Bottled Maple Sap

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Overview of Bottled Sap and its Potential Uses

Producing maple syrup (66.0 to 68.9 °Brix) from maple sap with approximately 2 °Brix requires extensive energy and labor. A lower input option is to market maple sap as a commercial beverage for consumers (Figure 1). On average, about 44 gallons of sap are required to produce one gallon of maple syrup. One gallon of syrup has a gross value of about $120 if sold in 16 oz retail containers. If instead of being processed into syrup, the maple sap was processed into 16 oz bottles of drinkable sap sold at $3 each, $1,056 of revenue could be generated from the same 44 gallons of sap; this represents a 780% increase in sales revenue.

Maple sap is harvested in eastern North America during thawing temperatures from January to April each year. For maple syrup production, sap is typically processed into syrup soon after harvest as sap is a perishable product susceptible to bacteria, yeast, and mold contamination across the season (Lagacé et al. 2002).

To preserve maple sap quality, care must be taken to ensure it has not spoiled or interacted with any potential contaminants, including lead and sanitizer residues. Once maple sap is harvested, it can be processed and packaged using multiple techniques, each of which ensure the product maintains quality and safety for consumers. This article reviews the benefits of maple sap

Figure 1. Shelf-stable maple sap beverage. Photo by Ailis Clyne.

as a bottled beverage while covering preservation and packaging methods, regulatory guidelines, and overview of commercial production procedures.

Maple Sap Composition and Market Potential as a Functional Beverage

Freshly harvested maple sap contains sugars, mainly sucrose, glucose and fructose, minerals, amino acids, organic acids, and phenolic compounds (Yuan et al. 2013; Lagacé et al. 2015; Table 1). Sap composition has been shown to change across the harvest season with a decline in pH and sucrose, and an increase in invert sugars (glucose and fructose), organic acids, and minerals from the beginning to end of each season (Lagacé et al. 2015).

In sap that was preserved through pasteurization, the content of sucrose, minerals, amino acids, and total phenolics (antioxidants) were maintained or increased. Simultaneously, invert sugars decreased slightly and malic acid increased slightly (Yuan et al. 2013). In a separate study, a commercially pasteurized maple sap was evaluated over 12-months of storage under refrigeration (4 °C or 39.2 °F). Sucrose, fructose, and glucose declined slightly after four-months of storage, while pH, amino acids, and total phenolic levels were maintained across the study (Torrey et al. 2023). Quality decline should be considered when establishing "Best By" dates for any preserved maple sap. Pasteurization and other preservation methods are described in detail in the Preservation Methods section below.

Table 1. Average composition of maple sap collected throughout the harvest season of twenty-one sugarbushes in Quebec, Canada

Analysis[1]	Average	SD[2]
pH	7.13	0.52
°Brix	2.03	0.50
Sugar (%)		
Sucrose	2.10	0.43
Glucose	0.03	0.041
Fructose	0.03	0.056
Acids (μg/g)		
Acetic	24.2	24.2
Fumaric	7.9	14.2
Lactic	18.0	42.0
Malic	305.2	387.8
Pyruvic	10.4	14.1
Succinic	39.3	61.3

[1]Data from Lagacé et al. 2015; [2]SD = Standard Deviation from the Average

The stability of maple sap after processing and during storage provides insight into its potential use as a functional beverage. Functional beverages are a category of the beverage industry that provide health benefits either naturally or through formulation. The health-benefiting components may include macro- and micro-nutrients, prebiotics, probiotics, dietary fiber, and antioxidants, among other substances (Temple, 2022). For instance, some bottled waters are fortified with functional ingredients, including vitamins, minerals, antioxidants, or amino acids (Dini, 2019).

Coconut water is a common functional beverage that provides a useful comparison. It contains antioxidants and minerals, particularly potassium and-magnesium (Santos et al. 2013). Compared to coconut water, raw maple sap has lower antioxidant capacity, as measured by the diphenylpicrylhydrazyl (DPPH) assay and presented as IC50 values (Table 2). The lower the IC50 value, the higher the antioxidant capacity or antioxidant strength. Coconut water was reported to have higher calcium, potassium, magnesium, and sugar concentrations compared to maple sap (Santoso et al. 1996; Yuan et al. 2013; Table 2). Maple sap contains higher sodium content and can be fortified with other minerals or concentrated to increase antioxidant, mineral, and other desirable attributes.

