pectins are the only variables.

12.8.2 Acids

A specific acidity (pH) is necessary for pectin to form a perfect gel. The optimum pH range for forming a pectin gel is 3.0 to 3.35. Within this pH range the consistency of the product will be primarily determined by the amount of pectin present. When whole grapes are present in the product, the fruit itself provides some spreadability and decreases the need for pectin.

US Federal Regulations allow the addition of vinegar, lemon juice, lime juice, citric acid, lactic acid, malic acid, tartaric acid, or any combination of two or more of these. The quantity of added acid must reasonably compensate for any deficiency in the natural acidity of the fruit ingredient without requiring a label declaration of added acid. The following standard acid solutions will produce the same general gel firmness under comparable conditions. Each acid may impart a slightly different tartness to the final product.

- Citric Acid. 0.454 kg of citric acid (crystals or powder) dissolved in 0.47 L of hot water will produce a solution with 17.6 gm of citric acid to 28.4 gm of solution.

- Tartaric Acid. 0.23 kg of tartaric acid (crystals or powder) in 0.47 L of hot water yields 11.1 gm of tartaric acid per 28.4 gm of solution.

- Lactic Acid is available as 50 percent food processing grade lactic acid and has a mildly acid taste that doesn't overpower delicate fruit flavours. It sets pectin approximately seven times slower than citric acid at the same pH and therefore can be used when a slower set is required. Its liquid form simplifies its use in most applications.

12.8.3 Buffer salts

If grape juice has a reduced pH in the natural state, the end product will have a pH lower than the optimum 3.0 to 3.35 and will cause premature setting of the pectin. Buffer salts (sodium citrate, sodium potassium tartrate or any combination of these) may be added to adjust the pH in this situation. The buffer salts may be added in solution or dry when mixed with the pectin. No label declaration is required.

12.9 Pectins

Pectin is a carbohydrate present in all plants, which, along with cellulose, is responsible for structural properties of the plant. Commercial pectins are normally produced from either citrus fruits or apples in accordance with internationally accepted specifications for identity and purity (Chapter 11).

The following discussion on pectins modified and adapted from the Handbook for the Fruit Processing Industry by Hercules Incorporated, Food Gums Group, 1313 N. Market, Wilmington, DE 19894-0001, now out of print.

High methoxyl pectins (HM-pectins) have a degree of methylation above 50 percent. HM-pectins require soluble solids above approximately 55 percent and a pH around 3.0 to form gels. Once formed, additional heating cannot melt the HM-pectin gel. The degree of esterification of HM-pectin determines the gelling rate and gelling temperature of the pectin, as reflected by the designations "rapid set" and "slow set" HM-pectins. At an elevated pH of 4.5, HM-pectin is stable only at room temperature or below. Elevated temperatures cause the pectin molecule to rapidly depolymerize and the gelling properties are completely lost.

Low methoxyl pectins (LM-pectins) are pectins with a degree of methylation below 50 percent. The gelling mechanism of LM-pectin differs substantially from that of HM-pectin. To obtain gel formation in a system containing LM-pectin, the presence of calcium ions is crucial. On the other hand, LM-pectins form gels at much lower percent soluble solids than HM-pectins and greater variations in pH are tolerated without a major effect on the gel formation. LM-pectin gels may melt when heated but show excellent stability at all temperatures in the pH-range 2.5 to 4.5. The right combination of two varieties of LM-pectins can very closely duplicate the texture and taste of a HM-gel at any Brix level from 20° to 70°.

Jellies are normally produced with slow set pectins because there is ample time for any air bubbles to escape from the product before gel formation starts. In jams and preserves, a uniform distribution of fruit particles throughout the container is desired. To avoid fruit flotation, gel formation must begin immediately prior to filling the container.

Choice of the type of HM-pectin for jams and preserves consequently depends on the filling temperature. Higher filling temperatures, used with small containers, normally require rapid set pectin. Medium-sized and large containers, where lower filling temperatures are necessary, require use of medium set and slow set pectins, respectively. In markets where jam standards state a minimum soluble solids of 68 percent, slow set pectin is normally preferred. At these high percent soluble solids, rapid set pectin gels at too high a temperature when pH is in the usual range. In jams with a relatively mild acidulous taste and high pH, rapid set pectin must be used, especially if soluble solids are at the lower end of a 60 to 68 percent range.

12.9.1 Addition of pectin

Pectin must be completely dissolved to ensure full utilization and avoid unhomogeneous gel formation. Complete dissolution requires dispersion without lumping and can be achieved by means of a high-speed mixer. The pectin is completely dissolved in a few minutes thus pre-blending with sucrose is not necessary.

12.9.2 Syneresis

The use of pectin in jams, jellies and preserves has two major purposes: creation of a desired texture and binding of water. If the water binding effect is not achieved completely, the final gel will show a tendency to contract and exude juice, known as syneresis.

Products based on HM-pectin must have greater than 60 percent soluble solids. High solids counteract the contraction of the gel structure and correctly produced HM-pectin-based products seldom show any syneresis. HM-pectin jellies do not reform their gel texture when mechanically ruptured and once initiated, the syneresis will remain constant or even increase over time. A small amount of syneresis will occur during normal consumption (when the gel is broken), especially if the product is stirred or pumped.

LM-pectins are usually used in jam, jellies and preserves with soluble solids below 60 percent for reduced calorie applications. The tendency for syneresis to occur increases with lower solids, but this phenomenon is partially counteracted by the ability of LM-pectin to reform the gel texture after mechanical rupture, especially if the calcium content of the system is relatively low.

Only a small amount of syneresis should occur after breaking the gel structure in the soluble solids range of 40 to 60 percent. At soluble solids lower than this range, syneresis becomes pronounced and it may be necessary to combine LM-pectin with other water binding hydrocolloids, such as locust bean gum, if a completely syneresis-free product is required.

The basic formula for making grape jelly is given in Table 12.2 and conforms to the Federal standards of identity. This formula has been tested on a commercial scale still, manufacturing processes and conditions may vary. Several test batches should be prepared and evaluated before a formula is used in commercial production.

12.9.3 Procedure

1. Begin heating the standardized unsweetened fruit juice in the cooker.
2. Blend the pectin with 6 to 10 times its weight of dry sugar and add this mixture to the juice in the cooker.
3. Add the balance of the sugar and/or corn syrup. Heat until the desired finishing temperature or solids content is reached. This finishing point is determined in one of the following ways, listed in order of preference
   (a) Heat to a refractometer reading of 65 percent soluble solids (ºBrix).
   (b) Heat to about 6ºC above the boiling point of water, about 106ºC at sea levels.
   (c) Heat to a ºBrix of 65 to 68.
4. The acid solution is not added until just before the filling operation. In some cases it may be desirable to add the acid directly to the container and pour the jelly solution into it while stirring.

Table 12.2: Basic jelly formula.

Ingredients	Pounds	Percent
Standard grape juice[1]	82	45
Sucrose	75	55
Corn syrup (43°Baume) acid	31	[2]
Pectin, slow set	$^1/_2$ to 1%	[3]

[1] any juice containing the specified amount of soluble fruit solids (86.5 percent)
[2] Quantity may be varied to obtain a pH of 3.0 to 3.35 in the finished product
[3] Quantity will be varied, depending upon type of juice and the pectin manufacturer's recommendation.

Source: C*orn Syrup in Jams, Jellies and Preserves,* Technical Service Bulletin No. ID1a, Clintonnes Corn Processing Company, Clintonnes, IA, undated.

The United States Federal Regulations stipulate that the juice portion of the basic jelly formula contains a minimum percentage of soluble fruit solids. In mixed juice products, the percentage is the average percent soluble solids of each respective juice as determined by the FDA. The average required soluble solids content of grape juice used to prepare jelly and the corresponding factor (reciprocal of each percentage times 100) are 14.1 and 7.0, respectively.

This factor is used in a short-cut formula to calculate the amount of juice that must be used to equal the soluble fruit solids of a standard juice in the basic formula. For example, the average soluble solids of grape juice is 14.1 percent. Therefore, the 37.3 kg (82 lbs) of standard grape juice in the formula must contain 5.3 kg (11.66 lbs) of soluble fruit solids. An adjustment is necessary in most cases, since the grape juice used by the jelly maker will not contain exactly 14.1 percent soluble solids. If the grape juice on hand contains 10 percent soluble solids, for example:

37.3 kg (82 lbs) of standard grape juice
0.10 (soluble fruit solids) x 7 (factor) = 53 kg (117 lbs) of juice would be required for each 45.4 kg (100 lbs) of sweetener solids (Clintonnes Corn Processing Company).

CHAPTER 13

TREE FRUIT : APPLE, PEAR, PEACH, PLUM, APRICOT AND PLUMS

13.1 Raw material

Apples are more widely grown than any other fruit; apple trees of one kind or another are grown all around the world. (Root, Somogyi, *et al.*, 1996b). Apple production can vary from one year to the next by as much as 20 percent, depending on the climate of any given year. There are hundreds of apple cultivars, but only about 20 cultivars are commercially important. More than 90 percent of this production is represented by 14 cultivars and only five of these account for most of the world's apple production: Delicious, Golden Delicious, McIntosh, Rome Beauty and Granny Smith.

Newer cultivars are becoming increasingly common in the marketplace. Some newly popular cultivars are Gala, Fuji, Jonagold, Braeburn and Lady Williams. Many new commercial cultivars are red strains of the primary cultivars. There is a wide variety in their characteristics. For instance, Gala matures in 100 days or less while the Western Australian cultivar Lady Williams needs more than 200 frost-free days to mature. Some need long cold winters to break dormancy while others can be grown in very mild climates such as Israel.

While some cultivars are grown exclusively for use in processing, at least some of the harvest of all commercial apple cultivars is used in processed products. Only sound, ripe fruit should be used for further processing because decay, damage, maturity, firmness, colour, soluble solids, acids and tannins of the fruit impact the quality of the product. Perfectly good fruit from the commercial fresh market cultivars (an average of 20 percent) are used for processing. Some fresh market cultivars produce excellent juice and still others produce superior sauce. Some apples are grown specifically for processing, but most of the apples that are sold to the processor are salvaged fruit grown for the fresh market. Premium price is paid for large, bruise-, disease- and insect-free apples delivered to the processor. This requires apple producers to pay full attention to their cultural details whether growing for fresh or the processing markets. Production practices for apples will vary not only with the apples' destination, but also with the climate and soils in which they are grown.

13.2 Harvest

The majority of the apple crop is hand harvested because only a very small percentage of that crop is intentionally harvested for further processing. To use mechanical harvesting, a grower or cooperative of growers must be producing at least 40 000 bushels (~ 700 MT), in order to justify the cost. Since apple processing is mainly thought of as a salvage operation, the amount of apples available to process is largely dependent on the size of the fresh market harvest and its quality. Consequently, processing apples are harvested and stored in the same manner as premium, fresh market apples.

Salvage operation or not, it is absolutely essential that fruit for juice (or any other application, for that matter) not be "drops", i.e. apples that have fallen from the tree and are collected off the ground. There have been numerous incidences of food poisoning associated with the use of drops for fresh, unpasteurized apple juice (Table 4.1). Even with improved sanitation and a microbial kill step between processor and consumer, drops will invariably contain many damaged or partially rotten fruit, impossible to grade out. In addition, it doesn't take many mouldy juice apples to exceed the 50 parts per billion limit in juice of the fungal metabolite, patulin, a human carcinogen (Ashurst, 1995). While most aflatoxin analyses have been done on major crops such as apple, grape and orange, it is likely that tropical fruits contain levels worth establishing (and probably reducing).

One advantage that apples have over other more perishable fruit crops is that the fruit may be successfully kept in storage for a few weeks to several months. However, to maintain their high quality for processing over storage time periods, it is extremely important that they are picked at the proper stage of maturity and storage conditions are optimized for specific apple cultivars. The processor must determine when the apples for processing are to be harvested.

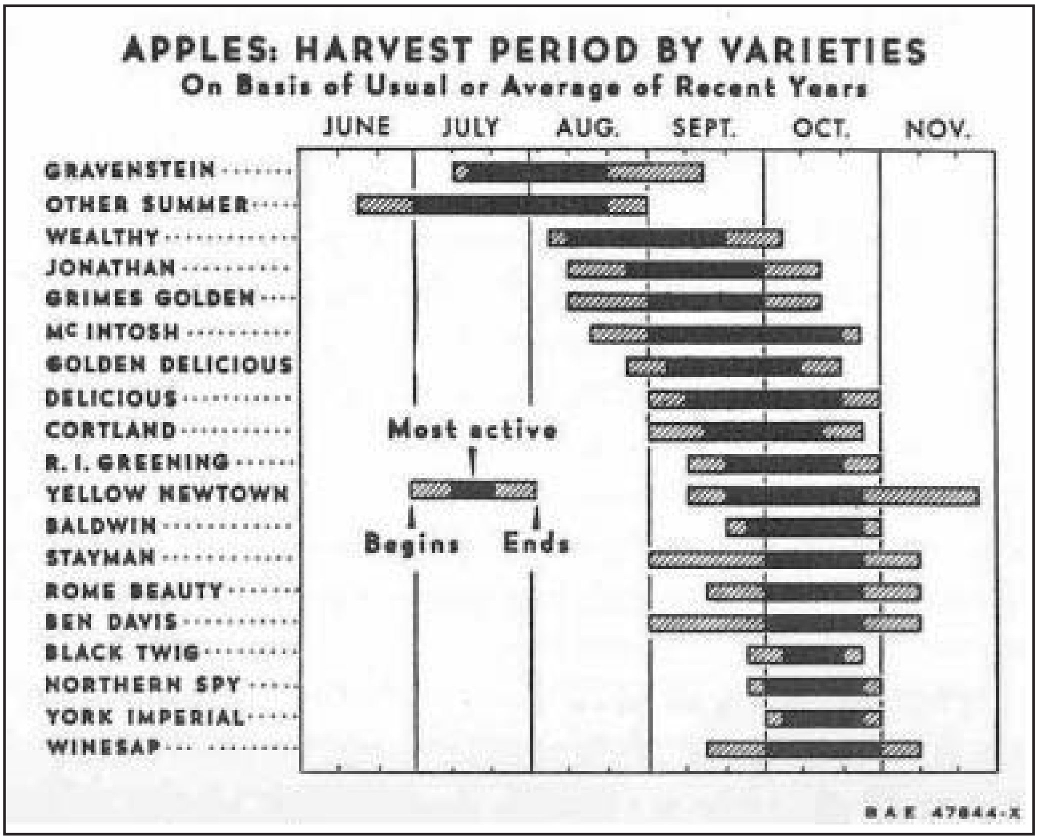


Figure 13.1: Apple maturity, Northern Hemisphere.
(Childers, *et al.*, 1995)

Generally speaking, there is a window of about five to 20 days, depending upon cultivar and climatic and cultural conditions, during which the fruit can be picked with reasonable assurance that the apples can be stored until they can be processed. Figure 13.1 illustrates these conditions (Childers, *et al.*, 1995). Apples continue to increase in size to maturity, when the apple drops from the tree. Harvest must begin as late as possible and yet while the fruit still adheres to the tree. Fruit mature enough to drop will not store well or make the best product. Of course, sound Good Agricultural Practices (GAPs) logically prohibit the use of drops for juice manufacture (FDA, 1998a).

While no one method is entirely dependable under all circumstances, there are several methods available to determine the proper time to pick. These indices may serve one cultivar differently from another. The intended use of the cultivar is also a consideration. It may be best to combine several of these indices with plain good judgement and experience to determine the proper harvest date. Some cultivars have such a body of research attached to them that these indices can be more specific to these cultivars.

13.2.1 Time elapsed from full bloom to maturity

It is important for the processor to predict when the apples will be arriving at the processing plant. Full bloom is considered to be that time when 80 percent of the blossoms on the north side of the tree are open. The time from bloom to maturity can be predicted for each cultivar for each growing region. Seasonal mean temperature seems to have little effect on this time interval, but other conditions may affect its accuracy. High temperatures just before harvest may cause excessive fruit drop before harvest time. Trees heavily fertilized with nitrogen may delay skin colour in the apples, or fruit drop may be more pronounced. A light crop tends to mature sooner than a heavy crop. These variables may be very disconcerting.

13.2.2 Starch/iodine test

This quick, widely used method uses a standardized iodine solution applied to a cut apple cross-section. A darkened pattern develops which indicates the level of starch remaining in the apple. The pattern is compared to established charts that are available commercially. If the starch level indicates that the starch is about half cleared from the fruit, then the apple is ready for harvest and storage. When it is almost all cleared, it is ready for consumption. Samples should be taken twice a week near to harvest of 10 apples/block from tagged, typical trees. Select two typical apples/tree.

13.2.3 Pressure test

One of the best methods of determining the proper harvest date is a firmness test. Firmness of flesh can be determined by a pressure gauge (Figure 13.4) designed for this purpose and available commercially. The determination is based on the fact that firmness gradually decreases as fruit matures. Several readings are averaged to get the result. Season, cultivar, sampling and testing techniques can influence firmness. Instructions on the proper use of the instrument are available from the manufacturer.

Figure 13.2: Penetrometer (Puncture pressure gauges).
Penetration pressure is one indication of ripeness

13.2.4 Soluble solids

Since starch in apples gradually changes to sugar as the fruit matures, a few drops of apple juice may be tested for sugar development right in the field with a hand-held refractometer (Figure 13.5). However, soluble solids values can be more variable than firmness readings. It is wise to blend the juice of several typical apples before testing for sugar. Cultivar, crop size, cultural practices and growing season can influence the readings.

Figure 13.3: Hand and bench refractometers.
For soluble solids (ºBrix) and specific gravity determinations.

