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Extension carries out programs in the broad categories of agriculture, natural resources and environment; home economics; 4-H and other youth; and community resource development. Extension staff members live and work among the people they serve to help stimulate and educate Americans to plan ahead and cope with their problems.

Some characteristics of the Cooperative Extension system are:

- The federal, state, and local governments cooperatively share in its financial support and program direction.
- It is administered by the land-grant university as designated by the state legislature through an Extension director.
- Extension programs are nonpolitical, objective, and based on factual information.
- It provides practical, problem-oriented education for people of all ages. It is designated to take the knowledge of the university to those persons who do not or cannot participate in the formal classroom instruction of the university.
- It utilizes research from university, government, and other sources to help people make their own decisions.
- More than a million volunteers help multiply the impact of the Extension professional staff.
- It dispenses no funds to the public.
- It is not a regulatory agency, but it does inform people of regulations and of their options in meeting them.
- Local programs are developed and carried out in full recognition of national problems and goals.
- The Extension staff educates people through personal contacts, meetings, demonstrations, and the mass media.
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Issued in furtherance of Cooperative Extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Robert E. Whitson, Director of Cooperative Extension Service, Oklahoma State University, Stillwater, Oklahoma. This publication is printed and issued by Oklahoma State University as authorized by the Dean of the Division of Agricultural Sciences and Natural Resources and has been prepared and distributed at a cost of 42 cents per copy. MHG 0716.

Robert M. Kerr Food & Agricultural Products Center

FOOD TECHNOLOGY FACT SHEET

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The Importance of Food pH in Commercial Canning Operations