Table 2. Average antioxidant and mineral profiles of maple sap and coconut water

Commodity	Free radical scavenging (DPPH IC_{50} µg/mL)	Calcium (mg/100g)	Potassium (mg/100g)	Magnesium (mg/100g)	Sodium (mg/100g)	Total sugars (g/100g)[3]
Fresh maple sap[1]	597.3 ±161.2	4.0 ±1.96	2.2 ±1.70	0.68 ±0.24	3.33 ±1.28	2.28
Pasteurized maple sap[1]	567.5 ±92.5	4.0 ±1.54	2.7 ±2.10	1.19 ±0.35	4.24 ±0.99	2.3
Coconut water[2]	150 to 390.2	27.35	203.7	6.4	1.75	5.23

[1]Data from Yuan et al. 2013; [2]Data from Santos et al. 2013 (antioxidants of young coconuts) and Santoso et al. 1996 (minerals of mature coconuts); [3]Total sugars are the sum of sucrose, glucose, and fructose.

Sap Collection and Storage

It is generally understood that sap is contaminated with microorganisms, namely bacteria, yeasts, and molds once it leaves the tree. These organisms will reproduce and consume resources (sugars, amino acids, and other nutrients) within maple sap until the sap is processed and stabilized.

The shelf-life of fresh maple sap is dependent on its cleanliness (i.e. low levels of microbial contamination), storage temperature, and storage time. Sap should be collected in cleaned and sanitized food grade materials, including tubing, buckets, releasers, and holding tanks. Sap should be stored consistently below 40 °F until processing and should be discarded if off-odors or off-flavors develop. In depth guidelines for cleaning and sanitation procedures are available through Good Manufacturing Practices courses or the North American Maple Syrup Producers Manual (Perkins et al. 2022).

If sap is stored improperly or for an extended period, spoilage will occur. Sap spoilage can present as sour, fermented, or musty flavors and odors, cloudy appearance, and/or formation of a clear to opaque, viscous, string-like liquid known as "ropy" sap.

Overview of Preservation

Preservation is the process of extending the shelf-life of a product by reducing or inhibiting microbial spoilage and reducing quality changes. Depending on the preservation method, sap can be stored for a few days (short-term storage) or months (long-term storage). Treatments for short-term storage include refrigeration (<40 °F) or thermal (heat) processing followed by refrigeration. Long-term storage treatments include freezing, thermal processing, chemical treatments, pressure treatments, and aseptic processing, among others (Chiozzi et al. 2022). A combination of techniques can be used to preserve a product.

Each preservation method has the goal of reducing or eliminating microbial growth and spoilage. There are two types of microorganisms to be aware of, foodborne pathogens and spoilage microorganisms. Foodborne pathogens such as Clostridium botulinum, Escherichia coli 0157:H7, Salmonella, and Listeria monocytogenes cause an estimated 48 million cases of illness per year (FDA, 2023). Although no foodborne pathogen outbreaks have been reported in maple sap, sap is a suitable environment for pathogens to grow. Spoilage microorganisms can spoil the sap by consuming its resources (e.g. sugar, amino acids) and/or by releasing byproducts (e.g. enzymes, acids, aromas) resulting in color, texture, flavor and odor changes in the sap. Multiple spoilage microorganisms, particularly bacteria and yeast, are known to survive and grow in maple sap (Filteau et al. 2012).

To control microbial growth, food products are first classified based on their pH and water activity. These factors are used to determine the relevant pathogens and spoilage microorganisms that must be controlled. Maple sap is classified as a low-acid food, meaning the pH is greater than 4.6 and the water activity (aw) is greater than 0.85 (Part 113, 2011)). Depending on the preservation method, sap can retain its low-acid food classification or acid can be added to change the classification to an acidified food. An acidified food is a low-acid food that has been treated to have a pH below 4.6 and a water activity that remains above 0.85 (Part 114, 2000). Beverages classified as low-acid foods include carrot and beet juices, dairy-based drinks, and some plant-based milks. They are either pasteurized and sold under frozen or refrigerated conditions with a short shelf-life or are sold as a shelf-stable product following aseptic or retort processing. Acidified beverages include sports drinks, some juices, and fruit flavored teas. They can be sold refrigerated, frozen, or as a shelf-stable product following a pasteurization regime. Acidified foods require a lower temperature heat treatment compared to low acid foods; they can be produced and sold as shelf-stable products using small-scale equipment. There are FDA-required processing, filing, and training for both low acid and acidified foods that are sold as shelf-stable products. More information on acidified and low-acid foods can be found on the FDA website under "Acidified and Low-Acid Canned Foods Guidance Documents and Regulatory Information" (FDA, 2021) or through Better Process Control Schools.

The **pH** is a measure of how acidic or basic a product is on a 1 to 14 scale, with acidic products having a pH below 7 and basic products having a pH above 7.

Products with a pH of 4.6 or greater are susceptible to Clostridium botulinum growth, a bacterium that can produce a deadly toxin and heat-resistant spores. C. botulinum is controlled by inhibiting its growth through acidification or, in low acid products, by destroying it and its spores. Both processes are described below.