13.2.5 <u>Ground colour change</u>

The green “ground” colour of the unexposed side of the apple changing to yellow can be an index of maturity. However, even this can be influenced by the nutritional condition of the tree and vary from cultivar to cultivar. Too much nitrogen may delay the change. Growers must know their cultivar. The colour change of Golden Delicious at 135 to 150 days from full bloom can give a good index of maturity. However, other cultivars may drop from the tree before colour change.

13.2.6 <u>Flesh colour change</u>

Flesh colour change from light green to white in Delicious, Golden Delicious and some other cultivars is useful. Harvest before the change may result in storage scald for susceptible cultivars. In contrast, seed colour change from white to brown is a poor index of maturity.

13.2.7 Water core

Water soaked areas in flesh for McIntosh and Jonathon can be an indication they are past good storage life. Water core early in Red Delicious can indicate prime condition for storage, but if water core areas are coalescing, storage will be shortened and apples should be moved early.

13.2.8 Easy removal of fruit from spur

When some cultivars are ready to pick, they can be separated from the spur without breaking the stem by lifting, with or without slight twisting. Some cultivars (McIntosh and Delicious) may drop before maturity because of early frost or other factors, while there are cultivars like Jonathan and Stayman that may retain fruit until over mature. Thus this index may only indicate when picking is necessary to save the crop. With the use of “Stop-Drop” chemical sprays to “stick” the apples on, this index is of little value.

13.3 Storage

Since most processors cannot use the whole harvest they receive as they receive it, some fruit is stored, short term, as they come in, not refrigerated. Other fruit is stored refrigerated in a temperature range of 1 to 4°C, depending on the cultivar. The next level of storage is controlled atmosphere (CA). CA storage usually consists of a modified atmosphere, 2 to 3 percent oxygen and 1 to 4 percent carbon dioxide, at a reduced temperature. The exact specifications are adjusted to the cultivar being stored. Apples can maintain quality under these conditions for 4 to 6 months. Only the highest quality apples destined for the fresh market are placed in CA storage. However, many times the fresh market price will drop to the point that CA apples will be dumped to a processing market. Apples from CA storage should be allowed to “normalize” for a few days before processing. These apples and apples from refrigerated storage are capable of producing good quality processed product. Processors take into consideration that different qualities of juice or applesauce can be manufactured from the same cultivar, depending on the type of storage, time of storage and stage of maturity when processed.

Advances in controlled atmosphere technology have had a dramatic effect on apple storage logistics and opened up markets hitherto unavailable for fresh and processed apple products. This is an advantage not fully shared by other fruit crops whose shelf life extension by CA is much less.

13.4 Storage facilities

There are essentially three types of storage buildings for apples: air cooled storage, mechanically refrigerated storage and refrigerated and controlled-atmosphere (CA) storage.

13.4.1 Air-cooled storage

These storage houses cool by admitting cold night air (applicable climates) at inlets near the floor of an insulated building and forcing upper accumulated warm air out at outlets near the ceiling. Both openings are closed during the day. These storages are economical and effective in areas where the night air becomes cooler than the accumulated air in the storage house.

13.4.2 Mechanically refrigerated storage

For longer periods of storage than is afforded by the air-cooled storages, mechanical refrigeration is needed. This would become necessary to extend the season on fresh-market apples or to extend the cooling of processing apples because the volume is so large they can not be completed in the period of time afforded by the air-cooled storage situation. Specifications of room size, room construction, capacity, compressors, condensers, expansion coils, etc. for both mechanically refrigerated storage and CA storage can be found in Childers, *et al.*, 1995.

13.5 Processing

Apples are processed into a variety of products, but by far the largest volume of processed apple products is in the form of juice. Apple juice is processed from apples that are unsuitable for peeling, such as “eliminator” apples, smaller than ~57mm diameter, too small to peel, etc.

Apple juice can be produced and sold in several forms. Fresh apple juice or sweet cider is juice of ripe apples, bottled or packaged with no form of preservation. This form needs to be sold at the orchard or at outlets close by. Even under these conditions it is important to pasteurize the juice to eliminate *E. coli* or other dangerous organisms. This recommendation has been established after several incidents of serious *E. coli* problems associated with unpasteurized apple juice in the United States of America.

Apple cider is considered around the world as the fermented juice of the apple, but in the United States apple cider refers to sweet cider, the simple juice of early season, tart apples. Shelf-stable apple juice is sweet cider that has been treated for preservation. This could include clarified juice (depectinized, filtered, pasteurized and bottled), crushed apple juice (pasteurized and with a high pulp content), natural unfiltered juice or juice concentrate; frozen (natural or clarified and concentrated to 42°Brix) or high Brix (clarified and concentrated to 70°Brix)

Table 13.1: Nutrients in the edible portion of 454 g of apples.

Products	Energy (Calories)	Protein (g)	Fat (g)	Carbohydrate (g)	Calcium (mg)	Phosphorus (mg)
Raw fresh	242	0.8	2.5	60.5	29	42
Applesauce	413	0.9	0.5	108.0	18	23
Unsweetened	186	0.9	0.9	49.0	18	23
Apple juice	213	0.5	0.1	54.0	27	41
Frozen slices	422	0.9	0.5	110.2	23	27
Apple butter	844	1.8	3.6	212.3	64	163
Dried, 24%	1 247	4.5	7.3	325.7	141	236
Dried, 2%	1 601	6.4	9.1	417.8	181	299

13.6 Apple juice manufacture

There are a number of procedures employed in apple juice production, depending upon the end product desired. Figure 13.6 is a generalized flow scheme for producing some of these products.

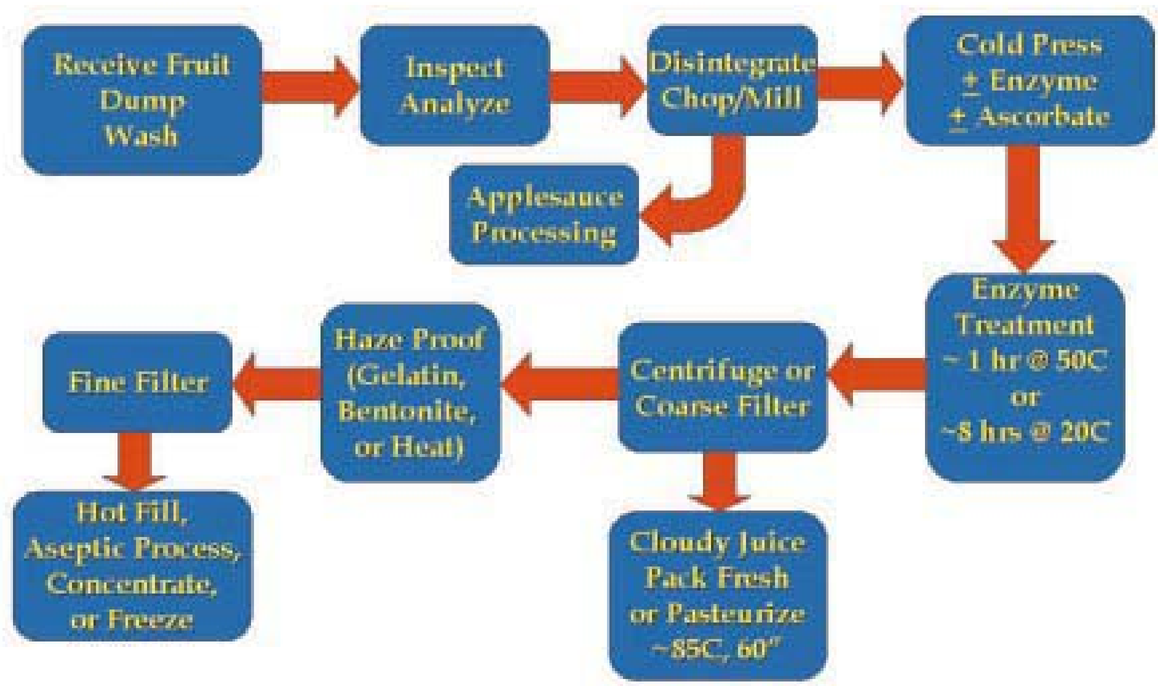


Figure 13.4: Apple juice flowchart.

Figure 13.5: Apple receiving at juice plant for immediate processing or storage.

13.6.1 Prejuicing

Apples are brought to the processing building and dumped by the truckload or out of pallet bins, into a water-filled tank (Figure 13.7). (Such practices should be discouraged for fresh juice manufacture, due to the potential for contamination, particularly when dump water temperature is lower than the fruit temperature. In this case water-borne pathogens may be sucked into the fruit and hence protected from subsequent fruit surface sanitary measures). Fruit are then spray washed and sorted (removing damaged and diseased fruit). Depending on process logistics, clean, sorted fruit may be stored as described in Sections 13.3 and 13.4 (and inspected again before juicing) or juiced immediately. To prepare them for juicing, a disintegrator, hammer mill or grating mill may be used to grind the apples. The mashed apples need to be free of large pieces yet not so fine that pressing becomes difficult. The type of extraction equipment may dictate the chopping method to achieve highest efficiency. The hammer mill adjusts more easily to different pulp consistencies.

Although apples contain potent browning enzymes, pectin enzymes are in low concentrations. Thus, commercial macerating enzymes are usually added. There are a number of enzyme products prepared just for apple mash pretreatment that break down cell walls to free the juice, lower the viscosity and reduce pulp slipperiness.

13.6.2 Extraction

Extraction may be accomplished through pressing chopped apple continuously or in batches. There are a number of pressing systems:

- The hydraulic cider press is one of the older methods of pressing ground apples but is still widely used in commercial setups around the world (Figures 6.9 and 6.10). Since the ground apple pulp passes directly from the chopper to the press cloth, this method usually does not involve using enzymes in the mash. The press racks are now made of food grade plastic. (They were previously square lattices of wood cut to fit each press.) They are slats about 1.9 cm wide and .6 cm thick, spaced about .6 cm apart. The top part of each slat is rounded for easy cleaning. Elm or poplar were the woods of choice for these slats, but oak has also worked well. All slats should be well coated with a chemical resistant varnish to make them nonabsorbent and easy to clean. Nails should be brass or, better still, stainless steel. For loading, a rack is placed in the press truck; a form or bottomless box is placed on the rack; a press cloth is placed on the rack so that the corners hang over the sides. The press cloths are coarsely woven cloths cut to fit a given press. They are made of cottons, wool, or nylon, with nylon being preferred because it is light, strong, easy to clean, nonabsorbent and resistant to stains and mildew. However, they need to be "heat set" so that they will not harden when washed in hot water during cleaning. Apple pulp is placed in the form until it is evenly filled. The apple pulp is then wrapped up in the cloth. Another rack is placed on the filled cloth and the process repeated until there is a stack of "cheeses" that fit the capacity of the press. Ripe apples allow thinner layers of mash than harder apples. The layers should be uniform for highest efficiency of pressing. Some plants have devices that measure the "cheeses (using either a volumetric or weight principle) to eliminate the chance of uneven loading. The average pressing cycle for a cider press is 20 to 30 minutes,

- The bladder press is an effective batch system. The Willmes Pressor is a horizontal, cylindrical screen lined with press cloth material, with a large inflatable tube in the centre that inflates and presses pulp up against the loth-covered wall (Figure 6.11). The whole assemblage is rotated after it is filled and closed and as the tube is being inflated. Juice is expressed into a catch trough below and collected from a drain. Pressure on the tube reaches a maximum of 6 atmospheres or approximately 600 kPa. Usually a press aid is needed to keep the pulp from adhering to the press cloth and stopping the free flowing of the juice. Cleaned rice hulls work very well and a good grade of disintegrated wood pulp (sheets of paper manufactured for this purpose) works well also, but is more absorbent,

- Continuous screw presses can be used successfully with slippery apple pulp with the addition of press aids. Ground apples and a press aid are fed into the top of the press and are gradually pressed down by a tapered screw revolving at 3 to 5 rpm. Stationary paddles or interrupter bars in the path of the screw prevent the mass from slipping on the screw. The cylinder around the screw is a reinforced screen through which the juice travels to a drainage pan at the bottom. At the bottom, the pomace is forced through an annulus that is partially closed by a sliding cone. The cone is mounted on the pistons of an air cylinder. Varying the air pressure to the cylinder varies the amount of compression on the pomace. Usually, a pressure of 500 to 600 kPa is required. Screw presses that operate in the horizontal plane, but otherwise in the same manner, are equally effective. A common press aid is a purified wood pulp that has been fluffed in a hammer or attrition mill to give a low bulk density of ~0.16g/ml. This press aid is added to the ground pulp at a rate of $1^1/_2$ to 4 percent as the pulp enters a horizontal-mixing trough equipped with open loop paddles. The paddles form a helix that mixes the pulp and aid in about 45 seconds at a speed of 50 to 60 rpm. Frequently a mixture of 0.5 percent to 1 percent rice hulls is used with 2 percent fluffed wood pulp. There is some danger in adding off flavours to the apple juice through the misuse of press aids or by excessive pressure and shear action that crush seeds and grind cores. Juice yields of 690 to 770L per MT of apples may be obtained. The suspended solids in the juice usually range between 2 to 6 percent,

- Continuous plate or belt press is a press in which a layer of apple pulp is squeezed between moving vertical plates. Apple pulp with press aid added is spread on a horizontal nylon belt having a weave similar to that in press cloths used in the hydraulic press. As the belt is moved forward converging chains to bring its outer edges together form a continuous U-shaped pocket before it passes between vertical panels attached to heavy roller type chains. Increasing pressure is exerted on the pulp causing the juice to be forced out between the plates and into the collection pan. At the end of the press, the cloth belt diverges until it passes over horizontal rollers for discharge of the pomace and cleaning. It then returns to the point of feed. A juice yield of 730L/MT of apples may be obtained,

- Screening type centrifuge is a revolving, cone-shaped, self-cleaning screen through which juice is squeezed by centrifugal force. The pulp that is discharged from this system is then pressed again by one of the first two methods listed. It has been determined that this method is rapid and gentle, but less efficient than the aforementioned methods.

Apple juice from any of the presses described is invariably cloudy and contains particles (bits of apple and press aid particles) that can be removed by screening. A cylindrical “cider” screen, which is made of stainless steel screening of approximately 100 to 150 mesh, revolves on a system of rollers. The revolving action keeps the screen clean by causing the pomace to gather into small balls and finally into a continuous roll which falls off the end of the slightly sloping screen. A stainless, dewatering shaker screen can also be used **(**Figure 6.14**)**. Screened juice reduces the load on the filter.

13.6.3 Unclarified juice

For the “natural” look associated with fresh apple cider, the ground apple pulp is treated with ascorbic acid before pressing to minimize browning. The juice is screened or settled, but not otherwise filtered. The ascorbic acid is best added directly to the mill, to be mixed with the pulp as soon as possible after the apples are crushed and pulp exposed to air.

About 30 grams of ascorbic acid added to 100 kg of apples seems to be effective, if all processing is done without delay. (This amount may be cultivar dependent since a cultivar may have a very active oxidative enzyme system requiring an increase in ascorbic acid.) In view of recent fresh cider food poisoning outbreaks, the majority of unclarified juice is flash pasteurized.

13.6.4 Enzyme treatment

An enzyme step is not employed if the end product desired is a cloudy or "natural" looking apple juice. Otherwise, after juice extraction, the raw apple juice must be treated with enzymes to remove suspended solid materials. If not removed, this colloidal material can clog filters, slowing production and can cause the juice to form a haze later on. Enzymes work by hydrolyzing soluble pectinaceous materials, hemicellulose and other polymers and colloids that increase juice viscosity, thereby leaving the juice more easily filtered. Many enzyme preparations are available both in liquid and powder forms. They are all subject to conditions that can influence enzyme performance such as pH, temperature, enzyme concentration and length of reaction time. Considering these variables, it is recommended that test trials be conducted with specific enzymes under typical operating circumstances to determine the proper concentrations and conditions.

There is a hot and a cold method for enzyme treatment. In the hot method, the enzyme is mixed into juice at 54°C and held for 1 to 2 hours. In the cold treatment, the enzyme is mixed into the juice at room temperature, 20°C and held 6 to 8 hours. The enzyme activity can be monitored by adding five millilitres of juice to 15 ml of HCL-acidified ethyl alcohol, observing the mixture for 5 minutes for gel formation. No gel formation means that the depectinization has been completed.

13.6.5 Tannin and gelatin treatment

For highly astringent apples, tannin removal is beneficial. Many of these tannins can be precipitated with addition of gelatin. However, in order not to remove all tannins and therefore some of the flavour and colour of the juice, it is often the practice to first add more tannins and then precipitate a certain amount with gelatin. A classic, older procedure of possible value with overly astringent juices is described (Walsh, 1934):

Solution 1. Dissolve 9.45 g of tannin (tannin acid) in 176 ml of 95 percent ethyl alcohol. Then add 704 ml of water and mix thoroughly.

Solution 2. Dissolve 21.2 g of gelatin in 704 ml of water and add 176 ml of 95 percent ethyl alcohol.

Heat a portion of the water and add the gelatin slowly, stirring continuously. Then add the rest of the water and dissolve the gelatin by heating in a pan of hot water or double boiler and stirring. Add the alcohol and mix well.

These solutions should be kept in stoppered bottles and may be used as needed, the alcohol acting as a preservative in both cases. In some cases the gelatin will gel when cold, but can be liquefied when needed by putting the container in hot water.

Four clear glass quart bottles should then be filled to the neck with apple juice and numbered 1, 2, 3 and 4. Then add to each bottle the following amounts of Solution 1 (tannin) and Solution 2 (gelatin).

