agents, which resulted in lower amounts of ellagic acid precipitate. The levels of soluble ellagic acid in the juice did not relate very well to the sediment formation in the juice (data not shown), which agrees with results from the previous studies.

Red Wine Study. Skin fermentation time had a large impact on the ellagic acid sediment formation in a red muscadine wine. Wines fermented on the skins had much higher levels of ellagic acid sediment than the immediate press wine (no skin fermentation) (Table 1). Levels of ellagic acid sediment increased significantly through 4 days of skin fermentation, then remained relatively constant between 4 and 6 days. Total phenol levels in the wine also increased with skin fermentation time, with the largest increase occurring between 0 and 4 days. Since grape skins are known to contain relatively high levels of phenolic compounds, longer skin fermentation time probably extracted more of the ellagic acid containing tannins. The levels of sediment formed in the red muscadine wine were considerably higher than levels formed in a white juice, which tends to illustrate the contribution of skin tannins to the sediment problem.

Conclusions

Heat pasteurization and high storage temperatures accelerate ellagic acid sediment formation in white muscadine juice. Treatment of the juice with the fining agents gelatin, egg albumen and PVPP reduced sediment formation. A commercial pectinase added to crushed grapes increased total phenolics and sediment formation in a white muscadine juice. Ultrafiltration membranes (10,000, 30,000 and 100,000 MWCO) were also effective in reducing sediment formation in the white juice. A red muscadine wine had much more sediment than the white juice, and longer skin fermentation times greatly increased sediment formation and total phenols in a red muscadine wine. More research is needed to determine the specific phenolic and tannin composition of muscadine grapes.

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CHANGING TECHNOLOGY IN CITRUS PROCESSING

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Abstract. **Changes in citrus juice market demands over the past 60 years have driven developments in technology which have resulted in higher quality juices. These changes in market demands are discussed and their impact on technological development is also explored. Specific technologies in extraction, finishing, concentration, pasteurization, automation, juice quality enhancement and by-product recovery are discussed. Finally, future trends in processing technology and fresh fruit packing technology, such as automated harvesting and non-thermal pasteurization of juice, are reviewed and several potential emerging technologies are discussed.**

Changes in Citrus Juice Markets

The development of the commercial citrus industry started with Spain's cession of Florida to the United States in 1821. The propagation of citrus in both Florida and California followed. Later, the industry concentrated in four states (Florida, California, Arizona, and Texas). Originally, the citrus industry was developed for the fresh fruit market. Fruit production increased at an accelerated pace by the 1930's, creating a fresh fruit oversupply. This surplus of fruit was the major factor in the development of different citrus products to increase consumption.

The unsalable fruit began to be expressed and sold as single-strength fresh orange juice which was processed and packed in glass and cans. Although the introduction of these two different products allowed the expansion of the shelf life and distribution of orange juice, the quality of these products was poor and their market never expanded significantly. In 1946, Frozen Concentrated Orange Juice (FCOJ) was developed by the United States Department of Agriculture (Florida's "Cinderella" product). The discovery that fresh orange juice flavor could be restored by blending non-concentrated fresh juice was the basis for the success of FCOJ. Frozen Concentrated Orange Juice allowed the commercial production and widespread distribution of orange juice in addition to fulfilling the consumer's desire for a product with a fresh juice taste. Additional marketing features included convenience, consistent product flavor, year-round availability, and lower cost. Frozen Concentrated Orange Juice was a success not only in the United States but also in some other countries.

The rapid increase during the 1970's and 1980's in the number of two-income families has significantly driven the market for convenience and packaged food products. With both adults working, there was a marked decrease in time for household chores and more disposable income. This resulted in a dramatic demand for ready-to-serve chilled juices. Improvements in product flavor, as well as new packaging technology to preserve flavor and increase convenience, helped drive the demand for ready-to-serve chilled juices.

The trend in the 1980's toward increased consumption of healthier, more nutritious, and natural (less processed) foods had a tremendous impact on the orange juice industry. The most widely recognized product satisfying these characteristics in the orange juice market has been the not-from-concentrate orange juice (NFCOJ). Its dramatic market increase has been at the expense of the FCOJ market, even though this product sells at a substantially higher price. Not-from-concentrate orange juice products had additional marketing appeal and claim that no water had been removed or added back. Thus, NFCOJ was promoted as not concentrated. With increasing popularity of this product the concept of heat evaporation or heat concentration became synonymous with lower quality.