Water activity is a measure of the free or available water in a product. When sugar dissolves in water, it physically bonds with the water molecules making the water unavailable for microorganisms to use for growth. The more bound the water, the lower the water activity. The water activity scale ranges from 0 to 1, with maple syrup at approximately 0.85 (Frasz and Miller, 2015) single-strength (not from concentrate) fruit juices at 0.97 to 0.99 (Schmidt and Fontana, 2020), and pure water at 1.00. Low-acid and acidified beverages and foods have a water activity above 0.85 according to regulatory definitions, and thus support survival and growth of both pathogens and spoilage microorganisms. Products with a water activity below 0.85 do not support the growth of pathogens (Ransom and NACMCF, 2005), but do support pathogen survival and spoilage microorganisms, mainly yeasts and molds, which can grow down to a water activity of 0.60.

Preservation Methods

Here we review common preservation methods used in the food industry that are applicable for maple sap. Some methods such as pasteurization, acidification, and carbonation can take place in a home kitchen or small-scale commercial kitchen, while others, such as retort or aseptic processing require specialized equipment that are not available in homes or typical maple syrup operations. For any preservation method used, it is recommended to submit a sample to a Process Authority for a product review. If the product is to be sold, a scheduled process by a Process Authority is required. More information is available in the Regulation Requirements section below.

Thermal treatments are used to destroy pathogens and spoilage microorganisms. One type of thermal treatment is **pasteurization**, a mild thermal processing technique designed to destroy pathogens and reduce the number of heat-sensitive spoilage microorganisms (Jay et al. 2005).

It is commonly used to extend the shelf-life of refrigerated products. A more severe thermal treatment, commercial sterility, is designed to destroy all pathogens and most spoilage microorganisms. When combined with proper packaging and often other treatments, it results in a shelf-stable product. Maple sap can be thermally treated by heating the liquid in a pot, vat, or kettle (Figure 2). It must be held at or above a preestablished temperature for a set period, as defined in each scheduled process by a Process Authority. Pasteurization and commercial sterility are common processes in the food and beverage industry with a wide range of temperatures and times to reach proper microbial destruction.

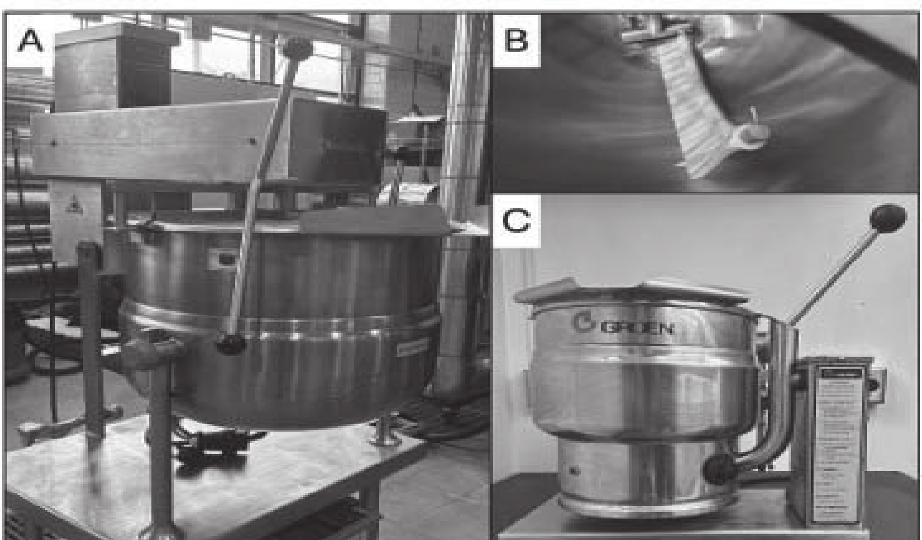

Figure 2. Open Kettle examples, Lee Scraped Surface Open Kettle (A, B) and Groen Steam-Jacketed Kettle (Courtesy of the Seneca Foods Foundation Pilot Plant).

