

ACIDULANTS

Acidulants are acids used in processed foods for a variety of functions that enhance the food. Acids are used as flavoring agents, preservatives in microbial control, chelating agents, buffers, gelling and coagulating agents, and in many other ways. Examples of these functions are:

- Flavoring agent—Contributes and enhances flavor in carbonated beverages, fruit drinks, and desserts.
- Preservative—An acid medium restricts the growth of spoilage organisms in mayonnaise and tomato sauce, and retards the activity of enzymes involved in discoloration in fruits.
- Chelating agent—Aids in binding metals that can cause oxidation in fats and oils, and discoloration in canned shrimp.
- Buffer—Maintains and controls acidity during processing, and maintains acidity within a given range in prepared desserts.
- Gelling agent—Controls the gelling mechanism of algin and pectin gels such as desserts and jams.
- Coagulating agent—Reduction of pH results in coagulation of milk protein which is used in the preparation of direct acidified cheese and desserts.

Acidulant selection depends upon the application or processed food. The properties to consider are flavor profile, pH, solubility rate, solubility, and hygroscopicity. Flavor profile refers to the perceived sharpness or blandness contributed by the acid. Tartaric and citric acids provide a sharp taste as compared to lactic acid, which provides a blander taste. Fumaric acid and tartaric acid provide the greatest degree of sourness. Comparing acids relative to similarity of taste to citric acid, the relative equivalents are citric acid: 100; fumaric acid: 55; tartaric acid: 70; malic acid: 75; succinic acid: 87; lactic acid: 107; and glucono-delta-lactone: 310. The acids provide different pHs at similar concentrations, falling generally in the range of pH 2–3 at 1% concentration. The solubility rate determines how rapidly the acid dissolves and contributes toward the flavor profile. In a beverage powder dissolved in cold water, rapid solubility is required, so perhaps citric acid would be used. The solubility of the acid refers to the quantity in solution. Cream of tartar and fumaric acid have low solubilities, which makes them suitable for bakery applications in controlling leavening systems. Phosphoric acid, a liquid, is miscible with water and used in beverage syrups. Hygroscopic acids will absorb moisture, and

hygroscopicity needs to be considered when the application is dry mixes. If hygroscopic acids, such as citric or tartaric acids, are used in dry mixes, proper packaging is essential. Alternative less hygroscopic acids are adipic and fumaric acid.

Table 1 illustrates the properties of the principal acids used in the food industry.

ANTIOXIDANTS

Antioxidants are chemical compounds that provide stability to fats and oils by delaying oxidation (which involves the loss of electrons and the gain of oxygen). The oxidation of fats and oils is believed to occur as a series of chain reactions in which oxygen from the air is added to the free fat radical. The fat molecule loses a hydrogen atom and becomes an unstable free radical with a high affinity for oxygen. Oxygen is added and the fat molecule, to complete its electron structure, reacts with another fat molecule and removes a hydrogen atom. This produces another free radical and results in a chain reaction. The antioxidant functions by replacing the fat molecule as the hydrogen atom donor in order to complete the electron structure of the free radical, thus terminating the chain reaction. Thus oxidative rancidity, which results in off-flavors and odors, is retarded until the antioxidant supply is used.

The most commonly used antioxidant formulations contain combinations of BHA (butylated hydroxyanisole), BHT (butylated hydroxytoluene), and propyl gallate. These formulations usually contain a chelating agent (reacts with metal to form a complex and thus prevents the metal from acting as a catalyst in oxidative reactions), of which citric acid is the most common. Natural antioxidants such as the tocopherols and guaiac gum usually lack the potency of BHA, BHT, and propyl gallate combinations.