	Bottle No. 1	**Bottle No. 2**	**Bottle No. 3**	**Bottle No. 4**
Solution 1. (ml)	10	10	10	10
Solution 2. (ml)	5	10	15	20

Measure and add the amounts of solutions shown to each bottle, adding the tannin first in all cases and shaking well after the addition of each solution. Let the bottles stand for 10 minutes. The bottle showing the clearest juice is the one to which the proper proportions of tannin and gelatin were added.

The quantities of tannin and gelatin to use for 380L-batches of apple juice are then found by referring to the table below. For smaller amounts of cider, proportionate amounts of tannin and gelatin are used. For example, if bottle 3 showed the clearest juice at the end of 10 minutes, 35 gm of tannin and 126 gm of gelatin should be added to each 380L of juice; for 190L, one-half these amounts should be added.

AMOUNTS OF GELATIN AND TANNIN TO BE USED FOR 100 GALLONS APPLE JUICE

	Bottle No. 1	**Bottle No. 2**	**Bottle No. 3**	**Bottle No. 4**
Tannin (grams)	35	35	35	35
Gelatin (grams)	42	84	126	252

The actual clarification of apple juice according to this procedure is carried out by first stirring into the apple juice a solution containing the proper amount of tannin. A few minutes later the correct quantity of gelatin, dissolved in hot water, is added, stirring constantly. It is most essential that the juice be very thoroughly stirred after the addition of the treating chemicals. After standing overnight, the clear supernatant liquids are drawn off and filtered. In some plants, the liquid is not separated from the sludge since the filter retains the sludge. This speeds up the operation and eliminates the waste due to discarding juice with the sludge."

The success of the tannin-gelatin method of clarification is due to some extent on the experience of the operator. Too much gelatin in the juice can slow filtering and cause the finished juice to cause a cloud or precipitate upon storage.

13.6.6 Heat clarification

Flash heating the apple juice between 82 and 85°C will coagulate the particles that interfere with juice filtration. The juice is then rapidly cooled and filtered or centrifuged. There are some difficulties with this method.

- An additional heating step prior to final pasteurization may have a detrimental effect on flavour,
- Rapid cooling is necessary to minimize flavour changes,
- The method efficiency is cultivar dependent and not applicable to all apples,
- If the pasteurization temperature is higher than that used for flash heating, additional heat-induced coagulation may occur after filling.

13.6.7 Centrifuged apple juice

Centrifuged juice is slightly clearer than unclarified juice but quite cloudy and viscous compared to the filtered juice although free of visible suspended particles. The pressed, screened juice is fed to either a tubular bowl or continuous centrifuge (Figure 6.15). Both types work well, but the continuous type is self-cleaning and therefore does not have its operation interrupted for cleaning.

13.6.8 Bentonnesite fining

A means of reducing both haze and juice astringency uses the adsorbtive properties of bentonnesite. The finely divided bentonnesite clay particles have an enormous surface area to which tannins and protein-tannin complexes adsorb. Since this may be at the expense of colour and flavour, treatment amounts must be carefully chosen. Fining is also effective in reducing harshness and astringency in some wines (Amerine, *et al.*, 1980; Vine, *et al.*, 1997). As such, it has an unexploited juice flavour cleanup potential.

13.6.9 Filtration

To obtain a brilliantly clear apple juice polish filtration is necessary. Filtering freshly pressed juice is a difficult operation due to the pectinaceous nature of apple juice and the potential for post filtration haze formation. Untreated juice can be rough filtered in large capacity filters with large filter areas that can be easily cleaned. The juice from this method has superior flavour and excellent body. It may have a slight haze that increases with time as proteins and tannins react. Filtering juice that has not been depectinized reduces the filtration rate to about $^{1}/_{3}$ of enzyme treated juices.

There are many types, styles and capacities of filters available. Plate and frame filters with disposable pads or sheets are easy to clean, but readily clog after extended use (Figure 6.16). Continuous filters with back flush capability are preferred. The juice contact surface should be stainless steel or food grade plastic. In a pre-coated filter, the liquid, containing suspended filter aid, is forced by pressure of vacuum through a coated membrane (Figure 6.16**)**. In the case of apple juice, the medium is usually diatomaceous earth. This medium is available in many grades. It takes skill and experience to operate a filter in an apple juice plant. There is a great deal to know about pre-coating, filter aids, special pumps, etc. Either a new filter must arrive with complete directions, or an experienced operator needs to be on hand for consultation (Tressler and Joslyn, 1971).

13.7 Pasteurization

The most important method of preserving apple juice is pasteurization, which involves heating the juice to a given temperature for a length of time that will destroy all organisms that can develop, if juice is put hot into containers that are filled and hermetically sealed. Flash pasteurization is, true to its name, the rapid heating of juice to near the boiling point (greater than 88°C) for 25 to 30 seconds. Steam or hot water passes the juice between plates (Figure 8.5) or through narrow tubes that are heated. Design of the heat exchanger provides juice flow turbulence and even heating to prevent scorching and burn-on in the unit. There are numerous flash pasteurization heat exchangers available. They are all adaptable to a continuous operation set-up.

Juice can be canned or bottled in cans, glass or plastic. Cans used are enamel or lacquer lined to resist corrosion from the juice. As the cans travel the canning line, they must pass through a can washer, be filled from filling machines and immediately sealed on a can-closing machine. After closure cans should be positioned or inverted so that the hot fill will be in contact with the lid and thus, pasteurize it. From here, the cans must be removed to a cooling room where they will be cooled to near 38°C to stop the effect of high heat on the contents. If cooled to a temperature lower than 35°C, the labels will tend to detach, the can will not dry and will be susceptible to surface rusting. This necessitates that the cans travel continuously from washing, to filling to cooling to labelling and packing.

Bottling juice requires specialized equipment. Cans can be roughly handled, but bottles are fragile ("bruising" not visible to the eye can cause breakage later) and susceptible to thermal shock. Temperature changes of greater than 7°C should be avoided. Bottles must be cleaned before filling then heated (steam jets) within 7°C of the fill temperature. The best filler draws the liquid into the bottle by evacuating the bottle, thus reducing oxidation. Bottle closures can be screw caps, crown caps or vacuum caps. The vacuum caps have the advantage of allowing less headspace; if the contents ferment only the cap will blow off rather than the bottle exploding. Bottles also must be cooled. This can be accomplished in a special cooler that sprays hot water on them and decreases the temperature as the bottles move along. At the end, they emerge close to 38°C, still warm enough to dry.

Newer packaging and processing systems use plastic containers that can be hot filled and rapidly cooled without the danger of thermal shock. In addition, aseptic processing greatly reduces heat-induced flavour changes. Still, glass bottles are the traditional standard and carry a quality image not implicit in cans, plastic bottles or aseptic packs. Recent concerns about contaminated fresh cider have resulted in United States Federal Regulations that strongly discourage unpasteurized juice and advise pasteurization of all apple juice products, even at small roadside stands and country markets that prepare juice on site. The alternative is a not very appealing warning label on fresh apple juice (FDA, 1998b).

13.8 Concentration

Apple juice may also be concentrated as a form of preservation, for use as reconstituted juice and in further processing. Evaporating systems such as rising film evaporators, falling film evaporators and multiple effect tubular and plate evaporators can be used (Chapters 8, 11 and 12). Because apple juice is so sensitive to heat the multiple effect of evaporation with essence recovery is the one most commonly used. This method heats the juice in stages. The juice is evaporated to 20 to 25°Brix at 90°C and the aroma captured by fractional distillation. This concentrate is brought to about 40 to 45°Brix at about 100°C. In the third stage it is heated to about 45°C and concentrated to about 50 to 60°Brix. The final heating at 45°C will bring it to 71°Brix. The concentrate is cooled to 4 to 5°C and standardized to 70°Brix and then bottled, barrelled or stored.

13.9 Applesauce

Although not strictly a beverage, applesauce merits mention as a co-product of apple processing operations. For making applesauce, clean, sorted, peeled apples, plus all the apple sauce recipe ingredients, are chopped and cooked in a cooker heated by live steam or jacketed steam. Liquid sugar is the preferred sweetener because it imparts a desirable “sheen” to the finished product appearance. The chopped apples are cooked at 93 to 98°C for 4 to 5 minutes to soften the apples and inactivate the enzymes responsible for browning. The cooked apples are passed through a pulper with a screen for the purpose of removing undesirables and for sizing the sauce. Baby food goes through a ~0.8 mm screen for the finest of textures. The sauce is next inspected by being poured over a backlit flat plastic sheet. Inspectors remove all dark pieces with a flexible vacuum tube.

The applesauce is now ready to be canned or bottled. It is heated to 90°C and piston-filled into cans or bottles. Applesauce must be filled and sealed at 88°C in the seamer or capper. To insure a vacuum in the container, a jet of steam may be passed over the top of the container just prior to sealing. As the steam condenses, a vacuum is created in the container. This step is important in cans to prevent headspace detinning. The containers are held for 1 to 2 minutes prior to cooling to insure sterilization of the lids or caps. Water-cooling takes place in a draper belt, walking beam or reel cooler to an average of 35 to 40°C to prevent “stack cooking” in the warehouse.

13.10 Pears

Pears are processed very similarly to apples. They should be ripened to a pressure test of 0.9-2.2 kg before processing. Pears may be harvested while they are still firm 7.6 to 9 kg pressure test and safe to handle without damage. If they are stored at 1°C for one week they can then be ripened uniformly for four to five days at 10°C and 85 percent humidity. To produce nectar, pears are washed and mechanically peeled and cored, after which they are heated to 85°C for 3 minutes in a continuous steamer. This hot fruit is passed through a continuous extractor with a 0.084 cm screen and then a brush-type finisher with a 0.08 cm screen. After adjustment with sugar, citric acid and water to a values of about 13 to 15°Brix and 3.9 to 4.2 pH, the nectar is flash pasteurized at 96°C in a heat exchanger then hot-filled into cans, sealed at (at least) 88°C and held inverted for 3 minutes before being cooled. Can linings should be used that have no reaction with the nectar .

Clear pear juice is generally obtained through the help of enzymes. Heated, sliced ripe pears are put through the finisher and cooled to 38°C. A macerating enzyme treatment is used for several hours at this temperature to depectinize the puree. At room temperature, the time should be extended to over night. When a clear sparkling juice can be obtained from the puree, then the depectination has taken place (this can be tested in a centrifuge). The amount of press aid will vary for each operation, but about 1 to 2 percent is added to purees put through most rack-and-frame presses. This juice and about 0.25 percent filter aid can then be clarified in a pressure filter with pre-coated plates.

13.11 Peaches

In contrast to the fruits previously mentioned, peaches are not usually extracted as juice, but rather as a pulp or puree. The juice, employing pectic enzyme treatment, is light in colour, flavour and body compared to the pulp. When dealing with peaches, the whole pulp refers to the peach pulp after mashing and before fibre and other coarse material is removed. Pulp refers to the whole pulp after fibre and coarse material is removed. Pulp base is pulp with such additives as sugar, acid, colour and, stabilizer. This product can be stored and used in a variety of ways. Peach juice drink is a product prepared by dilution of peach pulp or peach pulp base. Cloudy concentrate is pulp base with some of the water evaporated. And clear juice concentrate is peach pulp or pulp base that has the insoluble material removed by pectic enzyme treatment and filtration, followed by evaporation.

Peach cultivars show a wide variation for ripening date, ºBrix, total acidity, flavour, colour and freedom from browning. Most of the cultivars grown for the fresh market are suitable for pulping. The ideal peach for processing will score high on these points: flavour; balanced soluble solids and acids; suitability for mechanical peeling, pitting and pulping without producing seed fragments; maximum of yellow colour and minimum of red colour; difficulty in turning brown; uniform ripening of whole peach; enough firmness and stability to withstand a reasonable amount of handling after ripening. This ideal peach is fully ripe and soft fleshed. The best peach is obtained from peaches graded for ripeness and free from rot, other spoilage and insect damage, rather than from orchard-run (second grade) fruit.

Peaches may be peeled by steam peeling or by lye peeling. In the lye peeling operation, whole peaches are either immersed in or sprayed with a lye solution (up to 5 percent in strength) at a temperature of at least 99°C for 15 to 20 seconds. They are held for another 60 seconds and then spray washed with cold water. Some operations disregard the peeling step and simply pulp the whole fruit with the skin intact. This yields 13 to 15 percent more whole pulp. The aroma and the colour of the pulp can be influenced by disregarding the peeling and is also a function of the cultivar and stage of maturity.

If peaches are heated before pulping, the pulping process can be made easier, oxidation reduced and cloudiness stabilized. This is best accomplished by heating in a continuous thermo-screw for 2 minutes at 93°C. The jacket around the thermo-screw should be kept at ~125ºC during this blanching/softening step.

Pulping the fully ripe peaches removes the seed and reduces the peach pulp by passing it through a ~3 mm screen. The speed of the paddle is best at about 1 000 rpm. Faster speeds will whip air into the product. This pulp is then passed through a finisher with screens having 0.061 to 0.084 cm perforations, operating at about the same speed. Pulp is separated from the fibre and unripe portions at this stage and is reduced to a liquid. A 1 MT load of peaches will produce about 494 L of puree. For peach nectar, 241 L of 30°Brix sucrose syrup should be added to each 380 L of puree. If the pH needs to be reduced to 3.7 to 3.9, then it may be necessary to add citric acid.

At this point, the puree may have air mixed in it, which can lead to deterioration of the nectar's colour and flavour. It may be advisable at this point to pass the nectar through a deaerator. The nectar is now ready for flash pasteurization. Processors mix in 0.14 percent ascorbic acid at this juncture and then feed the nectar uniformly into the pasteurizer. Puree is pasteurized at 88 to 93°C and quickly cooled to 1.7°C if it is destined to be aseptically canned and refrigerated. Otherwise the puree may be filled hot directly into cans or bottles. These cans should be closed using vacuum and nitrogen or a vacuum produced with a steam jet. Cans should then be cooled with water spray, dried with warm air, labelled and stored in a cool dry place.

13.12 Apricot

Apricots for juice or concentrate are processed in the same manner as peaches, but are not peeled, although the skin and other fibrous material are eventually removed in the juicing process. Fruit, unsuitable for cutting, but without rot, are heated to 99ºC in a thermal screw, then run through a pulping unit to remove the stones. A series of finishers removes the skin and fibrous material. The juice can be made into nectar with the addition of sugar, water and acid. The juice made into concentrate is brought to 32ºBrix. Puree is sweetened with approximately 1.8 times its volume of 15 to 16ºBrix sugar syrup and acidified with citric acid. Apricot puree can be processed in cans or hot filled directly from the pasteurizer (Somogyi, 1996b; Tressler and Joslyn, 1971).

13.13 Plums and prunes

In areas of heavy plum production, harvest date is determined by skin colour changes that are described for each cultivar. There are colour chip guides available designed to determine maturity for each cultivar. Some cultivars have skin ground colour that is masked by full red or dark colour development during maturation. For these cultivars, flesh firmness is measured for an indicator of maturity. Plums are less susceptible to bruising than most peach and nectarine cultivars at comparable firmness.

Plums do not usually give up a juice upon crushing and pressing and must be treated with a macerating enzyme in order to yield an actual fruit juice. The method for obtaining this juice is similar to the following:

- The fruit are first sorted, washed and drained. The fruit is then steam heated for about 10 minutes to prepare it for pulping with a very coarse screen to remove the pits. It also helps inactivate the naturally occurring enzymes and prevent darkening. The resultant puree is put through a heat exchanger to cool to 50ºC,

- At this point an appropriate enzyme is thoroughly mixed in (amount dependent on type and cultivar of fruit). This mixture is left to stand from six to 12 hours until juice drains readily through a sample of cheesecloth. Now a pressing aid is added, such as infusorial earth. From this point on the juice is pressed similarly to apple pulp, except two layers of cloth are used. A normal heavy apple press cloth is covered with a light canvas or heavy white muslin to insure a clearer juice and keep the seams from bursting upon pressing. A "cheese" of pressed cloths and racks should be built up as with apple pulp pressing,

- The plum juice thus obtained must be filtered and have the Brix adjusted to ~23ºC. The juice is ready to be pasteurized. It may be flash pasteurized to 88ºC and filled into appropriate bottles or cans at 82 to 85ºC, sealed and placed on sides a few minutes to pasteurize the lids and then cooled. Alternatively, the juice may be filled cold into crown-capped bottles, placed in water and heated to 85ºC for 30 minutes for litre size and smaller bottles.

Prunes, which are dried plums, have long been used for juice. Prune juice is reported to have laxative properties. This effect plus the shrivelled appearance of prunes has resulted in a negative image for the product. Hence, the industry is attempting to replace the word prune with "dried plum", hoping for a more positive image.

The plum changes appreciably during dehydration with both enzymatic and Maillard reactions contributing to the dark colour and typical heated fruit flavour of prunes. At ~18 percent moisture, it is impractical to extract juice, so prunes are subjected to an aqueous extraction (Figure 6.7**)** to produce the sweet brown juice with prune-like characteristics and similar physiological effects.

Two methods are used to produce prune juice from dried plums. Manual diffusion is seldom employed commercially anymore, although it is mentioned here because this method is simpler, less expensive and requires less equipment. This method calls for dried fruit to be steeped in large vats (holding 160 to 180 kg of prunes and 300 to 380 L of water) at 83ºC for 2 to 4 hours. This extracted juice is combined with the juice of a second extraction of the same fruit, done the same way, except only 63 L of water /100 kg of fruit is used. These combined juices are added to the juice of a third extraction; again performed the same way, only using 40L water/100 kg fruit. This combined extract is either used to extract a fresh vat of prunes (in which case the Brix is generally over the desired level) or is concentrated to the desired ºBrix of 18.5 to 21. The extracted residue pulp is discarded.