William McGlynn
Extension Horticultural Foods Scientist

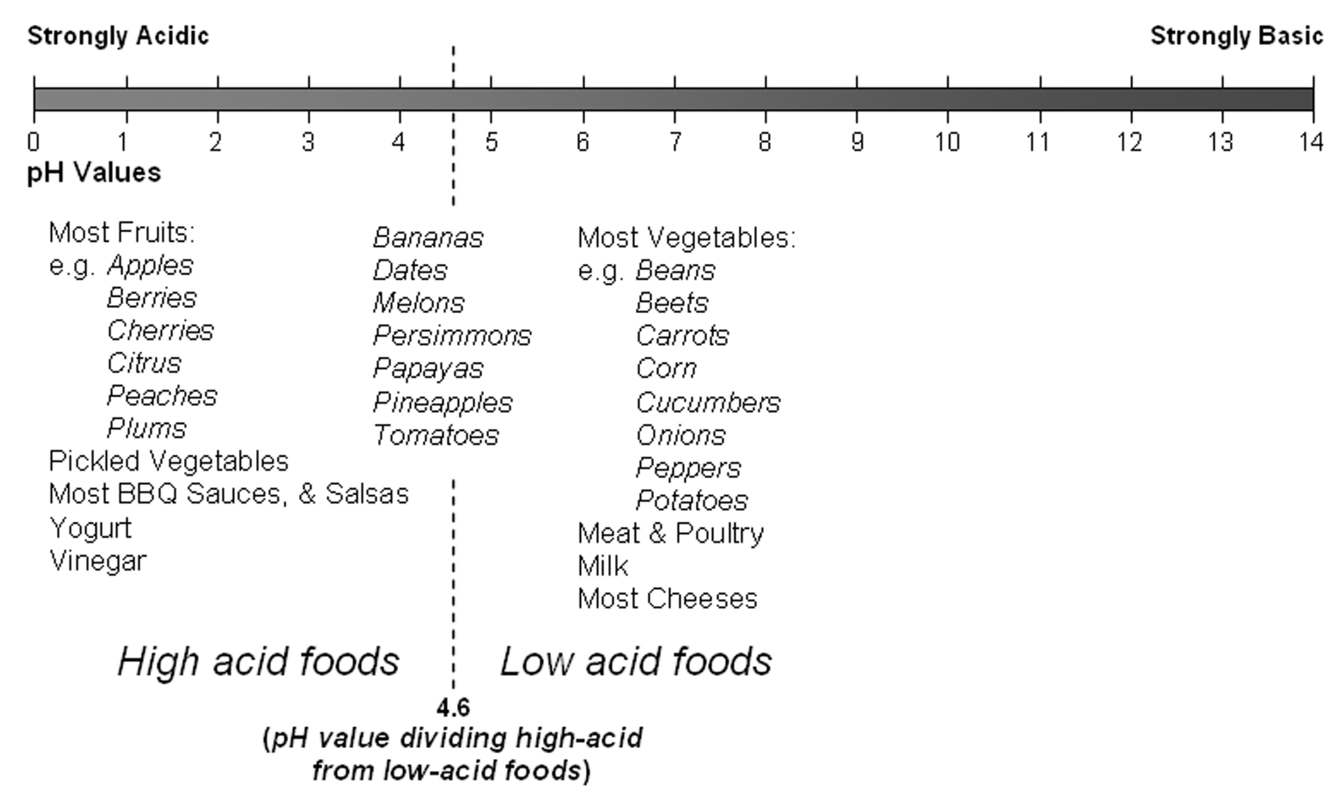
Introduction

The pH value of a food is a direct function of the free hydrogen ions present in that food. Acids present in foods release these hydrogen ions, which give acid foods their distinct sour flavor. Thus, pH may be defined as a measure of free acidity. More precisely, pH is defined as the negative log of the hydrogen ion concentration.

Therefore, if a food has a pH value of 3, then the concentration of hydrogen ions present in that food is equal to 10^{-3} (0.001) moles/liter. If the pH value is 6, then the concentration of hydrogen ions equals 10^{-6} (0.000001) moles/liter.

These examples show the concentration of hydrogen ions decreases as the pH value of the food increases. This explains why a low-pH food is a high-acid food and vice versa.

The range of pH is commonly considered to extend from zero to 14. A pH value of 7 is neutral, because pure water has a pH value of exactly 7. Values less than 7 are considered acidic, while those greater than 7 are considered basic or alkaline. Figure 1, below, shows the approximate pH values of several types of foods. A more detailed list is given in Appendix 1. A few foods, such as egg whites, sweet corn and some baked goods may be basic. Most foods are naturally acidic, with a pH value less than 7.0. Even so, the pH value of a particular food may have a dramatic effect on the type of processing needed to safely preserve it.



pH and microbial growth

Microorganisms, including yeasts, molds and bacteria are sensitive to a food's pH. Very low or high pH values will prevent microbial growth. As a practical matter, no unprocessed food has a pH value high enough to offer much preservative value. Many foods do have pH values low enough to offer some protection against microbial growth. However, very few foods have pH values low enough to completely inhibit the growth of microorganisms, especially yeasts and molds, which can tolerate lower pH conditions than most bacteria. For almost all foods, some combination of microbial controls, such as heat processing, refrigerated or frozen storage, or drying must be used to help preserve the food. The most common of these is heat processing or canning. Canned foods may be defined as any food sold in a hermetically sealed (water and air-tight) container at non-refrigerated temperatures.

Some of the most important pieces of information used in a canning operation are processing times and temperatures. To be clear, processing times do not, in this case, refer to the time needed to cook the food. Rather, processing times mean the heating times needed for canned food products to reach what is known as "commercial sterility." Commercial sterility may be defined as the point when any harmful microorganisms capable of growing in the food have been killed. The exact processing time for a canned food product will depend on several factors. These include the pH of the food, the thickness or viscosity of the product, the size of the food particles, the dimensions of the container and the temperature of the cooking medium. For canning in particular, the pH of the food plays a key role in determining the extent of heat processing needed to insure a safe final product.

Canning low-acid foods

As seen in Figure 1, a low-acid food is defined as a food having a pH of more than 4.6, while a high-acid food is defined as a food with a pH value of 4.6 or lower. This value is critical because of one particular bacterium, *Clostridium botulinum*, which produces a dormant form called a spore. These spores are extremely hard to kill and may survive for many years, waiting for a chance to grow. An improperly processed can of food provides an ideal environment for *Clostridium botulinum* spores, since the bacteria cannot survive in the presence of oxygen. *Clostridium botulinum* produces an extremely potent neurotoxin among the deadliest poisons known. Trace amounts of this toxin, which causes the food-borne illness known as botulism, are enough to kill. Fortunately, the spores of *Clostridium botulinum* will not grow if the pH of a food is 4.6 or less. For low-acid foods with a pH value greater than 4.6, these spores must be killed by heating during the canning process. Because these spores are very heat resistant, canned low-acid foods must be pressure-cooked at high temperatures for long periods of time. Temperatures of 240°F (115.6°C) or greater are commonly used and process times may range from 20 minutes to several hours. Most vegetables, meat and poultry foods fall into the low-acid food category. Because of the necessity of insuring the proper processing of low-acid foods, there are a number of detailed regulations governing their production. Anyone wishing to can low-acid foods must be registered with the FDA, use certified equipment, have received proper training at a "Better Process Control School" and keep extensive records as specified by federal regulations (21CFR Part 113 for FDA-regulated foods and 9 CFR Part 318 for USDA-regulated foods).