Acidification is the process of lowering a product's pH through the addition of food grade acids. While this step alone is not sufficient to produce a shelf-stable beverage (Jennifer et al. 2020), it is a key step to lower the thermal treatment 5 parameters (temperature and time) required to produce a shelf-stable maple sap. For instance, to achieve commercial sterility, maple sap can be acidified to 4.00 pH and heated to 180 °F for a processing time of 10 minutes. Alternatively, it can be acidified to 3.90 pH and heated for 6 minutes at 180 °F with the same result (Pflug, 2003). A longer and higher heating time will lead to more cooked flavors while adding more acid to lower the pH can result in a sour flavored beverage.Maple sap undergoing pasteurization can also be acidified to extend the shelf-life of refrigerated product. Once acidified, sap must be thermally treated by heating the liquid to a set temperature for a defined time period followed by hot packing the sap in food grade, heat-resistant containers, such as glass, PET bottles, or aluminum cans with vinyl coatings (Figure 3).Multiple food grade acids are available for acidification. In maple sap, malic, lactic, and citric acid were evaluated for palatability. Lactic acid was rated as the most neutral flavored acid in acidified and pasteurized maple sap samples (Ott et al. 2022). Among the acids, lactic acid has the lowest acid dissociation constant (pKa) values, meaning it is the weakest of the three acids. With this, higher amounts of lactic acid are needed to lower the pH of

a product compared to malic and citric acids, respectively. Interestingly, citric acid is the most common of the three acids used in commercial beverages (Table 3). This is likely due to the higher sugar concentration in beverages that balance the tartness from citric acid.

Table 3. Food grade acids flavor, strength, and common uses in the food and beverage industry.

	Citric acid	Malic Acid	Lactic Acid
Flavor	Tart[1]	Smooth tartness[1]	Acrid[1], mildly sour, astringent (bitter)[2]
Use in Beverages	Coconut water, tea, energy drinks, sports drinks	Fruit juices, sodas, Energy drinks, teas	Teas, Sodas

[1]Da Conceicao Neta et al. (2007), [2]Hartwig and McDaniel (1995)

Maple sap can be concentrated prior to acidification but care must be taken when concentrating to higher levels. In preliminary experiments it was found that maple sap concentrated above 10 °Brix was resistant to pH changes meaning that it will take more acid to lower the pH when the sap is concentrated than when the sap is not concentrated. In maple sap, the factor or factors interfering with pH have not been evaluated. More information on acidification and advice for selecting a pH meter can be found through university extension programs, including Oklahoma State University (McGlynn, 2003a and 2003b).

Carbonation is a process in which carbon dioxide is dissolved into the sap under pressure, creating an effervescent sensation in the final product. Producing a shelf-stable carbonated maple beverage involves acidification and thermal treatments, with the addition of a carbonation procedure. First, the sap must be acidified to a pH below 4.6 to reduce microbial growth and reduce the thermal treatment requirements, as previously described. Once acidified, the sap is carbonated by refrigerated forced carbonation, a method common in the sparkling beverage industry in which carbon dioxide is pumped into a pressurized kegerator. The procedure should take place at refrigerated temperatures (38 °F) where carbon dioxide is more stable. The carbon dioxide will dissolve into the sap in the form of carbonic acid and over time an equilibrium will be reached between the sap and the container headspace. While the carbonic acid will lower the pH of the product, carbonic acid is not considered an acceptable acidification method.

Figure 3. Acidified and thermally treated maple sap bottled using a water jacketed tank. This same unit is used for bottling maple syrup and similar bottling units are common in maple syrup production facilities. Photo by Ailis Clyne.

Figure 4. Carbonated Beverage Counter Pressure Can Filler (Courtesy of XpressFill Systems LLC)

Following carbonation, the sap is bottled using counter-pressure filling equipment under refrigeration, generally at a pressure of 10 to 12 pounds square inch (PSI; Figure 4).'

Suitable packaging options include PET bottles or cans with vinyl coatings as they can withstand the internal pressure from carbonation (Robertson, 2013). To achieve microbial stability, the carbonated sap must undergo thermal treatment in a water bath or tunnel pasteurizer. Due to the added pressure from carbonation, these beverages require lower thermal treatment temperatures but longer treatment times to minimize the risk of bottle rupture caused by the buildup of pressure. More information on the science of carbonation and guidelines for producing carbonated beverages can be found through Song et al. (2020).

Retort processing is a method used to produce commercially sterile products through in-container sterilization (Jimenez et al. 2023). The process involves filling and sealing containers, followed by applying thermal processing under pressure. For maple sap, which has a pH of 6 to 7.4 (Nimalaratne et al. 2020), retort processing requires a processing time of 60 to 90 minutes at temperatures of 250 °F or higher. This is the same principle be=hind home pressure canning; however, multiple types of retorts exist including batch, continuous, steam, shower, and water immersion still retorts (Jimenez et al. 2024; Figure 5).Additionally, packaging must withstand the high temperatures for extended periods of time. Common packaging options include metal cans, glass bottles, retort pouches, aluminum foil pouches, and retort-tolerant semirigid containers (Jimenez et al. 2024).