The second method is called the disintegration method. As much as 550 kg of prunes are washed and vigorously boiled and agitated for 60 to 80 minutes, until disintegrated. This mash is then pressed as described for apple pulp or put through a high-speed centrifuge (approximate 4 000 rpm). The resulting juice, about 10 ºBrix, is allowed to settle, siphoned off and then must be concentrated to the desired ºBrix of 18.5 to 21.

Curiously, other dried fruit extracts are not as popular as prune juice, although the dramatic effects of dehydration followed by extraction should yield some rather novel, high value beverages worth exploring.

CHAPTER 14

BERRIES

Berry juices have long been popular in Europe where the technology has been extensively developed for high value added fruits (Ashurst, 1995). The recognized phytochemical composition of berry fruits is resulting in renewed global interest in and industrial demand for these juices and beverages (Hakkinen, *et al.,* 1999**)**. Economic considerations limit but do not eliminate 100 percent berry juice products. The characteristic dominating flavour and potent colour of these fruits make them ideal for blending. Curiously, the only three commercially important fruits originating in North America are cranberry, blueberry and certain grape species such as V*itis labrusca, rotundafolia* and *aestavalis.*

Berry and berry-like fruit are characterized by relatively soft fleshed, small diameter (5 to 25 mm) pieces (often with complex morphology) that lack a peel or inner core. Seeds are small and easily separated during juicing. However these fruit grow on or close to the ground and are easily contaminated (Figure 14.1). In addition, the soft flesh is more susceptible to physical and insect damage. The small unit size also makes detection of defects and blemished portions difficult to discern and eliminate.

Figure 14.1: Strawberry harvesting on sandy soil.

14.1 Cranberry

Cranberries grow in reasonably severe temperate climates and require substantial moisture. In fact peat bogs or fields that can be flooded to protect from frost and facilitate harvest are ideal (Cranberry Institute, 2000). Other Vaccinium species such as the swamp cranberry *(Vaccinium oxycoccos),* native to Northern Europe, are less well known. They grow up to the Arctic Circle and have health and phytochemical value worth exploring (Konovalchuk and Konovalchuk, 2000).

The model for berry fruit utilization is arguably the North American cranberry (*Vaccinium macracarpon*). The small, firm, red berry is too high in acid and low in sugar (Brix/acid less than 2.0, pH less than 2.6) to consume directly. However, the strong characteristic flavour and stable red colour make cranberry a popular component of beverage blends (Figure 14.2). In fact, creative blending and marketing of cranberry juice with other fruit juices and non-fruit ingredients have resulted in the current and increasing demand for cranberry beverages. The imputed health value further increases consumer interest in all types of cranberry products as a cure for bladder and urinary tract infections.

Figure 14.2: Cranberry-based juice beverages.
Other popular blends include apple, grape, cranberry, kiwi and raspberry.

Cranberry, although firmer than most berry fruit, is relatively easy to juice (Nagy, *et al.*, 1993; Somogyi, *et al.*, 1996b). The firm flesh and cool harvest climate permit handling, cleaning and holding procedures that would be quite damaging to other berry fruit. A coarse chopping followed by paddle or screw finisher with ~5mm screening will produce a thick seed and skin containing pulp suitable for juicing. In view of the high value of the juice, extraction procedures are designed for maximum juice yield, consistent with acceptable quality. Macerating enzyme treatment, hot press and water extraction of the press cake optimize yield. The extract can be combined with the press juice or concentrated separately. If not over extracted, the press cake has value in sauces or other co-products, including natural colour extracts.

In view of the popularity of cranberry products, production is expanding rapidly, but the price of concentrate is still much higher than all large volume juices. Whether exploitation of other Vaccinium species will offer processing alternatives remains to be seen. If these or similar species could be grown in regions with low labour and land costs, favourable climate and necessary automation, dramatic industrial growth should follow.

14.2 Strawberry

Except in regions where strawberries are grown for processing, the cultivars available and supply of strawberries for puree and juice is usually dependent upon the vagaries of the fresh market. When the fresh market price drops due to competitive pressure from cheaper growing regions, the crop is harvested and either frozen whole (four parts fruit, one part sugar) for bakery, jam, or jelly use or pureed for pulp/juice manufacture.

Furthermore, when the demand for processing raw material drops too far, or the processing/frozen storage pipeline is full (no available capacity), the crop is abandoned in the field. This unfortunate situation often faces juice processors a seasonal peak in fruit that exceeds fresh market demand and factory capacity or processing plant operational difficulties that reduce juice throughput. In either case sound fruit is wasted.

The extremely soft and delicate strawberry is one of the easiest to juice. A rigorous inspection is necessary to remove rotted and mouldy fruit. A gentle chlorinated water spray then eliminates soil. The whole fruit can be fed directly to a paddle or screw pulper fitted with a 0.5 to 10 mm screen to pulp and separate the puree from the cap, leaves and larger seeds; a few small seeds are acceptable in many puree uses. A second pulper with a less than 0.5mm screen effectively removes remaining seeds and produces a smooth, is then filled into 20 to 200 litre containers and frozen at –18ºC. Actually, the puree should be deaerated prior to freezing and frozen in less than 25 litre portion at less than 25ºC for optimum quality retention but this is rarely done. It takes many hours for the centre of a 200 litre barrel of puree or frozen fruit to freeze, ample time for quality deteriorations to commence.

Although frozen and thawed fruit are quite mushy, almost a puree, juice does not separate easily from either fresh or frozen pureed strawberries. The thick seed-containing puree requires a macerating enzyme treatment. About 50 to 100 ppm of enzyme followed by holding at 10 to 20ºC for two to three hours (cold press) or 30 minutes at 60ºC (hot press) produces juice at a 70 to 80 percent yield (puree basis). The cold press provides a better strawberry flavour, while from the hot press yield and colour are higher. Centrifugation followed by filtration produces a clear juice with typical strawberry flavour and colour.

Unfortunately, strawberry anthocyanin pigments are less stable than those in many fruits are. Thus rapid handling and deaeration are recommended. An additional problem is the formation and subsequent precipitation of ellagic acid in the juice. While ellagic acid is a desirable phytochemical in strawberries, in juice it forms unsightly, powdery sediment. This precipitate forms slowly in a brilliantly clear juice, even after microfiltration or sterile filtration and is accelerated by pasteurization (Musingo, *et al.,* 2001**)**. The “brute force” remedy is heating the juice rapidly to ~80ºC, immediately cooling, holding until sedimentation is complete and then polish filtering. If the juice is later subjected to elevated temperature during concentration or pasteurization, quality suffers.

Steam extraction is well suited to strawberry (Figure 6.8). This procedure yields a juice with diminished fresh flavour, but excellent colour and overall stability. Strawberry juice with a ~5 to 8ºBrix and acid level of 0.5 to 1.0 percent is rarely consumed as is, but contributes flavour, ascorbic acid, moderate red colour, (and a good image) to blends **(**Figure 14.2a. and b.). Strawberry juice can be concentrated, but the colour is somewhat diminished by even the gentlest process.

Figure 14.3a: Chilled strawberry juice cocktail blend.
Contains orange, apple, pineapple and grape.

Figure 14.3b: Pasteurized strawberry-kiwi beverage, 15 percent juice.

14.3 Blueberry

Blueberry (*Vaccinum* species) is another fruit whose popularity is soaring due to its phytochemical properties. Fruit in excess of fresh market needs are much higher priced and less available than strawberry. Hence, the juice is expensive and extraction procedures are designed to maximize yield.

Blueberry juice preparation can be more difficult than other berry juices due to their high level of mucilaginous material. Cold press extracted juice has a light blue colour and delicate flavour, although hot press enzyme treated juice has a deep purple-blue colour and stronger flavour. Blueberry pigments are more stable than strawberry, but less stable than cranberry and blackberry.

14.4 Blackberry

Blackberry juice can be extracted either from fresh or frozen fruit. Frozen berries may be cold pressed because freezing plays the part of heating in breaking down the mucilaginous components. This method usually produces a higher yield, allows the plant to operate outside of harvest season, produces a better colour than from fresh cold press juice and nearly as good as from heated fresh berries and seems to have a fresh fruit flavour not present in the heated berry juice.

For hot processing, clean, ripe, wholesome berries are heated and agitated in a steam-jacketed kettle between 60 to 82ºC. When this temperature range is reached, the crushed berries can be pressed in a hydraulic rack and cloth press.

Single strength puree can have a ºBrix from 10.5 to 18; a puree concentrate from 20 to 40ºBrix; a single strength juice 10ºBrix; and a juice concentrate at 45 to 68ºBrix.

Although most berry fruit and the accompanying juice technology originate from the temperate zone, there are related tropical species that can be handled in a similar manner. For example, Mora de Castilla (*Rubus glaucus*a) tropical blackberry grows well in the Central American highlands. The deep red berry is an important commercial crop and has domestic and export use in canned and frozen form. Mora can produce stable, highly coloured red juice and wine. However, the harvest season does not coincide with cooler temperature, as in the temperate zone. Thus the fruit is more subject to deterioration in the field and spoilage throughout processing steps.

14.5 Raspberry and other berries

There are a number of berries whose processing steps are similar with the important caveat that many factors discussed in Chapter 5 dictate specific treatments. The juice process of choice for fresh or frozen berries (raspberries, boysenberries, loganberries, young berries and assorted berries) is the hot press method. The fresh ripe berries must be inspected for soundness and cleanliness and cleaned before being put in a steam jacketed kettle and heated to between 60 to 82°C. Berries should be agitated while being heated. As soon as the desired temperature is reached, the berries can be pressed directly or passed through a pulper fitted with screens sized to remove seeds. [Refer to thermal screw discussion in Part 1].

The juice should be deaerated, either in batches (~710mm Hg or higher vacuum for 30 minutes) or by a continuous process (again at a similar vacuum, but almost instantaneously).

Berry juices are preserved best through flash pasteurization. Temperatures of 80ºC or higher for 30 seconds are recommended. Bottles or cans must be filled completely and closed immediately, followed by prompt cooling. Cans must have special enamel lining, since juices high in nitrates or containing SO_2 (less used now) easily compromise some can enamels.

14.6 Cherry

Cherries can be processed similar to some berry fruits even though they come from a fruit tree. Cherry cultivars range from extremely sour to sweet low acid with °Brix/A ratios from 7 to 35. Juice processing and utilization will vary accordingly. Fresh or frozen whole cherries can be crushed in a grape crusher or fed directly to a paddle or screw pulper. Machine clearance and speed must be set so that seeds are not broken. Depitting is unnecessary for juice, although it is needed for other cherry products. Heating the whole fruit to about 60ºC with gentle agitation and a macerating enzyme greatly facilitates juice and colour extraction. A cold press produces a more fresh flavoured juice provided that subsequent processing does not adversely affect flavour.

Sour cherry juice is amenable to blends with less acidic juices or as a nectar with added sugar. The clarified juice can be concentrated with good colour retention and, for a 100 percent cherry juice, sour and sweet juices can be blended. Sweetened cherry puree forms the base of syrups and ice cream toppings (Somogyi, *et al.,* 1996b).

CHAPTER 15

TROPICAL FRUITS

There are a number of semi-tropical and strictly tropical fruit both with recognized and unrecognized juice, puree or pulp potential. Processing technology, including juice products from the better-known fruits such as pineapple, guava, mango, papaya and passion fruit have been well covered by Jagtiani, *et al.*, (1988) and Nagy, *et al.*, (1993). The semi-tropicals, such as citrus and kiwi, can grow in tropical highlands to freeze-limiting elevations. Most others are strictly tropical as their commercial production is severely limited by temperatures close to freezing and actual freezes are devastating. Even tropical highlands may be impractical, except in protected microclimates (Popenoe, 1920; Martin, *et al.*, 1987; Mortonnes, 1987).

Some products such as pineapple juice, banana puree, mango and papaya puree and, increasingly, guava puree and passion fruit juice are commercially important. Others are:

- Less well known or so many species/cultivars exist that commercial selections have yet to be developed,
- The fruit is not available in sufficient quantity to justify industrialization,
- Strong, fresh whole fruit demands preclude a juice co-product, except locally,
- Highly dispersed production makes a central juicing facility impractical.

Fruit includes lychee, rambutan, mamay, carambola, acerola, mangosteen, naranjilla, pitaya, babaco, guanabana (and other members of the *Annonceaea* family) and a host of other fruit recognized and consumed only locally and sporadically.

Many undoubtedly possess sensory, nutritional, nutraceutical/phytochemical and other desirable quality features as yet under exploited. Compared to the shelves of a health food store, there are many with food and dietary supplement value awaiting discovery. When prepared and stabilized in liquid form these exotics can provide additional value and diversity to juices.

At one time the Tropical Plant Introduction Station at Lancetilla, Honduras, operated by the United Fruit Company, had the start of a comprehensive, growing selection of tropical fruit germplasm. Sadly this international resource, now owned by the Honduran government is comparatively unrecognized, under-funded and depleted in germplasm. The Inter-American Institute for Cooperation on Agriculture (IICA) in Trinidad is encouraging tropical fruit utilization (IICA, 1998). It will take a global effort, considerable international cooperation, increased funding and many decades to put tropical horticultural crops in proper perspective.

15.1 Pineapple

The manufacture of pineapple juice is a good example of the interaction of plant breeders, horticulturists, food technologist and engineers in an industrial process that evolved over many decades (Tressler and Joslyn, 1961 and 1971; Nelson and Tressler, 1980; Mumaw, Somogyi, *et al.*, 1996b**)**. Peeling and coring equipment was predicated on a cylindrical pineapple, figuratively the shape and diameter of a number $2^1/_2$ can (~99 mm diameter by ~109 mm height). The 'Smooth Cayenne' (Figure 15.1) was well suited to the Ginaca machine that, in a series of operations turned a cleaned, crown and root-free, whole pineapple into an intact cylinder (subsequently sliced into rings), core and extracted flesh from the residual side peel and 2 ends. Several sizes of Ginacas accommodate inspected and sized uniformly cylindrical fruit at the rate of over 90 fruit/minute, while off shape fruit are routed to other uses for instance juice or vinegar.

Figure 15.1: Smooth Cayenne pineapple.

The juice was and to some extent still is a by-product of solid pack operations. Table 15.1 shows the partitioning of processed pineapple products in roughly descending order. A fresh whole fruit or the cored and peeled flesh has the highest market value, but a limited shelf life, up to three weeks under proper conditions. Large slices in syrup or juice are next in value. Broken slices and smaller fruit can be cut into spears and chunks. The odd pieces are diced into ~1 cm cubes as crush. These operations generate a large amount of juice. The eradicator flesh (scooped from the peel or shell and ends), together with peeled off-size/shape fruit and core, are comminuted and passed through a finisher or screw press. Screening and centrifugation of these fractions is necessary to remove skin specks or eyes and adjusts the pulp level for blending with other juice streams.

Table 15.1: Hierarchy of pineapple products.

Product	Procedure
Fresh fruit, whole	Careful selection with refrigerated holding
Fresh peeled and cored	Refrigerated cylinder, slices, or spears
Whole slices	Frozen or thermally processed in No.$2^1/_2$ to No.1 cans
Spears and chunks	Odd or broken rings, frozen or thermal processed
Crush	Eradicator flesh, frozen or thermal processed
Juice	Canned single strength or frozen concentrate
Vinegar	From combined process waste streams
Stems	Bromalain

The pineapple thus goes from intact fruit to at least five separate product streams within several minutes in a high throughput, labour efficient, capital intensive system. Many pineapple cultivars are ideally suited for juice, including some with exceptional flavour, but lighter in colour than the typical “pineapple yellow” of ‘Smooth Cayanne’. Of course, odd sized, noncylindrical-shaped cultivars and fruit with deep seed pockets are not amenable to a Ginaca machine. In these cases, other mechanical or even hand peeling/coring devices are used. Yet, given the commercial effectiveness of ginaca type operations, it is hard to compete with anything less than a highly mechanized operation.

Thorough comminution of pineapple flesh and cores followed by passing the slurry though finishers with ~0.5 to 1-mm screens produces a pulpy juice of 12 to 15ºBrix and °Brix/A around 20. Decanting centrifugation then adjusts the pulp (insoluble solids) level to 12 to 24 percent (Hooper, Ashurst, 1995).

Pineapple juice with a pH of ~3.5 can tolerate moderate thermal processing. A fill temperature of 70ºC followed by rapid heating to 95ºC or a hot fill at ~90ºC with rapid cooling in both cases maintain quality. Major quality defects are: excessive heating or slow cooling, resulting in a dark, scorched juice; too little or too much pulp creating a thin or thick consistency; excessive shell material yielding dark specks and harsh flavour. Home or village processing operations exist where under/over ripe or spoilt fruit are juiced with poor results. The juice can be concentrated to 72ºBrix with or without essence recovery and add-back. The frozen concentrate has a global market as reconstituted juice or a major blending stock. Pineapple is either the base or component of many juice and beverage blends. The trade demands a bright yellow colour, however, some pale yellow, even whitish-fleshed cultivars, when fully ripe can have an excellent flavour, although only appreciated locally.

Despite the impressive efficiency and automation of all pineapple operations, from production through juice processing and shipping, competitive pressure from low labour and land cost Pacific Rim countries have largely decimated the Hawaiian pineapple processing industry. Since the early 1960s when Ginacas and other high throughput equipment became available outside the United States, efficient, low cost producers have captured the majority of global markets for processed pineapple.