The canning process must also be reviewed and certified by a Recognized Process Authority. A Recognized Process Authority is any person recognized to have the training, experience and equipment needed to determine or verify the sufficiency of a thermal process. This person serves as an independent information resource for both the processor and regulatory agencies. Recognized Process Authorities may be affiliated with private companies, universities or trade organizations.

Canning high-acid foods

Examples of high-acid foods include jams and jellies, pickles and most fruits. Because there is no fear of *Clostridium botulinum* growth, these foods require much less heating than low-acid foods. To be safe, such foods need only to reach pasteurization temperatures. For foods with a pH value of 3.5 or less, 175°F (79.5°C) is a sufficient pasteurization temperature. Those foods with a pH range between 3.5 and 4 have a recommended pasteurization temperature of 185°F (85°C). For foods with a pH range of 4 to 4.3, the recommended pasteurization temperature rises to 195°F (90.5°C). Foods with a pH value of 4.3 to 4.5 have a recommended pasteurization temperature of 210°F (99°C).

These pasteurization temperatures are sufficient to kill all microorganisms except for bacterial spores. Since the spores will not grow because of the low pH, the food is considered commercially sterile. A high-acid food will therefore not need the high-temperature process a low-acid food requires. A high-acid food may typically be processed in a hot water or steam bath at atmospheric pressures – no pressure-cooking is required.

For this type of processing, the sealed container is heated in the bath until the internal temperature of the slowest heating point reaches the recommended pasteurization temperature for two to10 minutes, depending on the pH value and other properties of the food. The time required to reach this temperature will vary, and is usually set by a Recognized Process Authority after reviewing the food, evaluating the process and perhaps conducting heat penetration tests.

It is important not to over-fill the containers when a water or stream bath process is used in order to allow room for product expansion during processing. A headspace of at least one-fourth of an inch (7 mm) is recommended between the lip of the container and the surface of the food or brine. It is also important to make sure the containers are completely covered with water during the process to insure even heat penetration and avoid under-processing.

An alternative processing method is to heat the high-acid food product to pasteurization temperatures and fill it hot into jars for sealing. This popular processing technique is known as "hot-filling" or "hot-fill/hold." Hot-filling works well if done properly. It is important to keep in mind the container must be sealed before the food drops below the recommended pasteurization temperature. For this reason, it is a good practice to heat the food to five to 10 degrees above the recommended pasteurization temperature before filling. This allows time for filling and sealing. For example, if the recommended pasteurization temperature for the product is 185°F (85°C), then the product should be heated to approximately 195°F (90.1°C) prior to filling.

Keep in mind with a hot-fill process the inner surfaces of the jar, jar neck and cap must also reach pasteurization temperatures in order to kill any microorganisms present on these surfaces. One good way to insure this is to turn each container upside down and hold it for least two minutes after filling and

Table 6 – pH Values of Various Cheeses

Food	pH	Food	pH
Camembert cheese	7.44	Cheddar cheese	5.9
Cottage cheese	5.0	Cream cheese	4.88
Edam cheese	5.4	Roquefort cheese	5.5 – 5.9
Swiss Gruyere cheese	5.1 – 6.6		

Table 7 – pH Values of Various Egg Products

Food	pH	Food	pH
Egg whites	7.0 – 9.0	Egg yolks	6.4
Egg solids, whites	6.5 – 7.5	Egg solids, whole	7.1 – 7.9
Eggs, whole, frozen	8.5 – 9.5		

Table 8 – pH Values of Various Bakery Products

Food	pH	Food	pH
Bread	5.3 – 5.8	Eclairs	4.4 – 4.5
Napoleons	4.4 – 4.5	Biscuits	7.1 – 7.3
Crackers	7.0 – 8.5	Cake, angel food	5.2 – 5.6
Cake, chocolate	7.2 – 7.6	Cake, devil's food	7.5 – 8.0
Cake, pound	6.6 – 7.1	Cake, sponge	7.3 – 7.6
Cake, white layer	7.1 – 7.4	Cake, yellow layer	6.7 – 7.1
Flour, wheat	6.0 – 6.3		