Another trend in the citrus industry worldwide has been the increasing market growth of fresh juice or freshly squeezed orange juice. Originally, this product was extracted and offered directly to the consumers by Florida roadside gift fruit shops. As they became more successful, their operations and market expanded (institutional, hotels, restaurants, etc.). Today, established juice processors have become interested in this market and non-citrus producing areas (United Kingdom, Belgium, Germany, etc.) have established citrus juice production facilities.

The continuous increased demand for higher quality orange juice products of high aromatic character, reduced bitterness and oil, improved microbiological stability, minimum heat treatment, and greater nutritional value (vitamins and fiber) has become the major stimulus for the development of more sophisticated technologies.

Extraction Technology. Extraction technology has evolved significantly over the years. In the early 1930's, juice extraction was accomplished by hand-reaming and mechanical extractors (roller press and rotary). These methods had limited extraction capacity and low quality, respectively. The development of FCOJ spurred the introduction of more efficient, high speed, high capacity mechanical extractors. Today, the two main extractor systems that exist in the market are the FMC citrus juice extractors and the Brown extractors.

The FMC extractor has undergone continual improvement and advancement for the past 40 years. One of the most significant developments to come along in many years is the introduction by FMC of its Premium Juice Extractor. The FMC Premium Juice Extractor (PJE) is the culmination of 10 years of development. The initial goals were set back in 1980 when Japanese citrus processors asked FMC to develop methodology to extract juice with low levels of peel oil. Since peel oil was, and still is, a major quantifiable constituent with a significant effect on the quality of OJ, FMC took that challenge seriously and developed several generations of machinery for producing low oil juice. During its research and development program, FMC scientists learned that the oil level in juice is just one of the many constituents of peel that cause degradation of juice flavor. Other peel extractives are currently being studied to determine their effect on quality and mechanical methods to reduce their introduction into juice are also being researched.

In developing its PJE, FMC took advantage of its unique extractor design. The PJE utilizes the prefinisher concept to control the quantity of membrane material introduced into the juice, and decreases the peel plug area that contacts the juice to reduce peel extractives. The results have been a machine capable of delivering extremely high quality juice at very high yields and a demand by the citrus industry that has exceeded FMC's expectations.

Finishing Technology. The function of this technology is the separation of liquids (juice) from solids (seeds, peel particles, excess pulp and membranes) by means of a rotating screw within a cylindrical screen. Finishing technology has continually improved over the years. FMC has also improved its finisher designs. FMC introduced the concept of close tolerance finishing (small distances between the screw and the screen) in the 1960's. The design is especially well suited to the juice sacs present in the juice from the FMC citrus juice extractor and has been very successful in improving both the yield and quality of the juice. During the last decades, FMC has continued introducing improved mechanical versions (strippers, gates, and plug valve) to discharge the solids from the finisher, thus allowing the juice processor to increase capacity and efficiency without sacrificing juice quality.

Concentration Technology. Concentration technology has undergone the most dramatic changes since the early 1940's. Initially, citrus juices were concentrated in low temperature, falling film evaporators. These evaporators operated under high vacuum, stripping off most of the volatile aromas while the juice was continually recycled until the desired concentration was reached. As technology progressed, the Temperature Accelerated Short Time (TASTE) Evaporator was developed. This evaporator used several stages and effects heating the juice to higher temperatures for shorter times. This evaporator also included systems for the pasteurization and stabilization of the juice, as well as for recovering essences. These essences could be added back to the juice, making the finished product more like fresh juice than the product from the low temperature falling film evaporator.

In the late 1970's, a new process was developed for concentrating citrus juices by separating ice crystals from the liquid. This process, known as freeze concentration, has the capability of producing high quality concentrated citrus juices with no cooked flavor. The process is very expensive and the equipment is mechanically complex. Although this process does not use heat for evaporation, the juice must be heat pasteurized prior to freeze concentration to inactivate enzymes and reduce microbiological counts. Moreover, the juice that is to be concentrated on this system must have a low oil level since any peel oil that is present in the juice simply gets concentrated in the process, causing the development of off flavors. Low oil juice levels can be achieved by preventing the introduction of this constituent (use of the FMC Premium Juice Extractor) or by removing it from the juice (de-oilers, centrifuges, etc). The preferred method of producing premium juice for any freeze concentration system is to use the FMC Premium juice extractor.

In the late 1980's, a new technology was developed by SeparaSystems, a joint venture of FMC Corporation and DuPont. The new process, known as the FreshNote® process, uses both ultrafiltration and reverse osmosis membranes to concentrate citrus juices or other fruit juices to high Brix levels. The principle of operation of the process is the separation of the incoming juice stream into a clarified serum and a pulp stream by using an ultrafiltration membrane module. The clarified serum is then passed through a reverse osmosis membrane module where it is concentrated to a high Brix level (up to 60° Brix dependent upon application requirements). The pulp stream is then pasteurized to inactivate enzymes and microorganisms. The delicate flavors and aromas are protected from heat since they pass freely through the ultrafiltration membrane and are concentrated in the reverse osmosis membranes without the use of any heat. In fact, the process is carried out in a chilled condition. Since this process separates the enzymes and microorganisms from the main juice stream and pasteurizes only them and not the flavors, the juice does not need to be pasteurized prior to introduction into the FreshNote® system.