These lines rapidly replaced hundreds of workers manually performing mundane preparation steps. Migration of the Hawaiian pineapple industry and ongoing shifts of citrus processing from Florida to Brazil and elsewhere serve as both an inducement and challenge to entrepreneurs interested in exploiting a region's juice potential. Given an adequate infrastructure, sufficient capital and skilled labour, developing regions can compete effectively against industrialized countries, but so can their evolving competitors.

15.2 Mango

Mango (*Mangifera indica* L.) is the prototypical tropical fruit, available globally in many forms. The puree can be the co-product of the fresh fruit or canned slice packing operations. In addition, some cultivars and mango seedlings are extremely fibrous but very flavourful. The fibre content precludes their use for fresh market, so juicing is the logical alternative. As long as this texture defect is not accompanied by the characteristic terpene-like flavour of many chance seedlings, the fruit has beverage value.

Mangos for puree should be fully mature, even soft, but not overripe. Ease of handling is quite variety-dependant. Mechanical peeling presents some difficulty due to the thick, leathery peel and the presence of bitter substances in the skin, requiring careful and complete removal. Heat treatment and lye peeling have been used successfully (Brekke, *et al.,* 1975). A paddle pulper fitted with brushes and 0.040 to 0.20 screens can effectively remove the pulp, provided that the discharge throat is large enough to eject the intact seed (Figure 6.6). It must be emphasized that success of mechanical peeling is highly cultivar dependent. Thick peel with the attendant latex and bitter compounds cannot be mechanically separated without contributing off-flavour to the puree.

The extracted puree is susceptible to browning and should be processed immediately. The pH will generally range from 4.5 to greater than 5.0. Thus acidification with citric acid to ~4.0 pH is necessary, if the puree is to be pasteurized. A hot fill temperature of ~95ºC for 2 min is adequate for sanitary puree or nectar, followed by rapid cooling. Canned or glass packed products should be heated and cooled carefully to prevent scorched flavour and browning. For optimum flavour and colour, rapid blanching at ~90ºC for 1 minute followed by cooling to about 30ºC and freeze preservation is recommended (Nagy, *et al.*, 1993).

Mango nectar is produced by mixing the puree with citric acid, sugar and water to a proscribed Brix/acid ratio, dependent upon raw material and desired use. Puree is blended with other juices that complement mango flavour, lower the pH and provide thinner viscosity. Various pulp dehydration methods can be employed to produce dried powders. The additional expense incurred by dehydrating mango puree must be balanced against the saving in transportation and storage.

15.3 Passion fruit

One of the more easily processed fruits, passion fruit (P*assiflora edulis* and *flavicarpa*) is more readily consumed as the juiced flesh than in the whole seed-containing pulp form. Yellow (edulis) and purple (flavicarpa) cultivars are popular, although many under exploited members of the *Passiflora* genus exist and are popular in tropical regions **(**Nagy, *et al.*, 1990). Although morphologically similar, the yellow is more acid and with a pH of less than 3.0, generally requires dilution and sweetening for consumption.

Parallel commercialization in Hawaii and Australia has resulted in fruit processing lines that efficiently separate the gelatinous pulp from the seed and rind. In Hawaii this is accomplished by a centrifugal extractor where the pulp and some seeds of mechanically sliced fruit pass through holes in the spinning centrifuge. The Australian system lightly crushes the whole fruit between rotating disks popping the placenta away from the rind. More recently an Italian compression roller system has been developed industrially (Somoygi *et al.*, 1996b). In all cases a finisher with a 0.8 to 0.3-mm screen separates seeds from the juice. Other systems employing a vacuum to remove the pulpy interior of halved fruit or an oversized pitting device have been mentioned (Jagtiani, *et al.*, 1988).

Single strength yellow passion fruit juice at ~17ºBrix and 2.8 pH is too strong for direct consumption. The nectar base, consisting of 55 to 60 parts sugar to 100 parts juice, is best preserved by freezing and reconstituted 1:3 or 4 with water for consumption. The purple cultivar and newer introductions are less acid and require correspondingly less sugar and dilution as nectar bases. Where freezing is not practical, rapid pasteurization or aseptic processing produces acceptable but flavour-diminished nectar.

Passion fruit juice is unique in containing from 0.5 to over 3 percent starch, resulting in an increase in viscosity upon pasteurization or concentration as the starch gels, unless pretreated with amylase or separated by centrifugation. The delicate flavour is diminished by pasteurization and even aseptic processing or gentle concentration systems cannot approach the fresh or frozen product in flavour. Despite the heat labile flavour, passion fruit is a major component in many processed tropical fruit beverage blends and popular with those unaware of the exquisite flavour of analogous unheated (fresh or frozen) products.

Acceptable passion fruit concentrate to greater than 60ºBrix can be produced with attention to low temperature or short residence time evaporators - centrifugal or falling film evaporators. Essence recovery and add-back approximate (but do not match) the original flavour. The concentrate, packed in 200L barrels (Figure 15.3) and frozen, can be held at –20ºC and used in tropical juice/beverage blends.

Figure 15.2: Passion fruit concentrate filling into 200Litre drums.

Although the rind is high in quality pectin and seeds are a source of protein and oil, no major co-product industry has developed. Despite the extensive research and industrial developments with passion fruit, there is much to be done. Probably the diffuse, mixed cultivar and comparatively small-scale cultivation has hampered more widespread investigations. And many other Passiflora genus merit development.

15.4 Guava

Guava (*Psidium guavajava* L.) is represented by a number of commercial cultivars with flesh colour ranging from red to white. The delicate fruit is sensitive to postharvest damage; thus pulping is one logical strategy for utilizing the fruit. In many regions the fruit is a host to fruit flies and other penetrating insects, so careful inspection is necessary. Maturity grading can be accomplished by submerging the fruit in clean water. Immature fruit sink and the floating mature fruit are thereby separated. The clean, whole fruit may be pureed by passing though a paddle pulper. Care must be taken to exclude stones cells that contribute a grainy texture to the puree. These cells are distinct from the seeds and are easily removed by the pulper; 0.3 to 0.5-mm mesh screen is adequate. Guava is high in ascorbic acid (~100 to 200 mg/100g) and the red/pink contributing pigment is lycopene. The more acid cultivars produce fine nectar bases with added sugar.

Depending upon the acid level, nectar bases consisting of 40 to 50 parts puree and 100 parts sugar can be either frozen or flash pasteurized. Reconstitution with $2^1/_2$ to 3 parts water produces flavourful nectar from the frozen base and acceptable nectar from the pasteurized base. Clear guava juice is obtained by treating the pulp with a pectic enzyme followed by centrifugation. The straw yellow juice retains fair guava flavour and can be blended or concentrated more easily than the puree. However, the colour remains in the pulp residue and contains most of the lycopene. So, unless there is a value-added use for the pulp, utilization in the original puree form is logical. The pulpy nature and high pectin level of the puree favour jams, pastes and confectionery products.

15.5 Papaya

One distinguishing feature of papaya (*Carica papaya* L.) is the unusually high pH of the flesh, ranging from 5.5 to almost 6.0 when at the eating ripe stage. The fruit come in many sizes from 300g to several kg and colour from light yellow to deep red-orange. The flesh is a good source of carotenoids, including beta-carotene with redder flesh associated with more lycopene. The thin skin and soft flesh requires careful handling with peeling best accomplished by hand to prevent off flavour pick up from the skin. Recent processing developments are well summarized by Chan, Nagy, *et al.*, (1993). A surface steam treatment to coagulate latex and toughen the skin is a pretreatment for slicing and mechanical peeling by a crusher-scraper (Anagara, *et al.*, 1969) in combination with a modified passion fruit centrifugal peel separator. The flesh is easily deseeded and pureed by finishing equipment. As emphasized, complete removal of skin and seeds is necessary to avoid off-flavour.

In view of the high pH, papaya puree is either frozen or acidified with citric acid or blended with acid juices prior to pasteurization. The flesh tolerates heat reasonably well during enzyme inactivation. Papaya is the source of papain, a protolytic enzyme with many food uses. Papain is found in the peel latex, primarily in the immature fruit and industrially extracted, but absent from ripe fruit. Fruit from which latex is harvested are unsuitable for quality flesh or juice utilization. Another enzyme in papaya, pectinesterase, acts rapidly to demethylate pectin and form low methyoxide pectin gel with calcium. Hence, rapid heat inactivation, sweetening to 26ºBrix, or acidification to less than pH 3.6 is necessary to prevent gelation. Acidification followed by aseptic processing is an effective method for bulk handling the puree whose colour, bland flavour and high carotenoid content make papaya a popular blending stock for tropical drinks. Pectic enzyme treatment is necessary to thin the puree sufficiently to affect about a three-fold concentration to 24 to 36ºBrix.

Another species, *Carica pentagona* Babaco from northern South America merits mention. The fruit resembles a large papaya with orange flesh, but is much more acid, more flavourful and roughly similar in nutrient content. The juice is popular locally, but relatively unknown elsewhere. The dramatic flavour difference in these species suggests that there are intriguing opportunities to improve upon the *Carica* genus.

15.6 Guanabana (Soursop)

There are few fruits with a more appealing, delicate flavour than guanabana (*Annona muricata* L.); the fruit is a natural sherbet in its fresh state even before sherbet manufacture. This large oblong fruit with soft, white, fibrous cotton-like flesh is best separated from the large black seeds and consumed as a puree **(**Figure 15.4). The fragile skin defies mechanical peeling, although the seed-containing flesh can readily be pureed in a paddle pulper. The puree at ~15 ºBrix and 0.5 percent acid, pH 3.6 is moderately susceptible to darkening, prevented by application of sulphur dioxide, ascorbic acid or rapid handling and freezing.

Figure 15.3: Guanabana, fruit can exceed 5 kg each.

There are other Annonacea species with equally distinctive flavour appeal such as the Cherimoya (*Annona cherimola)* or custard apple (Nagy, *et al.*, 1990). These are about as difficult to handle and puree as the bulky guanabana. All merit greater commercial development.

15.7 Acerola

Acerola (*Malpighia punicifolia* L), known as Barbados Cherry due to the fruit's appearance, has the distinction of having exceptionally high ascorbic acid levels (Figure 15.5). Green mature fruit, although inedible, contain over 3 percent ascorbic acid and represent a natural source of vitamin C when harvested and extracted. The ripe fruit can have over 1 percent fresh weight of ascorbic as the major acid (Nieva, 1955). The red, cherry-shaped fruit are readily crushed and pureed in a paddle pulper to separate a thin orange pulp from the seeds. The acerola flavour is acid, ~5ºBrix, but bland and easily blended with other more flavourful juices. At 5 percent addition to other juices acerola contributes roughly the ascorbic acid equivalent of single strength orange juice, ~50mg/100ml.

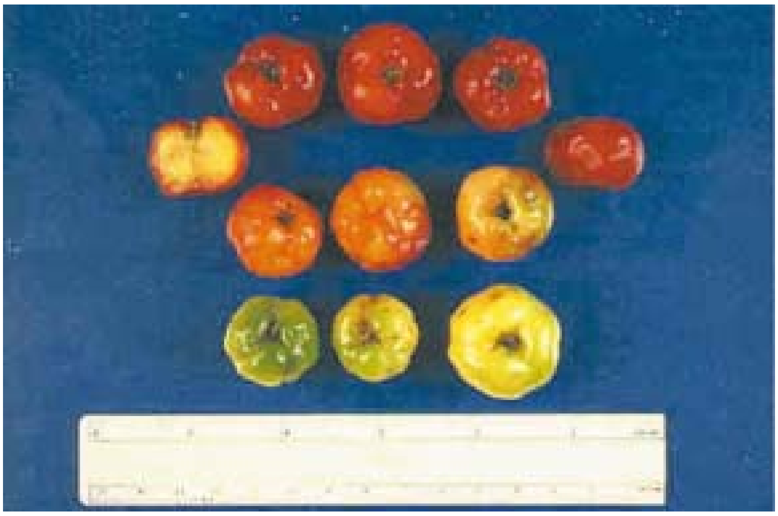


Figure 15.4: Acerola fruit at various stages of maturity.

A popular frozen nectar base consisting of 45 percent passion fruit nectar (55:100 juice: sugar), 45 percent guava (48:100: puree: sugar) and 10 percent acerola nectar (juice: sugar 1:2) served as a well received example of tropical fruits for visitors to the University of Hawaii Manoa Campus. The product stored well at –20ºC and no change in colour or flavour was detected over a two-year period. With a reliable annual supply of fruits, it was unnecessary to carry frozen nectar base over one year.

Storage time is an important point to consider in juice sales. Even though processing and packaging technology can accomplish a lengthy shelf life, the goal is to sell the product to satisfied consumers who will promptly use it and generate repeat sales. All storage is expensive, particularly freezer space, so a very stable product that doesn't sell has no commercial advantage over a less stable but faster moving item. Stability simplifies inventory control and maintains quality, but sales appeal is most critical. Economics usually trumps technology; even mediocre products can survive and thrive over better items with less marketing support.

15.8 Naranjilla

There are few fruits more aromatic than naranjilla (*Solanum quitoense* Lam), resembling an orange in size, shape and colour (hence the Spanish designation "little orange"). A ripe fruit in a room is readily detected and appreciated for the pleasant scent. Unfortunately this fragrance is diminished in the fresh juice and easily destroyed by heating. The flesh is a light green with the morphology of a tomato to which it is related. The fruit is easily juiced without peeling by passing though a paddle pulper with a ~1mm screen to separate the seeds, skin and pulp from the green juice. At a ºBrix of around 8 and over 1 percent acid (as citric), pH ~ 3.5, the juice is best used for blending **(**Ashurst, 1995).

15.9 Carambola

The carambola (*Averrhoa carambola*) or star fruit, so called because of the 5-pointed star shape cross section of the fruit, has appeal in salads and as a garnish. The fruit is easily pureed to produce a thin yellow juice of ~6ºBrix and moderate acidity consisting primarily of oxalic acid. Single strength juice is weak, acidic and not very flavourful. Major products are a sweetened juice and a salted, fermented juice in the Orient (Nagy, *et al.*, 1993). A locally popular carambola wine is produced in South Florida from sound culls from the fresh market.

15.10 Lychee

Another popular Oriental fruit now grown widely in the Tropics is lychee (*Litchi chinensis* Sonn.) The white translucent flesh is also illusive to juicing, being protected by an attractive, inedible, red leathery skin and containing a large brown seed. The flesh and juice posses a fragrant pleasing flavour, greatly diminished by pasteurization. The ~16ºBrix juice is low in acid, has pH~4.6 to 5.0 and requires citric acid or blending with acid juices to optimize the B/A ratio and reduce the pH to around 4.0.

The seed that adheres to the flesh and the pliable, bitter skin require tedious hand peeling and separation. In view of the rapid discolouration accompanying juicing, the fruit must be handled gently and rapidly. Mechanization for peeling and deseeding has been reported on a commercial scale in Taiwan **(**Nagy, *et al.*, 1993). The high value of the fruit dictates inclusion of lychee in nectars and beverage blends, instead of pure juice.

Lychee, along with close relatives, rambutan and pulisan, are highly prized as the fresh fruit in the Orient, so juice is still a comparatively minor co-product of fresh, canned and dried fruit operations. Canned nectars sampled in the mid-90s were overly sweet, but at least were not oxidized nor scorched, as they had been a decade previously. Curiously, lychee wine has a fairly harsh, sour flavour after fermentation requiring ageing and sweetening.

15.11 Banana

Banana is the highest volume tropical fruit in world trade. It is to the credit of horticulturists and post-harvest physiologists that ripe bananas are readily available year-round in remote reaches of the Northern Hemisphere. The fruit is primarily consumed fresh or as puree for baby food, bakery and confectionery uses. Harvesting and ripening regimes dictate that a substantial volume of fruit cannot be shipped. Consequently, much is available for puree and other processed products.

The major restriction in manufacturing banana puree is its tendency to brown rapidly. Procedures for overcoming the enzymatic browning involve:

- Heating the whole fruit to greater than 80ºC for about 3 minutes to inactivate the polyphenol oxidase enzymes, followed by peeling and pureeing,
- The ripe fruit is either hand or machine peeled and immediately pureed, deaerated, aseptically processed and bulk packed,
- The blanched puree (30 seconds at ~90ºC with rapid cooling) can also be frozen in bulk, with better retention of volatiles (Sole, Somogyi, *et al.*, 1996b).

A juice can be made by enzymatic treatment of the puree according to the flow scheme depicted in Figure 15.6. Since enzymatic browning is very rapid, the procedure calls for peeling, acid adjustment to pH 4.2 with citric and ascorbic acids and rapid heating to 85ºC. The puree, now thickened due to starch gelatinization, is cooled to 60ºC, a macerating enzyme is added and held for 30 minutes. Afterwards, the thinned puree can be easily centrifuged and/or pressed to express the juice at about 22ºBrix. Yields average about 75 percent, puree basis. The juice can be clarified by centrifugation, filtered and concentrated to greater than 60ºBrix. Volatile essence recovery and add back reinforces the banana character of puree and juice.