Table 9 – pH Values of Various Miscellaneous Foods

Food	pH	Food	pH
Caviar (domestic)	5.4	Apple cider	2.9 – 3.3
Cocoa powder	6.3	Corn syrup	5.0
Corn starch	4.0 – 7.0	Ginger ale	2.0 – 4.0
Honey	3.9	Jams/Jellies	3.1 – 3.5
Mayonnaise	4.2 – 4.5	Molasses	5.0 – 5.5
Raisins	3.8 – 4.0	Sugar	5.0 – 6.0
Vinegar	2.0 – 3.4	Yeast	3.0 – 3.5

1. Values taken from the U.S. Food & Drug Administration Center for Food Safety & Applied Nutrition Foodborne Pathogenic Microorganisms and Natural Toxins Handbook. http://www.cfsan.fda.gov/~mow/app3a.html, 1992.

Table 3 – pH Values of Various Meats and Poultry

Food	pH	Food	pH
Beef (ground)	5.1 – 6.2	Beef (aged)	5.8
Beef (unaged)	7.0	Beef (canned)	6.6
Beef Tongue	5.9	Ham	5.9 – 6.1
Lamb	5.4 – 6.7	Pork	5.3 – 6.9
Veal	6.0	Chicken	6.5 – 6.7
Turkey (roasted)	5.7 – 6.8		

Table 4 – pH Values of Various Fish & Seafood

Food	pH	Food	pH
Fish (most fresh)	6.6 – 6.8	Clams	6.5
Crab	7.0	Oysters	4.8 – 6.3
Tuna fish	5.2 – 6.1	Shrimp	6.8 – 7.0
Salmon	6.1 – 6.3	Whitefish	5.5
Freshwater fish (most)	6.9 – 7.3	Sturgeon	5.5 – 6.0
Herring	6.1 – 6.4		

Table 5 – pH Values of Various Dairy Products

Food	pH	Food	pH
Butter	6.1 – 6.4	Buttermilk	4.5
Milk	6.2 – 7.3	Acidophilus	4.0
Sweet cream	6.5		

sealing.This allows the hot product to sterilize the inner jar surfaces. After this hold period, the jars may be cooled if desired.

Note hot-filling may not work for large particulate products such as pickled whole cucumbers or beets, in which the pieces are filled into the jar and then covered with hot brine. The mass of the food pieces may cause the filling brine to cool to below-safe pasteurization temperatures before the container can be sealed, even if the brine is boiling hot. For these products, water or steam bath processing may be the only alternative.

Regardless of the method of heat processing employed, if glass jars are used, the glass should be pre-heated before filling/processing in order to temper the glass to avoid breakage and to avoid cooling the food excessively during hot-filling. A temperature of 140°F (60°C) should be sufficient to accomplish this.

The type of spoilage most often encountered in high-acid foods not receiving a sufficient heat process is caused by yeast or mold. The most common sign of mold spoilage is visible mold growth on the top of the container (mold requires oxygen to grow). Yeast spoilage will cause increasingly cloudy liquid and often container swelling as fermentation causes gas pressure to build up in the sealed container. Both yeast and mold spoilage are easily noticed and will not usually cause serious illness if the food is accidentally eaten. However, cases have occurred in which the growth of yeast or mold has consumed natural acids present in the food and allowed the pH of the food to rise to the point where *Clostridium botulinum* grows and botulism toxin is produced. For this reason, yeast and mold spoilage of high-acid canned foods should be viewed as a potentially serious matter. Containers with visible or suspected spoilage – even a light surface layer of mold – should be discarded.

Acidified foods and formulated acid foods

Acidified foods are high-acid foods containing a significant percentage of ingredients that are naturally low-acid. A significant percentage is typically deemed to be 10 percent or more. The pH value of the low-acid ingredients is lowered by the presence of acid in the formula. This acid may be added directly – as in the use of vinegar for pickling – or it may result from the use of naturally acid ingredients such as tomatoes. No matter how the acidification is achieved, all the low-acid components of the food must take up enough acid to drop their pH values below 4.6 within 24 hours.