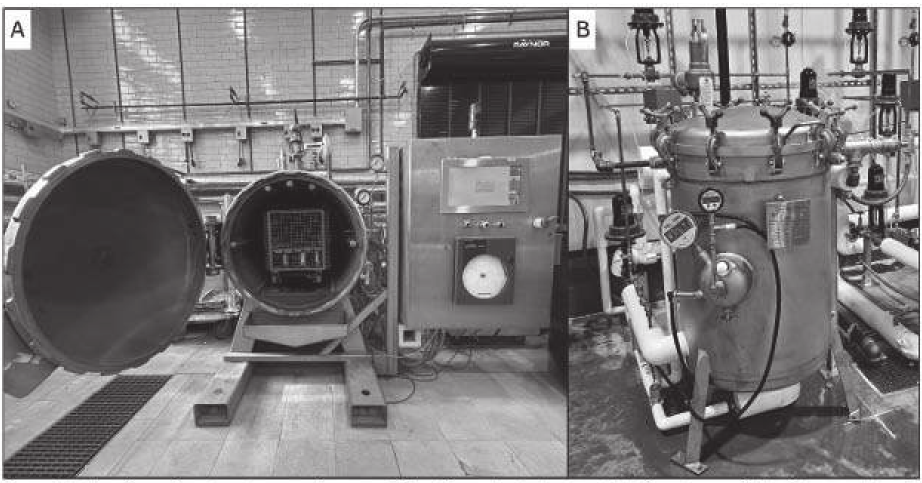

Figure 5. Small-scale retort examples, small batch agitated retort (A; Courtesy of the Seneca Foods Foundation Pilot Plant) and Dixie RDSW-3SS Retort (B; Courtesy of Dixie Canner Co.).

The high costs for retort equipment and maintenance, safety evaluations, and personnel costs make it impractical for most small-scale processors. Additionally, this low-acid product has stricter regulatory requirements to ensure that pathogens like C. botulinum are properly controlled. The regulatory requirements include following a scheduled process and the requirements specified in Title 21 of the Code of Federal Regulations (CFR) Part 113 (Part 113, 2011). By regulation, products for sale may not be produced in a home canner. Small-scale producers may consider partnering with a co-manufacturer, also referred to as co-packers, to reduce costs, although this option often involves high minimum order quantities. Information on co-manufacturers can be found in resources such as Holcomb (2016).

Aseptic processing is another method

for producing shelf-stable products, where the product is commercially sterilized, cooled, and then transferred into presterilized containers within a sterile environment and aseptically hermetically sealed with a presterilized closure (Nelson, 2010). Among processing methods, aseptic is the most complex (FDA, 2005) but can be ideal for maintaining original product flavor and nutrition (Betta et al. 2011). Since pure maple sap is a low-acid product, it would require a processing time of at least 7 minutes at 250 °F in an ultra-high-temperature (UHT) pasteurizer to control for C. botulinum (Ott, 2022). However, the specific time and temperature parameters must be determined by a Process Authority, as these values depend on the aseptic processing technique, product, and packaging used. Packaging options include metal cans, paperboard or plastic containers, thermoform containers, plastic or glass bottles, and plastic or foil bags (FDA, 2005; Chiozzi et al. 2022). Each packaging option must undergo proper sterilization, such as sterile water for metal cans or a hydrogen peroxide treatment in paperboard or plastic containers, as defined in your scheduled process (FDA, 2005). Aseptic processing allows for flexibility in packaging options, as the assembled package does not require further heat treatment after filling.'

Aseptic processing equipment is designed for high production rates, often producing 30,000 or more units at a time. For these reasons, like retort processing, aseptic manufacturing is generally impractical for small-scale producers. Use of a comanufacturer may be necessary to produce shelf-stable maple sap using aseptic processing.

Regulation Requirements

Commercial production of a shelf-stable maple sap beverage requires a scheduled process from a Process Authority. A refrigerated product is likely to require at least review by a Process Authority, while acidified, carbonated, retorted, or aseptically processed maple sap will require a scheduled process. Scheduled processes are required for most food or beverage products manufactured for sale in which refrigeration or additional steps such as thermal treatment are necessary to ensure a safe, stable product.

The Cornell Food Venture Center offers scheduled process services. A scheduled process is a document specific to a particular food product that states the process for making the product and all parameters that must be controlled in order to make the product safe. The guidelines presented in this document are for informational purposes only and are **not scheduled processes;** it is the responsibility of each maple producer or food facility to ensure compliance and adhere to regulatory requirements.

Maple sap is classified as a low-acid food; if acid is added to it, maple sap is classified as an acidified food. Shelf-stable low-acid (Part 113, 2011) and acidified foods (Part 114, 2000) are subject to additional regulatory requirements outlined in the Code of Federal Regulations. These include but are not limited to Current Good Manufacturing Practices, record keeping, approved containers and closures, and scheduled processes. All 9 processing of low acid shelf-stable products, including both retort and aseptic processing and packaging, must follow federal regulations described in 21 CFR Part 113 (Part 113, 2011).