This membrane concentration system is mechanically simpler than the freeze concentration system. Product quality is equal to or better than that of freeze concentration since the whole juice stream does not need to be pasteurized. The FreshNote® system is almost completely automated, simplifying operation and aiding in reliability.

Recently, GEW Wiegand has introduced a new evaporating concept for concentrating orange juices by applying thermal vapor recompression. This technology is not new and has been used very successfully for many decades in other industries. The manufacturer claims that, with this evaporator, it is possible to obtain favorable energy consumption, extended operating periods and good product quality.

Pasteurization Technology. Tremendous strides in pasteurization technology have been made in the last 10 years. Heat exchangers have been made more efficient; much research has been done into determining the minimum

sulted in increased extractor utilization, improved clean-up efficiency, increased yield, reduced operating costs, and consistently higher quality juices. Some of the juice room automation systems designed by FMC use computer logic with touch CRT screen graphics. In other locations, keyboards have been employed. Either way, the systems have been designed to be user friendly and allow the operator to monitor all operations of the juice room, from fruit handling to clean-up, without leaving the control room.

Automation of evaporators has been carried out successfully on a limited scale on some commercial units. The University of Florida and the Florida Department of Citrus have jointly worked on this application of computer technology in the citrus industry. Some Florida citrus processors have operational automated evaporators in various stages of commercialization.

One area which has seen the most significant evolution in automation is in clean-up system operation. FMC has developed computer controlled automated clean-up systems for extraction, finishing, and oil recovery systems as well as many juice handling systems. Sanitation is a very important consideration in the production of premium quality juice and FMC's Automatic Clean Up Systems (ACUS) assure the most consistent degree of sanitation by removing human error from the clean-up process.

Juice Quality Enhancement Technology. In very recent years a number of new technologies have been introduced into the citrus industry aimed at improving the quality of citrus juices. These include debittering systems, deacidification systems, decolorization systems, and bulk aseptic storage systems.

Several debittering systems have been developed in the past five years. Each of these systems uses a clarification separation stage to remove pulp and a debittering stage using a resin column to remove bitter substances such as limonin and naringin from juice. Some of these systems use centrifugation to clarify the juice prior to treatment with the resin, while another system uses an ultrafiltration membrane system in conjunction with centrifuges to clarify the juice. The resins used are primarily adsorption type resins which adsorb the bitter molecules. The bitter constituents are later removed when the column is regenerated. Debittering systems are being used commercially to process navel orange and grapefruit juice as well as several by-product streams such as peel wash, and other types of secondary solids streams. Most of the basic research on debittering was done in the early 1980's in Australia. Debittering systems are now in operation in Australia, Greece, U.S., Israel and several other countries. Debittering may well prove to be the technology that significantly improves the marketability of grapefruit juice.

Another system which uses the same basic principle as

dling and packing have been developed to achieve these quality standards.

There has been a significant increase in the use of technical monitoring activities to insure that high quality fruit arrives at the extractor. FMC Technical Service Advisors monitor the fresh packing process to identify areas where damage to fruit is occurring. Since injuries are required for infection by many citrus pathogens, identification and correction of problem areas reduce the potential for decay without the need for additional fungicide treatments. Airborne spore levels are measured and sanitation strategies are developed to reduce inoculum and infection potential. The degreening process is monitored and controlled to reduce the development of latent infections, such as stem-end rot (*Diplodia natalensis*) and anthracnose (*Colletotrichum gleosporoides*), reducing the amount of decayed fruit shipped to the processor.

New developments in the application of postharvest chemical treatments can control postharvest decay, yet leave minimum residues on the fruit surface. FMC has recently introduced and developed a new technology for the application of fungicide to entire truckloads of field run citrus. This process, called Truck Drenching, provides decay control during the critical degreening process, yet allows the standard washing procedure to remove most of the pesticide residue left on the fruit. Other areas under consideration include the use of physical treatments, biological decay control agents, naturally occurring compounds and improved storage methods.