Some acidified foods are easy to identify. All pickled vegetables clearly fall into this category. However, some foods, salsas for example, contain amounts of low-acid ingredients such as peppers or onions that make them borderline acidified foods. In these cases, review by a Recognized Process Authority can determine the regulatory status of such foods. A food deemed to be naturally acid rather than acidified is termed a "formulated acid" food.

Acidified foods have a pH 4.6 or lower; therefore, they need only be pasteurized to be safe. However, they are regulated more stringently than formulated acid foods, simply because any misstep in their production that reduces the ratio of acid to low-acid ingredients in the formula could result in a food with ingredients that are not sufficiently acidified. Some portions of the food could then have a pH greater than 4.6. If this mistake is not caught, the result can be a deadly case of botulism.

For these reasons, producers of acidified foods must register their formula and processing procedures with the FDA, just as canners of low-acid foods do. However, the equipment and record keeping regulations (CFR 21 Part 114) are less involved.

In short, there are four basic requirements for acidified food processors, in addition to the usual requirements for facilities, record keeping and Good Manufacturing Practices (GMPs).

1. The facility where the food is produced will need to be registered with the FDA. This is accomplished by filing FDA form 2541.

2. The processing procedures for each product sold need to be registered with the FDA. This is done by filing FDA form 2541a. According to Federal regulations, both form 2541and 2541a should be filed within 10 days of beginning to produce and sell product.

3. Certain production records are required to be kept on hand. Simply stated, the processor needs to keep basic records on formulation, processing times and temperatures, pH tests, and container closure evaluation for each batch of product produced. These records need to be kept "in an accessible location" for three years from the date of manufacture.

4. At least one party who is directly responsible for and present during the actual production of the acidified food product(s) needs to receive the proper training by attending a "Better Process Control School."

Again, as with a low-acid food, process times and procedures for acidified foods must be reviewed and approved by a Recognized Process Authority.

Intermediate foods

Some foods listed in Figure 1, primarily tropical fruits and tomatoes, vary in acidity and may have a pH more or less than 4.6, depending on the season and variety. When preserving these foods, it is best either to treat these foods as low-acid foods or else add an acidifying agent such as vinegar or citric acid to lower the pH well below the critical value of 4.6. These foods would then be treated as acidified foods for regulatory purposes and processed as any other high-acid food.

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"Acidified Foods" Title 21, Part 114 (21CFR114) in Code of Federal Regulations, Government Printing Office, Washington D.C. 1999.

Bridges, M.A., and Mattice, M.R. 1939. "Over two thousand estimations of the pH of representative foods." Am. J. Digest. Dis. Nutr. 9:440-449.

FDA Bacteriological Analytical Manual, 6th Ed. 1984. Chapter 23, Table 11.

Appendix 1 – pH Values of Various Foods[1]