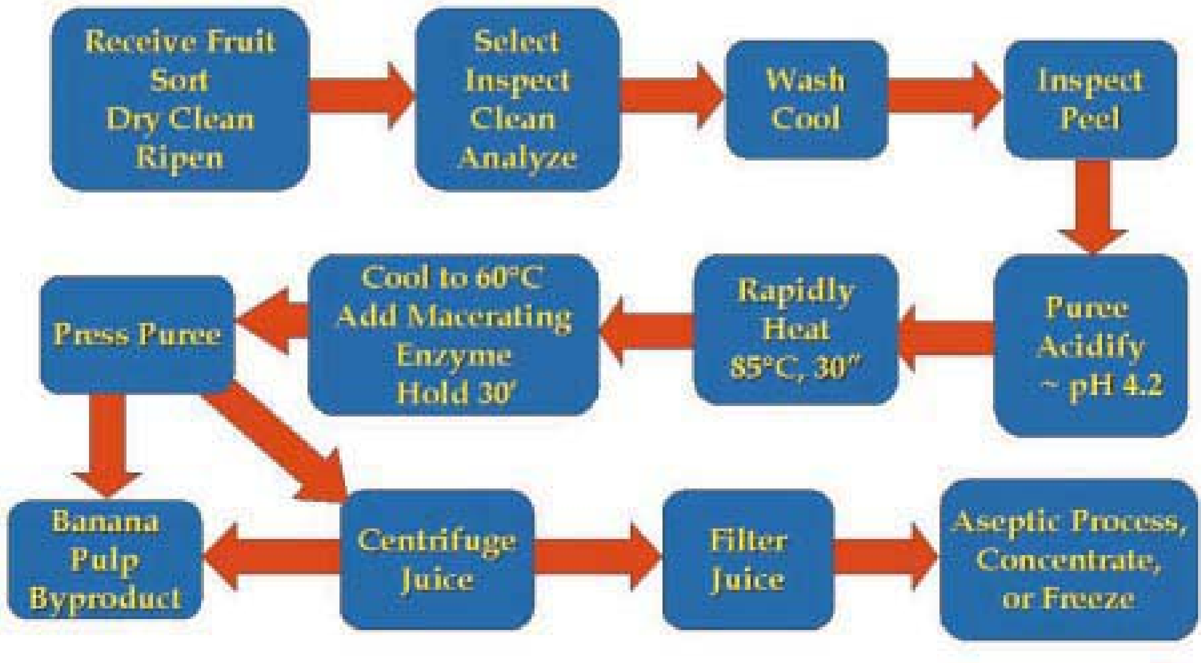


Figure 15.5: Banana juice flowchart.

Single strength banana juice has a characteristic overly sweet, slightly salty, cloying taste, particularly if maintained at the initial banana pH of above 5.0. Acidification improves the flavour, but at such a high solids level, the clear yellow juice is best blended with more acid juices for balance and colour. In view of the year-round abundance of bananas at ripening facilities and substantial waste of fruit too ripe to ship, more uses for juice should be explored.

15.13 Other fruits for juice

There are many other fruits of both tropical and temperate climate origins that merit exploitation as juice. These range from species and cultivars related to fruits already mentioned to those relatively unknown. Undoubtedly niche markets exist or could be developed for some. Most tropical countries have indigenous fruits with special local appeal. It is only a matter of time before those amenable to cultivation and processing scale-up appear on the world scene. Table 15.2 lists a few worth exploring.

Table 15.2: Some unique tropical fruits meriting juice evaluation.

Fruit	Rationale
Coconut	Widely available and extensively utilized
Cashew	Widely available and underutilized
Coffee and vanilla berries	Not exploited, but available
Pitaya	Cultivars exist with brilliant purple flesh
Longan, rambutan and pulisan	Related to lychee and as appealing
Tamarind	Flavourful, high Brix pulp
Sapote and sapodilla	Widespread, popular throughout the tropics
Mangosteen	Exquisite flavour, very delicate fruit
Feijoa	Regional delicacy in parts of South America

Of some note is coconut water, a sterile filtered product developed and patented (pending) by FAO’s Agro-industries and Postharvest Management Service, Agricultural Support Systems Division. The isotonnesic nature of coconut water makes it a natural oral rehydration fluid (sports drink). The water is quite perishable, but available as a by-product of coconut processing. Thermal processing adversely affects flavour, so sterile filtration represents a practical solution (FAO, 2000d). Coconut is also an ingredient in other juice beverage blends (Figure 15.7). The coconut component is probably coconut water. Although the milk, derived from comminution and pressing of the flesh and requiring stabilization of the emulsion also has beverage use (Somogyi, *et al.*, 1996b).

Figure 15.6: Pineapple coconut drink.

CHAPTER 16

VEGETABLE JUICES

Vegetable juice is defined (FAO, 1992) as: "the liquid unfermented but fermentable product or lactic acid fermented product intended for direct consumption obtained from the edible part of one or more sound vegetables and preserved exclusively by physical means. The juice shall be free from skins, seeds and other coarse parts of the vegetables. It may be clear, turbid, or pulpy. It may have been concentrated and reconstituted with water…" "Vegetables for the purpose of the standard are: the parts of edible plants including roots, corms, tubers, stems and shoots, leaves and flowers and legumes." Although the standard applies to edible plants, herbs, botanicals and possibly medical plants may also fit the definition provided that the plant part(s) is edible and not toxic (Figure 16.1).

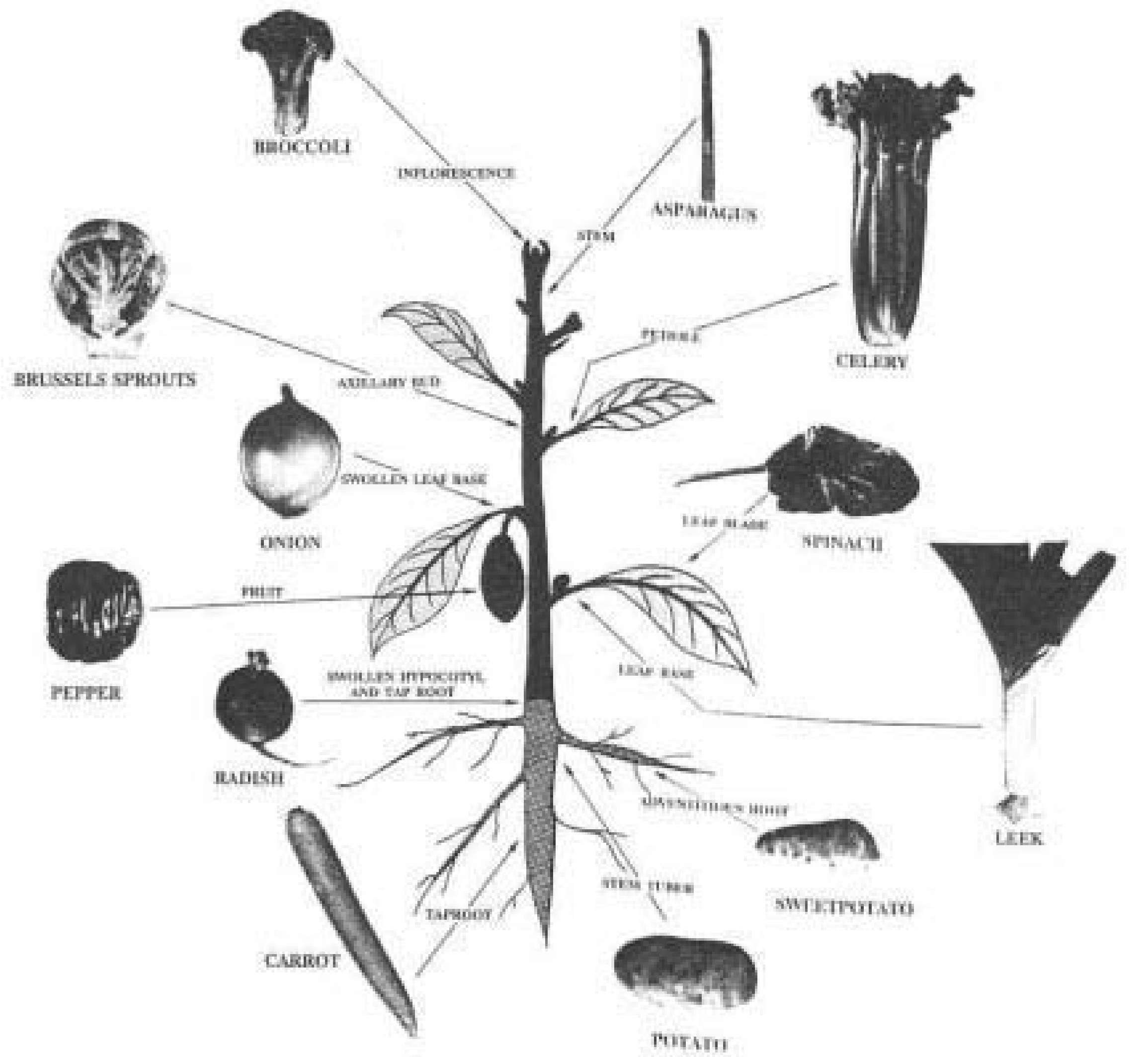


Figure 16.1: Plant parts as vegetables.
(Kays, 1991)

Vegetable juices are attracting more attention due to the nutritional and phytochemical value of many vegetables. Tomato juice and blends based on tomato have long been popular and account for over 90 percent of the non-fruit juice trade. However, other vegetables are becoming more acceptable. Blurring the distinction between fruits and vegetables are a range of fruit-carrot juice blends (Figure 16.2). Although the major ingredient is carrot, the fruit character (as represented by other juices and acids) predominates. Carrot supplies the health image and contributes to the colour, while the fruit juices provide the flavour and necessary pH reduction. The V-8 juice blend consists of carrot, high fructose corn syrup, pear, apple, pineapple and cherry, with added malic and ascorbic acids, natural flavours, beta-carotene and red 40. (Unless HFCS and flavours count as juice, it's actually V/F-5).

Figure 16.2: Carrot-fruit juice beverages.

Thus the distinction, sweet and acid for fruits and salty for vegetables (Section 2.2) may play a secondary role to the phytochemical composition (and popular image) of vegetable juices and extracts. If the carrot-based juice beverage (albeit only 25 percent total juice) is a market success, other vegetable juice blends will follow. Clever blending and marketing will be needed to provide a fruit character and a vegetable image.

Aside from traditional uses, the major distinction between fruits and vegetables is compositional. Most vegetables are not particularly high in sugars and, tomato excepted, are low in acids, resulting in pH values generally over 4.5. Consequently, the juices are more subject to microbial spoilage and require either pH reduction, thus changing the vegetable character, or more stringent processes to eliminate potentially dangerous microbes. Low acid thermal processing is much more severe, requiring temperatures in excess of 120ºC and process times of minutes in contrast to less than 100ºC and ~ 60 seconds for acid products.

16.1 Tomato juice

Few fruits are easier to juice than tomato or more amenable to a range of juice products and blends. Tomato solids range from 5 to 8ºBrix, somewhat lower than most juices. However, the high pectin content and pulpy nature of the juice provides an adequate taste. Most tomato cultivars have sufficient citric acid to insure a pH below 4.5, although citric acid or lemon juice is often added to compensate for the reduction in acidity that accompanies ripening.

Juice tomatoes can be specific cultivars with high solids and good colour or come from canned whole tomato or tomato piece canning operations. Fresh market fruit are less likely sources, since these fruit are often shipped at the mature green stage too immature for juice and already in distribution channels. Under no circumstances should damaged overripe or immature tomatoes be juiced, as quality will invariably suffer. In view of the delicate nature of ripe fruit and likelihood of machine harvest, thorough washing followed by careful inspection and grading is essential to eliminate damaged and mouldy items. Machine harvest contributes more dirt and field debris that must be removed. Fluming, by which tomatoes are dumped into and transported by water (Figure 16.3) is a dangerous practice that should be replaced by gentle brushing and water spraying, a more sanitary and water-conserving procedure.

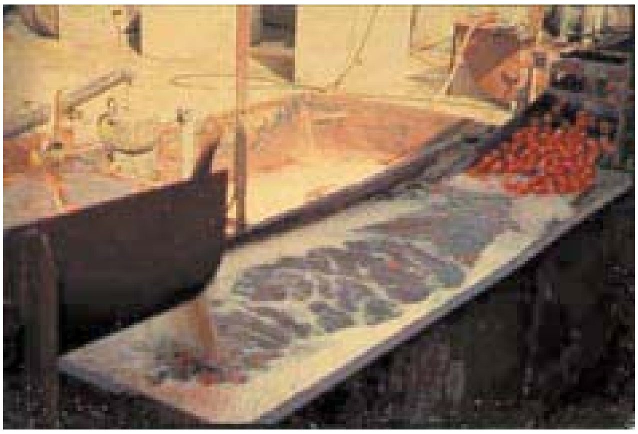


Figure 16.3: Tomato fluming operation, circa 1960.

Peeling or coring is unnecessary, but depending upon cultivar and end use, tomatoes receive either a cold or hot break at juicing. A very rapid acting pectin enzyme system, primarily polygalacturonases and pectin methlyesterases, will break down the pectin upon juicing, thus reducing juice viscosity. Consequently whole tomatoes are coarsely chopped and immediately heated to ~80ºC to inactivate these enzymes hot break. The cold break immediate chopping followed by rapid juicing, deaeration and processing is simpler, allows for some pectin enzyme activity, but retains more tomato flavour. The reduced viscosity is desirable for some derived products such as blends and concentrates. A larger mesh finishing screen that allows more insoluble solids in the juice and/or homogenization at ~100Mpa can increase viscosity.

Juicing is accomplished by passing chopped fruit through a disintegrator or a paddle pulper fitted with a 1 to 0.5-mm screen. Skin and seeds are effectively separated with juice yields around 70 percent. At this stage, deaeration is recommended to reduce oxygen exposure, particularly damaging after the hot break. Since most tomato juice is thermally processed, the retention of fresh tomato flavour is not critical, as long as excess cooked flavour is prevented. In fact, fresh unsalted tomato juice is not as acceptable as properly heated juice containing about 0.5 to 0.75 percent added salt.

Prior to thermal processing, the juice pH should be checked and, if necessary, adjusted to below 4.5 with citric acid. Certain cultivars and overripe fruit can exceed pH 4.6 and ascorbic acid levels range from over 30 to less than 10 mg/100g. Rapid processing can retain over 90 percent, whereas poor practices destroy practically all vitamin C. Ascorbic acid is often added in amounts representing the recommended daily intake (RDI) of 70 mg.

Tomato juice was traditionally packed in unlined tin cans or glass jars. The acid etching of the tin plate provided a desirable flavour and minimized pinholing (a danger with enamel lining where weakness in the enamel allows acid to selectively attack the steel plate). Glass jars provide a visually pleasing juice and inertness. Other container options including plastic, laminates, etc. are now available. Thermal processing consists of hot filling containers at ~95ºC, sealing, inverting and holding about 30 seconds followed by rapid cooling. Of course, high pH (near but below 4.6) or highly contaminated juice require a higher temperature hot fill a boiling water bath at 100ºC for 5 to 10 minutes or even a slight pressure process ~105°C for 10 minutes.

Another notable feature of tomato juice is tolerance to heat. Providing that the product is not held at greater than 40ºC for extended time (greater than several hours) the flavour is not damaged. In fact, consumer preference is for thermally processed salted compared to fresh, unsalted juice. However, excessive heating greatly reduces the natural and any added ascorbic acid. Tomato blends well with a variety of other juices (Figure 16.4), spices as well as clam juice.

An appreciable amount of tomatoes are converted to sauce, puree and pulp, which in turn are used as the base for ketchup, salsas and pizza sauce. Depending upon end use the juicing may use a coarser screen and include some tomato pieces. The United States Standards are available (United States Department of Agriculture, 2000b). Most of the grading criteria are descriptive, i.e. colour, flavour, absence of defects, but soluble solids are well defined. The distinction between concentrate, paste, puree and pulp is vague, except for soluble solids (Table 16.1).

Figure 16.4: Tomato vegetable juice blend ingredients.

Tomato products are increasing in popularity due to the discovery that lycopene, the major carotenoid pigment responsible for the red colour in tomatoes, watermelon, pink grapefruit, some papaya cultivars and other fruits, has anti-carcinogenic properties. Curiously, the bioavailability of lycopene is greater in processed/heated tomato products than in fresh items. Unlike B-carotene and other closely related carotenoids, lycopene has no pro-vitamin A activity.

16.2 Carrot

Carrot juice also typifies the current appeal to the health conscious consumer. Carrot has long been a component of tomato blends. Now, unlike tomato, carrot juice is frequently blended in fruit type concoctions where only the colour and natural sweetness carry over. The health image of carrot is strongly promoted while the blending juices, citrus and tropical fruits (Figure 16.1) provide flavour and reduced pH. Pure carrot juice at a ºBrix of 6 to 9 and pH ~5 to 6 requires a retort process at 121ºC. Consequently, the juice has an unappealing cooked carrot flavour and coagulation of carrot solubles occurs.

There is generally an abundant supply of raw carrots from fresh market rejects i.e. roots that are off size or shape, but otherwise high quality (Figure 16.5). Cultivars should be sweet and highly coloured. Topping and peeling are necessary to remove bitter substances associated with those parts. Fresh carrots are difficult to juice and the fresh juice coagulates upon heating. Thus blanching at about 80ºC for several minutes softens the roots and facilitates juicing by comminution and 0.5 to 10 mm screening. Homogenization yields a juice suitable for blending.

Table 16.1: U.S. Soluble solids standards for tomato products.

Product	Minimum Soluble Solids	Remarks
Juice, single strength	Not specified	Presumably as juiced
Juice, from concentrate	5.0	When reconstituted
Concentrate	>20 to <24	
Paste	24 to <28	Light (designations)
	28 to <32	Medium
	32 to <39.3	Heavy
	39.3 or greater	Extra heavy
Puree (Pulp)	8 to > 24	Total range
	8 to <10.2	Light
	10.2 to <11.3	Medium
	11.3 to <15.0	Heavy
	15.0 to <24.0	Extra heavy
Sauce	1.3445 RI, ~ 8 to 9 ºBrix Some seeds allowed	Includes salt, spices, vinegar, flavouring ingredients
Catsup	33	Grade A
	29	Grade B
	25	Grade C

USDA, 2000b

Figure 16.5: Carrots receiving at a juice plant in ~ 18 MT trailers.