In New York State, maple sap beverages for sale must be produced in a kitchen with a 20C Food Processing Establishment License from New York State Department of Agriculture and Markets. Food facilities and maple producers located outside of NYS should check with their state department or state regulatory agency prior to commercial production.

Production Overviews
Below are overviews of three production methods for maple sap beverages. These methods were chosen based on the ease of incorporation into an existing maple production facility utilizing equipment maple producers already own. If the product is to be sold, you must follow state and federal regulatory requirements. The outlines below are for informational purposes only and are not a replacement for a Scheduled Process.

Production Overview for Refrigerated Pasteurized Maple Sap

To produce a refrigerated maple sap beverage using pasteurization you will need a heat source, pot or kettle, temperature probe, and hot-fill food grade containers, such as glass, PET bottles, cans with vinyl coatings, or a food grade drum.

1. Harvest fresh maple sap and freeze or store below 40 °F until processing.
2. Heat the sap in a pot, vat, kettle, or syrup bottling unit until the sap is at or above 165 °F. Hold it at this temperature for a minimum of 15 seconds.
3. Cool sap so that the product temperature cools from 165 °F to 70 °F within 2 hours, and ideally to below 41 °F within a total of 6 hours.
4. Bottle the sap and immediately cap and seal.
5. Store bottled sap at or below 40 °F for up to 10 days. The estimated Best By date is for 5 to 10 days. A Process Authority may require a laboratory shelf-life study to grant a shelf-life of >5 days, as shelf-life of this product is dependent on current Good Manufacturing Practices (cGMPs) and the thermal treatment.

Production Overview for Acidified Shelf-Stable Maple Sap

To produce a shelf-stable maple sap beverage using acidification and commercial sterilization you will need a heat source, pot, kettle, or syrup bottling unit, temperature probe, pH meter, and hot-fill food grade containers, such as glass, PET bottles, cans with vinyl coatings, or a stainless-steel drum

1. Harvest fresh maple sap and freeze or store below 40 °F until processing.
2. Adjust the pH of the maple sap to below 4.20. This can generally be accomplished by adding 0.05 to 2.0% powdered citric, malic, or lactic acid. Acidic fruit juices may also be added.

Ensure the acid is fully dissolved in the solution and measure the pH when the sap is at room temperature (68 to 72 °F). Note that the sap may need to be acidified to a lower pH depending on the heating requirements of the pressurized package. This will affect flavor.
3. Cool the acidified sap to below 40 °F.
4. Add the acidified sap into a cleaned and sanitized kegerator. Assemble the kegerator and carbon dioxide tank according to manufacturer's instructions.
5. To begin carbonating, allow the carbon dioxide gas to flow into the kegerator and monitor the PSI levels. Adjust the PSI levels until they are between 20 to 25 PSI.
6. Allow carbonation to proceed in a 40 °F environment.
7. Once the desired carbonation level is reached, dispense the carbonated beverage directly from the kegerator or bottle the beverage under 10 to 12 PSI.
8. Beverages dispensed from the kegerator should be consumed within 1 to 2 weeks or before quality declines.
9. Bottled beverages can be pasteurized in a water bath or tunnel pasteurizer at so that the internal temperature is at least 160 °F. Hold it at this temperature for at least 32 minutes.
a. This time and temperature regime is an example. Shelf-stability for products processed at lower temperature and/or shorter times, and for products with pH values above 3.90, will need to be confirmed with a microbial shelf-life study.
10. Allow the product to cool and check for an airtight seal.
11. Store bottled sap at or below room temperature. The estimated Best By date for carbonated beverages in plastic bottles is 6 to 12 months (Del Nobile et al. 1997)

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Literature Cited

Betta, G., Barbanti, D., and R. Massini. 2011. Food Hygiene in aseptic processing and packaging system: A survey in the Italian food industry. Trends Food Sci. Technol. 22(6), 327-334. https://doi.org/10.1016/j.tifs.2011.02.006

Nelson, P.E. (Ed.). 2010. Principles of aseptic processing and packaging. Purdue University Press. https://doi.org/10.2307/jj.9474314

Chiozzi, V., Agriopoulou, S., and T. Varzakas. 2022. Advances, applications, and comparison of thermal (pasteurization, sterilization, and aseptic packaging) against non-thermal (ultrasounds, UV radiation, ozonation, high hydrostatic pressure) technologies in food processing. Applied Sci. 12(4), 2202. https://doi.org/10.3390/app12042202 da Conceicao Neta, E.R., Johanningsmeier, S.D., Drake, M.A., and R.F. McFeeters. 2007. A chemical basis for sour taste perception of acid solutions and fresh-pack dill pickles. J. Food Sci. 72(6), S352-S359.https://doi.org/10.1111/j.1750-3841.2007.00400.x