Table 1 – pH Values of Various Vegetables

Food	pH	Food	pH
Artichokes (fresh)	5.6	Artichokes (canned)	5.7 – 6
Asparagus, whole (fresh)	4 – 6	Asparagus, buds (fresh)	6.7
Asparagus, stalks (fresh)	6.1	Asparagus (canned)	5.2 – 5.3
Beans	5.7 – 6.2	Beans, string (fresh)	4.6
Beans, lima (fresh)	6.5	Beans, kidney (fresh)	5.4 – 6
Beets (fresh)	4.9 – 5.6	Beets (canned)	4.9
Brussel sprouts	6.0 – 6.3	Cabbage (fresh)	5.2 – 6.0
Cabbage, green (fresh)	5.4 – 6.9	Cabbage, white (fresh)	6.2
Cabbage, red (fresh)	5.4 – 6.0	Cabbage, Savoy (fresh)	6.3
Carrots (fresh)	4.9 – 5.2	Carrots (canned)	5.18 – 5.22
Carrot juice	6.4	Cauliflower	5.6
Celery	5.7 – 6.0	Chives	5.2 – 6.1
Corn (fresh)	6.0 – 7.5	Corn (canned)	6.0
Corn, sweet (fresh)	7.3	Cucumbers	5.1 – 5.7
Dill pickles	3.2 – 3.5	Eggplant	4.5 – 5.3
Hominy (cooked)	6.0	Horseradish	5.35
Kale (cooked)	6.4 – 6.8	Kohlrabi (cooked)	5.7 – 5.8
Leeks	5.5 – 6.0	Lettuce	5.8 – 6.0
Lentils (cooked)	6.3 – 6.8	Mushrooms (cooked)	6.2
Okra (cooked)	5.5 – 6.4	Olives, green	3.6 – 3.8
Olives, black	6.0 – 6.5	Onions, red	5.3 – 5.8
Onions, white	5.4 – 5.8	Onions, yellow	5.4 – 5.6
Parsley	5.7 – 6.0	Parsnip	5.3
Peas (fresh)	5.8 – 7.0	Peas (frozen)	6.4 – 6.7
Peas (canned)	5.7 – 6.0	Peas (dried)	6.5 – 6.8
Pepper, red or green (fresh)	5.15	Pimiento	4.6 – 4.9
Potatoes	6.1	Potato tubers	5.7
Potatoes, sweet	5.3 – 5.6	Pumpkin	4.8 – 5.2
Radishes, red	5.8 – 6.5	Radishes, white	5.5 – 5.7
Rhubarb (fresh)	3.1 – 3.4	Rhubarb (canned)	
3.4			
Rice, brown (cooked)	6.2 – 6.7	Rice, white (cooked)	6.0 – 6.7
Rice, wild (cooked)	6.0 – 6.4	Sauerkraut	3.4 – 3.6
Sorrel	3.7	Spinach (fresh)	5.5 – 6.8
Spinach (cooked)	6.6 – 7.2	Spinach (frozen)	6.3 – 6.5
Squash, yellow (cooked)	5.8 – 6.0	Squash, white (cooked)	5.5 – 5.7
Squash, Hubbard (cooked)	6.0 – 6.2	Tomatoes, red (fresh)	4.2 – 4.9
Tomato paste (canned)	3.5 – 4.7	Tomatoes, red, whole (canned)	3.5 – 4.7
Tomato juice	4.1 – 4.2	Turnips (fresh)	5.2 – 5.5
Zucchini (cooked)	5.8 – 6.1		

Table 2 – pH Values of Various Fruits

Food	*pH*	*Food*	*pH*
Apples, Red Delicious (fresh)	3.9	Apples, Golden Delicious (fresh)	3.6
Apples, Jonathan (fresh)	3.33	Apples, McIntosh (fresh)	3.34
Apples, Winesap (fresh)	3.47	Apple Juice	3.4 – 4.0
Apple Sauce	3.3 – 3.6	Apricots (fresh)	3.3 – 4.0
Apricots (dried)	3.6 – 4.0	Apricots (canned)	3.74
Bananas	4.5 – 5.2	Blackberries (fresh)	3.2 – 4.5
Blueberries (fresh)	3.7	Blueberries (frozen)	3.1 – 3.35
Cantaloupe	6.17-7.13	Cherries (fresh)	3.2 – 4.1
Cranberry sauce	2.4	Cranberry juice	2.3 – 2.5
Currants (red)	2.9	Dates	6.3 – 6.6
Figs	4.6	Gooseberries	2.8 – 3.1
Grapefruit (fresh)	3.0 – 3.3	Grapefruit (canned)	3.1 – 3.3
Grapefruit juice	3.0	Grapes	3.4 – 4.5
Lemons (fresh)	2.2 – 2.4	Lemon juice (canned)	2.3
Limes	1.8 – 2.0	Mangos	3.9 – 4.6
Melon, Cassaba	5.5 – 6.0	Melon, Honey Dew	6.3 – 6.7
Melon, Persian	6.0 – 6.3	Nectarines	3.9
Oranges (fresh)	3.1 – 4.1	Orange juice	3.6 – 4.3
Orange marmalade	3.0	Papaya	5.2 – 5.7
Peaches (fresh)	3.4 – 3.6	Peaches (canned)	4.2
Persimmons	5.4 – 5.8	Pineapple (fresh)	3.3 – 5.2
Pineapple (canned)	3.5	Pineapple juice	3.5
Plums (fresh)	2.8 – 4.6	Pomegranates	3.0
Prunes (fresh)	3.1 – 5.4	Prune juice	3.7
Prune quince (stewed)	3.1 – 3.3	Raspberries (fresh)	3.2 – 3.7
Strawberries (fresh)	3.0 – 3.5	Strawberries (frozen)	2.3 – 3.0
Tangerines	4.0	Watermelon	5.2 – 5.8