Although only about 25 percent of total carrot beta-carotene is extracted by juicing, retention during processing is reasonable high. Carrot juice may be vacuum concentrated and stored and shipped in the frozen form. This highly cooked carrot-flavoured reconstituted juice is acceptable primarily to those committed to the health value, whereas creative blending produces juices acceptable to a wider market.

16.3 Other juices

While tomato and carrot are the major juices, a number of other vegetables also find uses. The components in V-8 include: tomato, carrot, celery, beet, parsley, lettuce, watercress, spinach as well as salt and spices (Figure 16.4). In truth, the sensory, nutritional, or phytochemical contribution of the minor juices is questionable, but the marketing appeal of 8 juices is clearly successful, as reflected in the market longevity of the product.

As additional valid nutraceutical data support the imputed health value of other vegetables, we can expect a plethora of vegetable juices and blends. For example, recent studies reported that rhubarb juice inhibits browning in apple slices and juice at 10 to 20 percent (Anon. 2000a). The high oxalic acid content (~3 percent in rhubarb) is an effective browning inhibitor. In view of the natural image of rhubarb juice, its use in other browning susceptible foods is logical. However, high levels of oxalic acid can bind essential minerals. Thus, there are downsides to natural products also. To the chemically illiterate, at any level, SO_2 is “dangerous”, whereas being a “natural” product, rhubarb is “safe”, independent of dose. (Consumption of occasional 100 to 200ml portions of 100 percent rhubarb juice would be innocuous; frequent ingestion of this amount or more would not be).

The juice manufacturing practices, although similar in principle, are vegetable-, even cultivar-specific. In general, sound, sanitary pieces free from seeds, stem or inedible/off-flavour components are suitable for juicing. If heating causes coagulation, preheating prior to juicing or subsequent homogenization can provide a stable puree-like product. Salt, spices and creative blending with other juices (fruit and/or vegetable) can result in appealing beverages.

Reduction in pH can be achieved with suitable fruits or fermented vegetable juices. Sauerkraut juice, the excess fluid produced in the manufacture of sauerkraut, is about pH 3.3 and contains appreciable ascorbic acid, ~2 percent salt and typical kraut flavour. In a similar sense lactic fermentation of other vegetables, either singly or in combinations, results in juices possessing distinctive characteristics. Carrot, celery, radish, cucumber, pepper and onion are interesting possibilities. Although shelf stability requires pasteurization, there is undoubtedly a market for freshly fermented juices that maintain the desirable viable microflora associated with probiotics, vegetable analogs to fermented dairy products.

Avocado puree or the Latin American guacamole is fairly removed from beverages, but merits brief mention, since lemon and onion juices contribute to the mix and preservation is an extreme challenge. The high lipids content (10 to 25 percent) and favourable fatty acid and to copherol profile of avocado overcome its calorie-dense reputation. Guacamole is a popular dish, requiring only avocado paste, salt, lemon, onions and additional spices/ingredients, depending upon the creativity of the chef. The major limitation is the susceptibility of avocado to heat. Heating, even to inactivate browning enzymes results in bitter, disagreeable off flavour. Thus, use of browning inhibitors like SO_2, ascorbic acid and rapid freezing are required. Hyperbaric processing is being explored and, conceivably avocado puree could contribute much to a valuable vegetable juice blend where thermal pasteurization can be avoided (Section 8.26).

16.4 Non-fruit/vegetable juices

In the fast paced development of novel juice and juice beverages, there are a number of juices, some traditional in part of the world, others quite novel, that have reached markets in developed countries. While it is too early to evaluate the staying power of these beverages, they represent crops with some potential and merit mention.

Cactus juice (actually iced tea sweetened with prickly pear (agave) nectar) has been noted (Anon. 2000b). Agave is an important crop in Mexico and when fermented and distilled, the source of mescal and tequila spirits. If the supply can be increased, agave as a natural sweetener with unique flavour has intriguing potential for regions where succulent cacti can grow.

Another more common sweetener also has juice possibilities. Sugar cane has long been crushed and the juice sold fresh by street vendors in growing regions. With simple roller crushing, clean, peeled cane produces a light green juice, mostly sucrose, at a pH of ~6 and about 20ºBrix (Figure 16.6). The cane must be clean and well peeled to avoid dark, off-flavoured juice; rapid processing (or the use of SO_2) is necessary to prevent browning. When blended with high acid juices and pH adjusted to ~4.2 a very pleasing beverage results. Cane juice blends are amenable to standard processes and have a strong “natural “ image. The alternate operation depicted in Figure 16.6 is highly inappropriate for cane juice; the resulting juice is brown, far from sanitary and suitable only for sugar refining.

Figure 16.6: Cane juicer for beverage use and for sugar extraction (trapiche).

CHAPTER 17

COMPLEMENTARY/COMPETITIVE PRODUCTS

There are a number of beverages that use or could use juices as part of their formulation. Where the juice or co-product is a major ingredient, the product can be viewed as complementary. If the juice component is trivial, the product is competitive.

17.1 Jams, jellies and syrups

The manufacture of jellied products from juices has been covered in Sections 11.3.2 and 12.8. The low pH, high solids and pasteurization contribute to the shelf stable nature of these products. Fruit as solids or juice must represent at least 45 percent by weight of jams and jellies. Not so with syrups that are simply clear juices or concentrates blended with added acid plus sweetener and preserved by benzoate or sorbate. Syrups can range from juice with sweetener to those containing primarily sweeteners, citric acid and artificial colours as well as flavours with very little juice. The low calorie alternatives use artificial sweeteners with a proportional reduction in calories. However, shelf stability is compromised after opening and the items have a limited refrigerated shelf life.

17.2 Smoothies

The health appeal of fruits and convenience of juices complement each other in the so-called smoothie a mixture of slush frozen pureed fruits in milk, sweetened to taste. Originally prepared fresh in the home and local shops, smoothies are now manufactured, packaged and distributed in refrigerated, frozen and shelf stable forms. A further development is dehydrated smoothie confectionery bars.

17.3 Dairy

Fermented dairy products are quite compatible with acid juices. Fruit flavoured yoghurt, kifir, kumis, etc. are in many combinations. The probiotic nature of these lactic fermentations and the phytochemical value of fruit juices are complementary. Unfermented milk is not compatible with acid juices as unappetizing curd forms upon mixing. However, cheese whey, containing the lactose, acid-soluble whey protein, much of the milk vitamins and minerals, blends well with juices.

17.4 Sports drinks

This is a rapidly growing beverage category closely associated with the nutraceutical trend (Sections 3.3, 11.2 and 10.1). Some of the purported benefits of these products are:

- Hydration/rehydration
- Muscle mass development

- Muscle recovery
- Endurance promotion
- Quick energy source
- Balance of electrolytes
- Glycogen replenishment
- Analgesia/pain relief/prevention
- Relaxation/mental composure
- Alertness/mental focus
- Injury repair.

The pioneer product was Gatorade, an isotonnesic fluid replacement based on oral rehydration technology, designed for extended, strenuous exercise in hot/humid climates. Similar products have followed (Figure 17.1; Ford, Somogyi, *et al.*, 1996). The product and competing brands do not contain fruit juices, although fruit juice formulation is feasible. In fact, dilute banana puree is the major component of indigenous oral rehydration fluids, long promoted as a treatment for acute diarrhea. When it is prepared to sanitary standards and diluted with two parts of clean water, it provides depleted water and minerals.

Figure 17.1: Fruit-flavoured sports drink labels.

Sports drinks now include performance-enhancing concoctions designed for all types of activities. Herbals, amino acids and various human metabolite precursors and chemicals find their way into beverages, confectionery bars, gels, etc. (Best, 2000). Some are based on sound research into exercise physiology while others appeal to human psychology. The placebo effect is undoubtedly a major "active" ingredient, even in drinks with some potential scientifically sound efficacy.

17.5 Herbals and teas

In the broadest sense plant extracts from herbs and teas are juice products. The fresh plant may be crushed or pureed to express a fluid with some potency. More likely, the dried material is subjected to an aqueous extraction to solublize plant substances that are then either stabilized by further processing or blended into beverages. These extracts are highly flavoured and may possess nutraceutical properties. Most importantly these are high value products that impart unique characteristics to beverages. For example juice and non-juice blends can include ginko or gingko biloba, St. Johns Wort, echinacea guarana and a host of herbs. Spices are also used in a similar manner (Figure 17.2). Highly flavoured, familiar, well accepted juices represent a means of flavour masking and otherwise making somewhat unpalatable substances more tolerable, even desirable. Nevertheless, it will be interesting to identify the consumer profile and follow market staying power for “Lizzard” products.

Figure 17.2: Herbal containing “New Age” beverages.

17.6 Competitive products

There are a number of beverages that also use fruit components, although they compete with juice products to some degree. Carbonated soft drinks, mostly synthetic powdered beverages, fruit punches, even flavoured bottled water can use natural fruit flavours and extracts. With the trend toward “natural” there are opportunities to popularize fruit flavours in this manner. Of course, fruit constituents will always be more costly and delicate than fabricated alternatives comprising sugar, citric and ascorbic acids and synthetic flavours and colours. In the United States of America pure juice retail prices range from about \$3/L for really up-scale brands with comparable packaging to less than $1/L for house brands. In contrast, fruit punch containing 1 percent juice is less than $0.30/L and soft drinks are less than $0.70/L.

Marketing strategies constantly emphasize the health and quality image of total juice products while competitive items allude to the juice image. The economic reality is that clever advertising can trump sound nutritional value and intrinsic product quality. Figure 17.3 shows a label of a “real fruit beverage” containing 5 percent juice. Note the implied Florida citrus image.

Figure 17.3: Citrus beverage label, 5 percent orange juice.

In some cases the fruit connection is even more remote. The beverage is based entirely on sugars, citric and other acids, nutrients, artificial/natural flavours and colours. Such products represent substantial beverage technology innovation and can actually be more nutritious, stable, flavourful and less expensive than comparable pure juice or products containing juice. Fortunately, labels must state juice content and all ingredients, so consumers can make informed purchase decisions. The mandatory statement of juice content is far from a prominent part of some labels (Figure 2.1.). Table 17.1 indicates some “pseudo juices” and their make-up.

Table 17.1: Juice-like beverages.

Product description	Remarks
Lemon/lime mixes	Citrus flavoured powder or concentrate
Koolade mixes	Some fruit juices used
Fruit punches	100% to 0% juice
Sports drinks	Fruit flavours common
New Age drinks	Fruits and herbals used
Flavoured water	Fruit flavours common (slight)

CHAPTER 18

COMMERCIALIZATION

18.1 The total picture

A successful juice manufacturing business/facility is strongly dependant upon the existing national infrastructure and the integration of all steps from fruit breeding, cultivation and procurement though warehousing, sales and distribution of finished products. Developing country visitors to an industrialized country's major juice processing facilities are often impressed by the efficient, automatic manner in which raw fruits are seemingly effortlessly transformed into juice and by-product streams in a continuous flow from fruit supplier to processed product consumers. Observers may not be aware of the decades of research and development invested in such operations or the infrastructure necessary to sustain it, let alone the exhaustive, detailed planning and enormous capital costs involved.

There is a myriad of important considerations inherent in juice processing, stretching from cultivation to the consumer. The metaphor "A chain is no stronger than its weakest link" has important relevance (Table 18.1) as does the dictate, "Forge Strong, Avoid/Strengthen Weak Links". Some of these connections are worth mentioning:

- A reliable source of quality raw material representing the appropriate variety, available over a reasonable season at a fair cost is essential. Ideally, a processing operation should be extended over as long a season as possible. Firm commitments by growers based upon mutually developed specifications are a must. A versatile organization can process different cultivars and crops sequentially to spread capital costs,

- Harvesting, transportation and storage scheduling are important to an integrated operation. Seasonal peaks and valleys must be buffered by adequate storage or ripening facilities combined with trained labour to perform necessary operations,

- Total production logistics must be considered well in advance of groundbreaking (Table 18.2). Any planning deficiencies may result in unpleasant surprises later on.

Table 18.1: Links in the FPD chain.

Link	Rationale
Marketing/consumer research	Know the market and consumer needs
Cultivation/growing specifications	Insure raw material safety and quality
Postharvest handling	Maintain in optimum condition
Production specifications	Insure uniformity and quality
Ingredient /packaging technology	Improve quality and handling
Manufacturing /processing technology	Safe, long-term stability
Quality/safety attributes	Enhance company image
Regulatory/labelling requirements	Legal compliance
Storage/distribution criteria	Efficient supplier
Economic/competitive considerations	Maintain competitiveness
Total logistics	Efficient operations
Supplier/customer relations	Goodwill and reliability
Product positioning/timing	Rapid response to market demands
Wholesale/retail marketing	Expand market
Environmental/political "correctness"	Company image/goodwill
Positive image/value	Brand/name recognition
Survival/growth tactics and strategies	Company's future
Intellectual property rights	Delay competitors
The regulatory environment	Avoid legal entanglements
Customization	Cover the market
Institutional capabilities/flexibility	Respond to demands
R and D strength	Proactive industrial pos

Some of the comprehensive references cited have valuable sections dealing with facilities, equipment and related matters (Ashurst, 1995; Arthy and Ashurst, 1996; Ashurst, 1998; Nagy, *et al.*, 1993; Tressler and Joslyn, 1961; Dauthy, 1995; Fellows and Hamptonnes, 1992; Fellows, *et al.*, 1996; Fellows, 1996; Fellows, 1997; Richter, *et al.*, 1996). In addition, specific chapters in these and other texts cited describe quite well operational equipment and alternatives.

Note the inclusion of texts from 80 to 40 years old and a reference from the 1930s. Popenoe, 1920; Tressler and Joslyn (1961) and Walsh, 1934, deal comprehensively with basic topics that are excluded or greatly condensed in newer texts. Also, equipment and processes are closer to the practical limitations and needs of some developing countries.

Although a much more recent FAO text is highly relevant to limited resource regions (Fellows, 1997), as are ITDG's Food cycle technology source books (UNIFAM, 1993 and 1996) and their Website (ITDG, 2000).

Adequate information and understanding of pertinent subject matter and dedication to the task doesn't insure commercial success. Truly a lack of data practically guarantees failure or at least a costly boondoggle. We hope to help you avoid these negative outcomes.

18.2 The outsourcing and co-packing option

Before making a lengthy, expensive commitment to an independent juice processing operation, it may be beneficial to consider these alternatives. The entrepreneur and small processor are not completely shut out by size and capital limitations. In some regions of the world there are many companies with expertise and manufacturing facilities that welcome the opportunity to conduct research and development (R and D), product development, even production activities for others.

The simplest arrangement is when the outside firm or individual has a reasonably viable product and a well-developed business plan, needing only a co-packer to manufacture the product to specifications. In turn, the co-packer has underutilized facilities, production capacity and most importantly, experience with similar products. The co-packing agreement can be nothing more than placing the client's label on a standard production run of product. Or the client can require certain modifications in ingredients, process or package to meet distinct quality criteria.

A more complex, arrangement is where the client does not have a final product and requires additional product development, analyses, regulatory advise, etc. In which case, the outsource company plays a more central, integral role in many phases of manufacture. Outsourcing can also be highly targeted having outsiders develop a specific formulation, use specialized processing equipment, provide the package technology, or supply a key ingredient. The proper outsource match can dramatically speed up and simplify some processing and manufacturing steps, but at a price. The advantages and disadvantages of outsourcing must be carefully weighed (Table 18.3).

Table 18.2: Juice process planning.

Factor	Considerations	Rationale
Raw material	Quantity, quality, uniformity, cost, species/cultivar, reliability, seasonality, maturity	Optimize process season Cannot be based on culls or fresh produce without a market
Handling	Harvesting, transportation, ripening, storage	A uniform, reliable supply is essential
Facilities	Location, size, design, construction details, services, sanitation, machine shop, expansion/accessory space	Should be near source of supply, labour and transportation
Utilities	Water, electricity, sewage, refrigeration/freezing, steam, power sources, cost, reliability, accessories air, vacuum, etc.	Spare parts and reliable back-up sources are needed
Labour	Availability, skills/training, cost, reliability (turnover)	Experienced mechanics and training provisions important
Equipment	Size (throughput), maintenance, reliability, sanitation, flexibility (versatility), automation	In-house machine shop or reliable outsourcing is essential
Suppliers	Reasonably priced, versatile/ adequate inventory, responsive/reliable, technically adept	Reliability, rapid response and good inventory are more important than lowest prices
Supplies	Quantity, quality, cost, delivery, storage	Adequate inventory and safe storage capacity needed
Government	Stable, favourable regulatory and business environment, financially responsible, even handed, reasonable tax base, good community relations, adequate technical support	Without a co-operative, or at least non-obstructive relationship, success is unlikely
Competitors	Legal, industry- cooperative, honest, law abiding	Illegal or covert politically linked firms have an unfair advantage

Table 18.3: Pros and cons of outsourcing.

Advantages	Disadvantages	Comments
Core competency undiluted	Dependent on outsiders	Develop partnership
Large selection of providers	Expertise outside	Select carefully
Large experience base	Proprietary information shared	Insure confidentiality
Versatile economy scale	Higher production costs	Schedule carefully
Low overhead		Establish cost/benefits
Capital conserved		Optimize core focus

CHAPTER 19

REFERENCES AND RESOURCES

Juice processing and utilization is a dynamic technical field. Competent industry, institutional and academic professionals with advanced degrees and decades of experience can devote productive careers to a single juice commodity and still consistently uncover new information requiring more fascinating research. The University of Florida Citrus Research and Education Centre staffed with dozens of scientists and a laudable 70 year history has contributed importantly to the advancement of the state, national and international citrus industry. Research centres in several other States of the United States of America other nations and continents also have comparable research centres. Still, there is much to be learned about citrus and all other juice crops, as citrus is probably the best researched of all juices. The resources cited here are a mixture of old (still relevant classic treatments that age well) and new fast-breaking information on the Internet.