Del Nobile, M.A., Mensitieri, G., Nicolais, L., and P. Masi. 1997. The influence of the thermal history on the shelf life of carbonated beverages bottled in plastic containers. J. Food Eng. 34(1), 1-13https://doi.org/10.1016/S0260-8774(97)00079-4

Dini, I. 2019. An overview of functional beverages. In A. Grumezescu and A.M Holban (Eds.). Functional and Medicinal Beverages: Volume 11: The Science of Beverages. (pp. 1-40). Duxford, United Kingdom: Elsevier Inc. https://doi.org/10.1016/B978-0-12-816397
9.00001-7

Filteau, M., Lagacé, L., LaPointe, G., and D. Roy. 2012. Maple sap predominant microbial contaminants are correlated with the physicochemical and sensorial properties of maple syrup.
Int. J. Food https://doi.org/10.1016/j.ijfoodmicro.2011.12.007
Microbiol. 154(1-2), 30-36.

Food and Drug Administration (FDA). 2023. Foodborne Pathogens. https://www.fda.gov/food/outbreaksfoodborne-illness/foodborne-pathogens

Food and Drug Administration (FDA). 2021. Acidified and Low-Acid Canned Foods Guidance Documents and Regulatory Information. https://www.fda.gov/food/guidance-documents regulatory-information-topic-food-and-dietary-supplements/acidified-low-acid-cannedfoods-guidance-documents-regulatory-information

Food and Drug Administration (FDA). 1984. Water Activity (Aw) in Foods. https://www.fda.gov/inspections-compliance-enforcement-and-criminal-investigations/inspection-technical-guides/water-activity-aw-foods

Food and Drug Administration (FDA). 2005. Guide to inspections of aseptic processing and packaging for the food industry. https://www.fda.gov/inspections-complianceenforcement-and-criminal-investigations/inspection-guides/aseptic-processing-and
packaging-food-industry

Frasz, S.L., and J.D. Miller. 2015. Fungi in Ontario maple syrup & some factors that determine the presence of mold damage. International journal of food microbiology, 207, 66-70. https://doi.org/10.1016/j.ijfoodmicro.2015.04.038

Hartwig, P., and M.R. McDaniel. 1995. Flavor characteristics of lactic, malic, citric, and acetic acids at various pH levels. J. Food Sci. 60(2), 384-388. https://doi.org/10.1111/j.13652621.1995.tb05678.x

Holcomb, R. 2016. Food Processing Using a Co-Packer. Oklahoma Cooperative Extension Service. https://extension.okstate.edu/fact-sheets/print-publications/fapc-food-and-agriculturalproducts-center/food-process ing-using-a-co-packer-fapc-106.pdf

Jay J.M., Loessner M.J., and D.A. Golden. 2005. Ch. 17 Food Protection with High Temperatures, and Characteristics of Thermophilic Microorganisms. In Jay J.M., Loessner M.J., and D.A. Golden (Eds.), Modern Food Microbiology, 7th ed. (pp. 415–441). New York: Springer U.S. https://doi.org/10.1007/b100840

Jimenez, P.S., Bangar, S.P., Suffern, M., and W.S. Whiteside. 2024. Understanding retort processing: A review. Food Sci. Nutr. 12(3), 1545-1563. https://doi.org/10.1002/fsn3.3912

Lagacé, L., Girouard, C., Dumont, J., Fortin, J., and D. Roy. 2002. Rapid prediction of maple syrup grade and sensory quality by estimation of microbial quality of maple sap using ATP bioluminescence. J. Food Sci. 67, 1851–1854. https://doi.org/10.1111/j.1365 2621.2002.tb08734.x

Lagacé, L., Leclerc, S., Charron, C., and M. Sadiki. 2015. Biochemical composition of maple sap and relationships among constituents. J Food Compos. Anal. 41, 129-136. https://doi.org/10.1016/j.jfca.2014.12.030

McGlynn, W. 2003a. Importance of food pH in commercial canning operations. Oklahoma CooperativeExtension Service. https://openresearch.okstate.edu/server/api/core/bitstreams/537e93e8-18ab-4a8a-b88fbafc8a2ae383/content

McGlynn, W. 2003b. Choosing and using a pH meter for food products. Oklahoma Cooperative Extension Service. https://openresearch.okstate.edu/server/api/core/bitstreams/cffa46a9-2c74-438c-b58d-2b75a8ef3996/content