Investigation of the effects of protective coatings on internal fruit quality and physiology is an area where fresh fruit technology is developing rapidly. Coatings are required to reduce water loss following the commercial harvest, packing, and storage or shipment of fresh citrus. New coating formulations that control gas exchange between fruit and the environment are being developed and tested. These coatings control development of off-flavors in the juice during long term storage and shipment. Recent advances in coatings technology by FMC provided excellent storage of Valencia oranges for over four months. New developments in other technologies are being evaluated to reduce decay, control chilling injury, and extend the shelf life of fresh citrus.

The Fresh Citrus industry has always recognized the value of internal fruit quality in the marketing of fresh Florida citrus. This value has been enhanced by the increased consumption of fresh squeezed juice. Increased utilization of technical expertise, the exploitation of evolving technologies for improved handling and packing, better control of microbial contamination, a longer shelf life, and a reduction in pesticide residues will provide the citrus processing industry and its customers with the high quality fresh citrus fruit that they require.

Non-Thermal Pasteurization Technology. There are several technologies currently being explored for non-thermal pasteurization. These methods will eventually be coupled with the production of not-from-concentrate juice and will enable processors to produce an excellent single strength juice with extended shelf life. As of today, large strides have been made in the application of high pressure stabilization in this area. A company in Japan has developed and implemented a process for the high pressure treatment of fruit juice and fruit products (jams, etc.).

Juice Flavor Enhancement. There are two areas currently under consideration for additional juice flavor enhancement. The first involves various physical and chemical/physical methods of selective component enrichment. This concept is similar to debittering or deacidification in that a process is used where certain compounds are concentrated in the juice, or conversely, other compounds are reduced in quantity. Another area currently under investigation involves the recovery of citrus juice essences at low temperatures. Such a process would enable producers of premium quality single strength juice to extract the essence prior to pasteurization and add it back after the main juice stream is pasteurized.

New Packaging Techniques. Many opportunities exist for improving the quality and stability of citrus juice through package design. Such practices as using inert gases in the headspace, and oxygen impermeable containers, are already being used by some processors. Other concepts involving the use of oxygen scavengers built into the packaging material, and more consumer friendly packages, have yet to be addressed.

Nutritional Fortification. Some work has already been done in the United States in using orange and grapefruit juice as a carrier for other nutritional components. Calcium fortified citrus drinks are currently on the market in the U.S. and other nutrients are being evaluated for possible incorporation into citrus juice. Regulatory authorities generally are hesitant to allow a food product to carry another nutrient if that nutrient is not normally found in the particular food ingredient.

Wastewater Treatment Technology. One of the major problems facing the citrus industry worldwide is not improving the quality or quantity of the product, but how to properly dispose of wastes. Citrus wastes are large in volume and because of the sugars, oils, pesticides etc., waste disposal has become a major issue. Some progressive citrus processors have developed systems to convert waste materials into alcohols that can be either sold or used as an internal energy source. This practice is especially important in countries like Brazil which do not produce any natural petroleum energy. New methodology is needed to enable processors to recycle as much of their process water as possible. Another incentive for recycling water is the fact that most citrus processing plants are located in areas of the world where water availability is becoming critical.

Controls and Automation. As labor costs continue to increase and consistent yield and quality become more important, the need for total plant automation becomes of more interest. In the future, new plants will have intelligent control panels instead of simple panels with on-off switches. FMC designed an automated juice room in the mid 1980's using an intelligent control panel with microprocessor technology to make some of the common decisions needed to assure consistent processing in the juice room. Many controls companies are currently developing software to fully automate food processing systems and to make on-line decisions as processing conditions dictate.

The use of expert systems and artificial intelligence will become more widespread as software becomes more sophisticated. At the present time, the technology to design the necessary software exists. As new citrus processing plants are constructed, many of these concepts will be incorporated into the design. New plants in the future will use expert systems and artificial intelligence to control blending and formulation as well as process operation.

Summary

Over the past 60 years, the citrus processing industry has progressed from one which extracted juice by hand and sold its products locally to a worldwide industry shipping a variety of products to markets around the world. Fruit production has shifted from the United States to Brazil, and looking toward the future, China appears on the verge of becoming a world leader in citrus production. Technology has played a major part in the evolution of today's modern, shelf stable, high quality products. The future holds many new surprises and much new technology will change the nature of the citrus products sold in the 21st century.