19.1 Working by analogy

From the emphasis given in this text to various juice commodities and processes, it can be seen that there is a substantial body of knowledge applicable to some and much less to others. Part of this background reflects the authors' experience and/or priorities. Thus, many fruits are treated too lightly or ignored. How is one to proceed with, say making mangosteen juice or dealing with an exotic cultivar of apple with a pink flesh that darkens very rapidly?

It is useful to work by analogy using Table 19.1 as a guide. The first approximation would suggest similar handling, juicing, processing and end use. For example, although peach and mango call for vastly different post-harvest handling and prejuicing steps, the general similarity in composition, flavour, consistency and colour suggest reasonably similar processed products specifically puree, nectar, jelly with, of course, fine tuning regarding °Brix/A, solids level, etc. In cases where the juice is difficult to extract, hot press or aqueous extraction may be appropriate. With haze formation, perhaps apple juice clarification procedures would work. An attractively coloured fruit with unbalanced flavour should suggest the cranberry analog as a start.

After such initial evaluations it is important to gain experience with the unique characteristics of the raw material at hand, keeping in mind those factors affecting juice practicality, safety and quality as emphasized in Chapters 3, 4 and 5 and those on well known fruits and vegetables analogous or otherwise. For example, the antidesma bunius, Bignnai. Bignay is a little known tropical fruit with deep red colour, noted by aficionados for its colour stability and wine quality. This immediately suggests pigment and phytochemical properties worth exploring, applying techniques developed for grapes and berries. Technical and anecdotal evidence points to numerous plants with analogous promise.

In a similar sense analogous thinking extends to equipment and procedures. Hot or cold press juice extraction options are dictated by the nature of the pulped fruit or vegetable,

Table 19.1: Unfamiliar juice raw material evaluation.

Evaluation	Rationale
Growth characteristics	Production feasibility
Morphology	Harvest/juicing strategy
Skin/seed characteristics	Removal ease or need
Intact durability	Handling, storage
Fresh flavour	Juice suitability
Heat stability – flavour, colour	Processing ease
Composition	Blend/phytochemical promise
Brix, pH, acid	Juice stability, processes
Juice/puree viscosity	Beverage type
Pigment intensity/stability	Blending/co-product promise
Juice clarity/turbidity	Juice finishing - clear/cloudy
Residue composition	By-product potential
Similarity to known fruits	Process adaptability, end use

need for and ease of colour extraction, flavour sensitivity, etc. For fruits with soft pulp and no or easily removed seed but instead inedible, off-flavoured skin, a fish deboner capable of gently mashing the flesh through a cylindrical screen by a flexible belt while maintaining and eliminating the intact skin has proven practical. The unit is expensive, but the concept can be modified and scaled to certain fruits, i.e. avocado, papaya, banana, possibly guanabana among others.

Working by analogy goes only so far and at some point differences instead of similarities defines the investigation. Local custom and tastes also suggest utilization schemes, as should international market demands. There are a number of tools at the juice technologist's disposal; use them creatively. However, there is no substitute for experience with a given crop. A hands-on feel for the whole product and the derived juice is essential and it cannot be gained solely on the Internet, from the literature, or by second hand experiences of others. Observe the local flora carefully and patiently; they will tell you their promise.

19.2 Doing your homework

No matter what your expertise, if you have a commitment and strong interest in the area of juice technology, it is essential to keep up with technical, business and legal developments. Of course, your background, professional focus and specific issues will dictate the magnitude of this continual task. Information in all forms whether speech, print, media, electronic, instructional is increasing at a frightening rate and will undoubtedly accelerate. Table 19.2 lists some major resources worth knowing. There is a substantial, growing body of knowledge dealing with all facets of juices. Unfortunately, the hubris (nonessential, marginal, even false information) is growing at an even faster rate. One must separate useful resources from clutter.

Table 19.2: Resources for juice technologists.

Resources	Guides
Text books	Subject indices of technical and business library holdings
Professional journals	Subject titles– food science, technology, microbiology, etc.
Abstract services	FS and T, Chem, Biological, Business, etc.
Review articles	Titled as reviews – periodicals and annual
Trade journals	Food and business press
Patent literature	U.S. and international
Periodicals	Financial and business press – daily, weekly, monthly
The Internet	Easy search in all - gov, org. com. edu. and international
Training	Courses, conferences, meetings, seminars, workshops
Trade Shows	Professional and trade associations
Institutional Resources	Universities and professional societies
Personal Network	Develop and maintain based on all of the above

Consider these resources as if it was an extremely large, versatile buffet line with a wide array of food items. Together with appealing dishes are displayed many not so appetizing including those that have minor relevance, are redundant or for which you have no interest. It's impractical to sample everything, particularly at one sitting. Yet in the interest of curiosity and "balanced intellectual nutrition" there are items you should consume or at least be aware are offered. Sample a few to gain familiarity and by all means get a feel for those resources that complement your own expertise. Ignorance is not bliss so an important first step is knowing what you don't know, while understanding how to access needed information. These are described here and listed in detail in the bibliography in Annex B. However, one need not be limited to English, as, increasingly much material is in other major languages such as French, German, Italian, Portuguese, Spanish, Chinese, Japanese, etc.

19.3 Textbooks

There are a lot of good ones out there, as cited. Some of the older books have strong chapters of current relevance that shouldn't be ignored. A library subject search can be a rewarding exercise. For example, if one is interested in food additives or food regulations, enter these terms in a library catalogue. There should be many sources, including recent texts, reviews, even research articles. In a more technical vein are some texts that assume that the reader has more of a food science and technology background and go into more industry detail.

19.4 Abstracts

For a quick review of a certain subject, abstract services are quite efficient. Specific details about technical, legal, business matters are presented effectively by abstracting services. The subject index can provide a comprehensive focus on original research, reviews, or patent literature. First conduct a well-structured subject search and peruse the titles generated to initially screen searches. Those of interest can be further screened by reading the abstract. Then access to the original article or review should provide needed information.

Most university libraries have “Food Science and Technology Abstracts” and “Chemical Abstracts”. Up until recently an abstract search involved access to a library with the appropriate holdings in either hard copy (printed) or on CD disc. Now library access is still important, but can be accomplished via the Internet. By the proper use of key words, practically the world’s literature (from at least the mid 1990s on) is at your disposal. In fact, too much, since a too broad search request will flag hundreds, if not thousands of selections.

19.5 Patents

A well-orchestrated abstract search rapidly leads to journals, texts and conference proceedings. Practically all professional societies and trade associations have a defining publication, such as a journal, proceedings, newsletter, etc.; some have more than one. Articles dealing with membership interests are usually topical and relevant. This is certainly true of the food field. For example, peruse a few issues of Food Technology to see what juice regulatory, business and technical concerns are topical. It would be a full time job to keep up with dealing with all aspects of juice business/technology; the commodity and industry orientation helps.

Professional journals go into detail regarding the interests of their membership and may include useful reviews and industry news. Special conference topics often end up as published proceedings. Trade journals are apt to be more sales oriented and feature articles and ads emphasizing solutions to industry problems and supplier sources. You should be aware of both as well as review journals, which provide topical overviews. A good current review article comprehensively summarizes pertinent text and journal literature and can be a gold mine of information and a real time saver. Table 19.3 lists some resources with juice relevance covering a broad range of commodities and economic interests (FPMSA, 2000). This list is far from complete.

19.6 Patents

The bottom line in creativity is reflected in patents, trademarks, copyrights and trade secrets. We have reasonable public access to the first three but the last is closely guarded by the ownership. As the depository of innovation, patent literature is invaluable to the entrepreneur. If for no other reason than to discover the rationale behind existing inventions, patent literature is essential. It’s hard to read, verbose and repetitive (written by lawyers, not scientists or inventors), yet worth the effort. Patent abstracts are available at most libraries, some major libraries are patent depositories and copies can be purchased from the U.S. Patent Office. International patents can be accessed at http://patents.uspto.gov/.

19.7 Periodicals

Newspapers and magazines as sources of information should not be neglected. The business press is a daily, weekly or monthly update. Promotional material is also useful. Most importantly news items, editorials and advertisements indicate popular trends and opinions before they are evaluated and reported by experts.

19.8 The Internet

No development has changed the Information Sciences more than the Internet. With tandem advances in personal computer (PC) hardware, software and Internet links we are in the early stages of an information revolution. Instead of visiting a library, one can readily access most of the above sources using a linked PC from almost anywhere in the world. Recent patent and abstract literature is at your fingertips via the Internet. On-line publication of journals in a growing phenomenon, so a PC with Internet access and a printer can go a long way toward staying abreast of current literature.

Internet as an information vehicle is not free of drawbacks. The Internet is rapidly replacing printed matter and greatly facilitates the task of disseminating up to date materials. However, the medium is in flux, access is sometimes very slow, sites vary greatly in quality, and Website addresses (URL's) change, appear or disappear at an annoying rate.

The ease of Internet access often makes it the method of choice in searches, often the sole choice. This is a mistake. Older literature is usually not on the Internet and provides valuable insights to where the juice industry came from and where it's going. Perusing old issues of Food Technology or trade journals from the 1950s can be a worthwhile exercise. Also, classic texts from the past can provide a sound technical introduction and put new developments in perspective, especially when combined with current literature awareness. One of the most valuable features of the Internet is immediate access to key resources such as government, industry, university, professional and trade societies, commodity groups, etc. It is a rare organization that doesn't have a Website. For a good introduction, check out the FAO, FDA, or IFT (ift.org) on the web. Although you may need to wade through copious screens of advertisements on commercial Websites, there's a wealth of information from government organizations, suppliers, even competitors. Table 19.3 illustrates some key journals and related Websites worth noting.

Until recently, any listing of background reference material has logically started with printed material and there is still much of value to recommend. However the Internet's explosive growth merits attention. This is particularly the case with government publications relating to food safety, regulations, grades and standards. FAO Codex, USA Federal and many State governments have impressively user-friendly Websites. Documents and contact information previously available only at libraries or the home office can now be accessed in current form on the web.

Of particular value are trade journal Websites. Their supplier indices and links are a comprehensive and easy access to trade information and greatly facilitate planning, evaluating, and purchasing. One caveat researchers should beware, as anyone can produce a Website, the credibility of the information is no better than that of the provider. There is an abundance of nonsense parading as fact on the web. Sadly disinformation is increasing faster than valid information. Nevertheless, learn to use the Internet in combination with credible and respectable literature.

Table 19.3: Professional and trade journals and supplier links with juice relevance

Journal	Organization	Link
Food Technology Journal of Food Science	Institute of Food Technologists (USA)	http://www.ift.org/
Agriculture and Food Chemistry	American Chemical Society	http://www.acs.org/
Beverage Digest		http://www.beverage-digest.com/
Beverage World		http://www.beverageworld.com/
The International Journal of Food Science and Technology	Institute of Food Science and Technology (UK)	http://www.ifst.org/
Food Science and Technology Today		http://www.ifst.org/fstt.htm
The World of Food Science	International Union of Food Science and Technology	http://www.worldfoodscience.org/
Cereal Foods World	American Association of Cereal Chemists	http://www.scioc.org/aacc/
American Oil Chemists Society	American Oil Chemists Society	http://www.aocs.org/
Many Trade Journals	Cahners Food Publications	http://www.cahners.com/
Many Trade Journals	Stagnito Communications	http://www.stagnito.com/
Frozen food publications	National Frozen Foods Association	http://www.nffa.org/
Food Processing		http://www.foodprocessing.com/fp/index.html
	Food Info Net	http://www.foodinfonet.com/
	Food Processors	http://www.fpmsa.org/
	National Food Processors Association	http://www.nfpa-food.org/
	SIAM	http://www.thaiusbusiness.com/
		http://www.packexpo.com/
	National Soft Drink Association	http://www.nsda.org/
	National Juice Products Association	http://www.njpa.com/
	Indian Ministry of Food Processing Industries	http://mofpi.nic.in/
		http://www.foodonline.com/BuyersGuide
	International Dairy Foods Association	http://www.idfa.org/
	The Contract Packaging Association	http://www.contractpackaging.org/index_cpa.jsp

19.9 Institutional resources

Practically every country, state and city has services fostering agricultural development. Add to these private entities such as banks, financial institutions, Chambers of Commerce and efforts at the international level. In the broadest sense, there is more interest in "high tech" promotion such as biotechnology and computer industries than in agriculture. Although our emphasis is juice, many non-agricultural organizations have valuable programs or information, i.e. finance, marketing, relocation, employee training, etc. well worth learning about.

These organizations hold workshops, conferences and short courses on pertinent subjects, with related published newsletters, bulletins, and conference proceedings. The trade shows and industrial exhibits of professional and trade societies can be extremely valuable "hands-on" experience. Of course, the attendant programs and activities are well publicized and promoted in Websites. Some of these half-day to several day activities can be quite costly, equivalent to a university's full semester course tuition (or more). And the fee usually doesn't include all meals, lodging or travel. Nevertheless, if on the basis of your participation you avoid serious technical or business errors, the event can be cost effective.

Courses of a half-day to week duration and industrial exhibits do provide background and specific information. Just as importantly, they can provide a good networking environment with the opportunity to interact with like-minded individuals and experts in the field. As with the Internet, course and exhibit quality varies, so keep in mind the reputation of the presenting organization.

In the United States of America, the Small Business Administration (SBA) provides statewide small business counselling, information services and training for both start-up and existing firms or individuals. Their strategy of providing information and advice while the clients do the legwork and make the decisions is typical of the self -help philosophy. In view of the highly competitive nature of the food industry, the SBA is a welcome and essential resource. A perusal of their Website is informative (SBA, 2000).

Such a huge inventory of resources can be intimidating, so remember the buffet dinner metaphor. You can't sample and digest everything. Get a good overview and feel for what's out there; then be selective. Remember, no one knows more about your juice product ideas and aspirations than you do. It's then a matter of identifying, evaluating, inventorying and utilizing those resources that serve your specific needs. As a matter of principle, maintaining awareness by perusing relevant texts, journals, the Internet and news sources; participating in relevant professional and trade association activities while establishing your personal network are good, if not essential insurance routines.

On the other hand, information is of minor value, until it's put into practice. That's where your expertise, focus, and ambitions come in. All cited resources are at your disposal. There are many local, national, and international agencies that can help and advise, but the ultimate effort must be your own.

ANNEX A.
Suppliers

The escalating complexity of food processing operations coupled with stricter regulatory control make the choice of raw materials, equipment, ingredients and service suppliers more critical than ever. Suppliers must understand client needs and the total business environment. The relationship between supplier and processor is now more a partnership than a one-time transaction. For example, a processor might demand third party verification of the grower's ability to meet GAPs during crop production, GMPs in shipping, and proscribed quality standards upon delivery. The processor, in turn may need to demonstrate a workable HACCP plan to the buyer, certify the quality in addition to the safety of the final product. Retailers may demand traceback assurance back to the farm. Equipment manufacturers equally have extended obligations relating to the safety, sanitary construction and durability of their wares.

These interrelationships complicate juice production logistics, but they are the unavoidable price of doing business. There are some positive features of this system. Product uniformity, safety and quality are apt to be higher. Unpleasant, well-publicized recalls are minimized. When recalls do occur, implementation is more efficient and liability assessment is less ambiguous.

In addition, suppliers have a much better grasp of industry needs and have developed improved products to meet the demand, albeit at a higher cost. Communications and information transfer between suppliers and processors are much easier. There are few suppliers that are not listed in trade journal guides, together with toll-free phone listings plus, increasingly, Internet addresses. Competition demands it. Therefore processors can readily obtain preliminary information on all possible supplier services. Upon review, they can target explicit inquiries to the appropriate supplier sources.

This is the situation in the developed world. It's more difficult to perform this process in the developing world for the following reasons:

- The operating scale is apt to be much smaller, entailing higher costs or specialized manufacture. For example a one head citrus juicer might cost 1/3rd that of a larger six-head extractor,
- Used equipment is less available and more costly for the same reason. When key items do exist they may well have been depreciated to zero by the previous owner and require exceptional mechanical services to operate and maintain,
- Parts, services, and trained labour are less available and more costly. In Europe or the United States of America, it is a simple matter to order a critical part and have it shipped and delivered the same day. Not so with international airfreight, import, and customs restrictions,
- Equipment may not exist or suppliers may not have experience with a needed operation. Can a Ginaca machine be adapted to conical pineapples? Is there an automatic mango or papaya peeler suitable for the many different cultivars?

- Even if the answers to the above questions are positive, will a firm be willing to manufacture units for a limited market at a reasonable price? Suppose proprietary designs are blatantly copied and sold overseas in competition with the original developer?
- Trustworthy company representatives and reliable services are scarce in many regions. Those that exist are overworked and less experienced.

Fortunately, the situation is changing for the better. The international network of suppliers is growing along with reliable representation. ('Reliable' is the operative word here. Shady wheelers and dealers continue to represent unaware suppliers to the detriment of clients and businesses). Therefore, juice processors must network carefully, become aware of their technical needs and economic limitations and explore supplier alternatives thoroughly. The technical and trade literature, industrial exhibits, Internet links and personal contacts via networking are all essential tools in building and maintaining supplier relationships.

ANNEX B.
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