Ransom, G. and National Advisory Committee on Microbiological Criteria for Foods (NACMCF).2005. Considerations for establishing safety-based consume-by date labels for refrigerated ready-to-eat foods. J. Food Prot. 68,1761-1775.https://doi.org/10.4315/0362-028x-68.8.1761

Nimalaratne, C., Blackburn, J., and R.R. Lada. 2020. A comparative physicochemical analysis ofmaple (Acer saccharum Marsh.) syrup produced in North America with special emphasis on seasonal changes in Nova Scotia maple syrup composition. J. Food Compos. Anal., 92,103573. https://doi.org/10.1016/j.jfca.2020.103573

Part 114 Acidified Foods, 21 C.F.R. § 114, 2000. https://www.ecfr.gov/current/title-21/chapter-I/subchapter-B/part-114

Part 113 Thermally Processed Low-Acid Foods Packaged in Hermetically Sealed Containers, 21C.F.R. § 113, 2011. https://www.ecfr.gov/current/title-21/chapter-I/subchapter-B/part-113

Perkins, T.D., R.B. Heiligmann, M.R. Koelling, and A.K. van den Berg (Eds.). 2022. North American Maple Syrup Producers Manual. Third Edition. The University of Vermont and the North American Maple Syrup Council, Burlington, Vermont. www.mapleresearch.org/manual/

Jennifer J.P., and C.F. Maria. 2022. A comprehensive review of maple sap microbiota and its effecton maple syrup quality. Food Rev. Int. 38(6), 1266-1285. https://doi.org/10.1080/87559129.2020.1788579

Pflug, I.J. 2003. Microbiology and Engineering of Sterilization Processes. 11th Ed. Environmental Sterilization Laboratory, Minneapolis, MN.

Ott, E., Wijaya, F., Lewis, J., Childs, M., Chan, T. 2022. Guidelines for Small Maple Producers for theProcessing and Packaging of Maple Sap into Shelf-Stable Maple Water (unpublished).Capstone Course in Food Science. Cornell University

Robertson, G.L.. 2013. Ch. 18 Packaging of horticultural products. In G.L. Robertson (Ed.). Food Packaging: Principles and Practice, 3rd ed (pp. 477-508). CRC Press. https://doi.org/10.1201/b21347

Santos, J.L.A., Bispo, V.S., Filho, A.B.C., Pinto, I.F.D., Dantas, L.S., Vasconcelos, D.F., Abreu, F.F., Melo, D.A., Matos, I.A., Freitas, F.P., Gomes, O.F., Medeiros, M.H.G, and H.R. Matos. 2013. Evaluation of chemical constituents and antioxidant activity of coconut water (Cocusnucifera L.) and caffeic acid in cell culture. Anais da Academia Brasileira de Ciências, 85,1235-1247. http://dx.doi.org/10.1590/0001-37652013105312

Santoso, U., Kubo, K., Ota, T., Tadokoro, T., and A. Maekawa. 1996. Nutrient composition of kopyor coconuts (Cocos nucifera L.). Food Chem. 57(2), 299-304. https://doi.org/10.1016/0308-8146(95)00237-5

Schmidt, S.J., and A.J. Fontana Jr. 2020. E: water activity values of select food ingredients and products. Water activity in foods: Fundamentals and applications. In. G.V. Barbosa-Cánovas, A.J. Fontana Jr., S.J. Schmidt, and T.P. Labuza (Eds). Water Activity in Foods: Fundamentals and Applications. (pp. 573-591). John Wiley and Sons, Inc. https://doi.org/10.1002/9781118765982

Song, X., Wendrick, N., Sims, C.A., and A. MacIntosh. 2020. A Guide to Carbonating Beverages at Small Scale (FSHN20-34). Gainesville: University of Florida Institute of Food and Agricul tural Sciences. https://edis.ifas.ufl.edu/publication/FS379'

Temple, N.J. 2022. A rational definition for functional foods: A perspective. Front. Nutr. 9, 957516.https://doi.org/10.3389/fnut.2022.957516

Torrey, K.J., Liu, Y., Li, H., Ma, H., Via, C. W., Bertin, M. J., and N.P. Seeram. 2023. What Is Authentic Maple Water? A Twelve-Month Shelf-Life Study of the Chemical Composition of Maple Water and Its Biological Activities. Foods, 12(2), 239. https://doi.org/10.3390/foods12020239

Yuan, T., Li, L., Zhang, Y., and N.P. Seeram. 2013. Pasteurized and sterilized maple sap as functional beverages: Chemical composition and antioxidant activities. J. Funct. Foods, 5(4), 1582-1590. https://doi.org/10.1016/j.jff.2013.06.009