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MICROBIALLY PRODUCED OFF-FLAVORS IN ORANGE JUICE

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Abstract. **Samples of reconstituted evaporator pump-out were commercially pasteurized and inoculated with individual strains of *Saccharomyces cerevisiae* Meyen *ex* Hansen. These were incubated for 24 hrs at 30°, 20°, and 10°C in separate runs. Production of volatile metabolites was monitored by direct headspace and by adsorption/desorption concentration using gas chromatography. Growth of microorganisms contributed to the development of several volatile compounds, including acetaldehyde, ethanol and several fusel oils (n-propanol, n-butanol, isobutanol, n-pentanol, active amyl and isoamyl alcohol). Reduction in incubation temperature resulted in reduced quantities of volatile metabolites produced.**

Premium quality orange juices (pasteurized not-from-concentrate, lightly pasteurized, and unpasteurized) represent one of the fastest growing segments of the citrus juice market. Flavor changes resulting from microbial growth are an important spoilage aspect of these ready-to-serve citrus juices. Although the low pH environment of citrus juices limits the types of microorganisms that can grow and cause spoilage, there remains a number of bacteria, yeasts and molds that are common spoilage agents (Hays, 1952; Berry et al., 1956; Parish, 1991). Of the yeasts, *Saccharomyces cerevisiae*, one of the more common spoilage agents in pasteurized juices (Parish, 1988), is known to cause spoilage by the generation of ethanol, CO_2, and other metabolic end product which are thought to contribute to the perception of a "fermented" flavor. Other flavor metabolites biogenerated by strains of *S. cerevisiae* have been studied in other fermented products, such as wines (Herraiz et al., 1990; Mateo et al., 1992), distilled beverages (Salo et al., 1972), beer (Buckee, 1992), and bread doughs (Torner et al., 1992). Those volatiles affecting flavor are higher alcohols or "fusel oils", including n-propanol, n-butanol, isobutanol, amyl alcohol, active amyl and isoamyl alcohol. Identification and quantification of off-flavor metabolites produced by yeasts have not been clearly defined in spoiled citrus juices. The purpose of this study was to investigate the production of off-flavor metabolites by *strains of S. cerevisiae* in an orange juice model system.

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Materials and Methods

Microorganisms. Two strains of the yeast *Saccharomyces cerevisiae* were isolated from various spoiled commercial orange juices. Samples of each strain were grown in Yeast-Mold Broth (Difco, Detroit, MI) and subsequently transferred to filter sterilized (0.2 μ) orange serum prepared by sequential filtration of commercial Valencia orange juice. Using a Spectronic 21 spectrophotometer (Bausch & Lomb, Rochester, NY) to determine relative growth, inocula were grown to an absorbance of 0.7 (600 nm) prior to sample inoculation. One 6-ml sample of inoculum was centrifuged using a Sorvall RC-5B (Dupont, Newtown, CT) at 19,000 $\times$ g for 10 minutes. The supernatant (serum) was discarded and the pellet (cells) resuspended (vortexed) in 6 ml of pasteurized reconstituted pump-out orange juice for inoculation.

Experimental. Two-liter samples of reconstituted evaporator pump-out were heated in a microwave oven (with carousel) to pasteurization temperature (ca. 90°C) and poured into sterile two-liter flasks. After cooling to room temperature, sample flasks were inoculated with the 6 ml resuspended inoculum and incubated at 30°C, 20°C, and 10°C in separate experiments. A 250 ml sample was withdrawn every 3 hours for analysis. Butyl acetate was added (5 ppm) as an internal standard. From this, four 5-ml samples were transferred to individual 9 ml septum screw capped test tubes and placed in a 45°C water bath for 40 minutes (for equilibration). From each test tube, 1 ml of headspace was removed using a sterile 1 cc 26G3/8

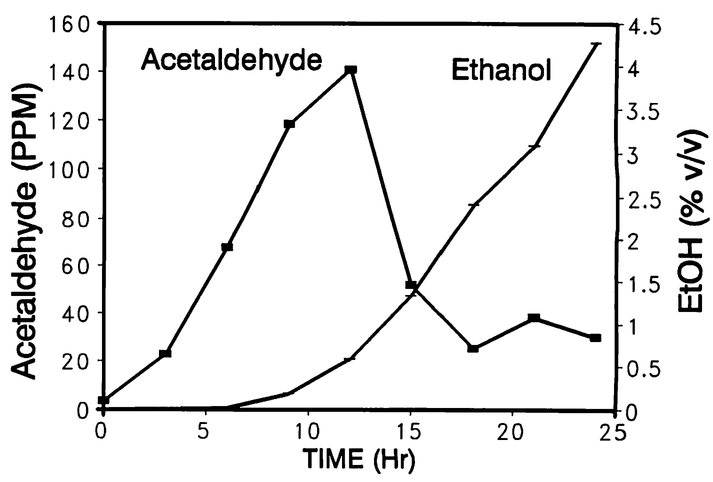

Fig. 1. Acetaldehyde and ethanol produced by *S. cerevisiae* in reconstituted pump-out at 30°C.