Antioxidants are effective at low concentrations, that is, 0.02% or less, based on the fat or oil content of the food. Examples of applications are:

- Rendered animal fat, such as lard
- Vegetable oils, such as cottonseed oil and corn oil
- Food products of high fat content, such as doughnuts and potato chips
- Food products of low fat content, such as cereals and dehydrated potatoes

Table 1 Comparative Acid Chart

Name	Chemical Formula	Solubility (g/100 ml Distilled H ₂ O at 20°C)	pH in H ₂ O		Tartness	Comments
			Percentage Solution	pH		
Adipic acid	C ₆ H ₁₀ O ₄	1.9	0.6	2.86	Smooth tart	Nonhygroscopic; imparts long-lasting flavor note
Citric acid, anhydrous	C ₆ H ₈ O ₇	1.46	0.12	3.20	Sharp tart	Immediate acid taste
			0.5	2.35		
Citric acid, monohydrate	C ₆ H ₈ O ₇ ·H ₂ O	175	—	—	Sharp tart	Immediate acid taste
Fumaric acid	C ₄ H ₄ O ₄	0.49	0.5	2.15	Tart	Nonhygroscopic
Gluconic acid	C ₆ H ₁₂ O ₇	100	1	2.80	Mild	Unobtrusive
Glucono-delta-lactone	C ₆ H ₁₀ O ₆	59	See gluconic acid	—	Mild	Low hygroscopicity; slowly converted to gluconic acid
Lactic acid	C ₃ H ₆ O ₃	Liquid	5	2.25	Smooth tart	Slow onset of acid taste which lingers
Malic acid	C ₄ H ₆ O ₅	130	1	2.35	Smooth tart	Hygroscopic; perception of sourness or sharpness, starts gradually, rises to peak and fades slowly
Phosphoric acid	H ₃ PO ₄	Liquid	0.12	2.68	—	Sour taste, high acidity
Succinic acid	C ₄ H ₆ O ₄	5	Low acid strength	—	Tart	Nonhygroscopic; has slow flavor build-up

Antioxidants should be added to fats and oils before oxidation has started in order to be effective. The antioxidant cannot reverse the oxidation process nor regenerate a product that has become rancid. The oxidation process is accelerated by heat, light, moisture, metals, and other factors.

Antioxidants include trihydroxybutyrophenone (THBP), dilauryl thiodipropionate (DLTDP), nordihydroguaiaretic acid (NDGA), guaiac gum, thiodipropionic acid, tocopherols, lecithin, sodium erythorbate, ascorbic acid, and ascorbyl palmitate.

CHELATING AGENTS (SEQUESTRANTS)

Chelation is an equilibrium reaction between a chelating (complexing) agent and a metal ion which forms a complex. Trace metal ions in foods can produce undesirable effects such as discoloration, turbidity, and oxidation. The chelating agents can form a complex with the unwanted trace metals, thus blocking the reactive sites of the metal ions and rendering them inactive. The complex formed is termed a *chelate*, that is, metal+chelating agent=metal complex.

An equilibrium constant K defines the ratio of chelated metal to unchelated metal. The $\log K$ is the stability constant, measuring the affinity of the complexing agent for the metal ion. A high K value indicates a high affinity of the complexing agent for the metal ion and thus a low value for free metal ion concentration. Stability constants for some metal ions are shown in Table 2.

The most problematic metal ions in foods are iron and copper. In a system containing several metal ions, the ones with the highest

Table 2 Metal Ion Stability Constants

<i>Metal</i>	<i>LogK</i>
Fe ³⁺	25.70
Cu ²⁺	18.80
Ni ²⁺	18.56
Zn ²⁺	16.50
Co ²⁺	16.21
Fe ²⁺	14.30
Mn ²⁺	13.56
Ca ²⁺	10.70
Mg ²⁺	8.69

stability constants will be chelated first, followed in order of highest stability constant until the chelating agent is used.

Chelating agents are used to control the reactions of trace metals in foods to principally prevent discoloration, such as that occurs in potatoes when iron reacts with phenolic compounds in the presence of oxygen. They are also used with antioxidants to complex trace metals, thus preventing the metal from acting as a catalyst in oxidative reactions. Application examples are the use of:

- Phosphates in soft drinks to chelate heavy metal ions that interfere with carbonation.
- EDTA in mayonnaise to eliminate the oxidative activities of trace metals and protect flavor.
- Sodium acid pyrophosphate to prevent discoloration in potatoes.
- Sodium hexametaphosphate to sequester calcium ions and permit the solubilization of alginates.

Examples of chelating agents include calcium disodium EDTA, disodium dihydrogen EDTA, tetrasodium pyrophosphate, citric acid, monoisopropyl citrate, phosphoric acid, and monoglyceride phosphate.

COLORS

Colors are usually designated artificial or natural, which indicates that they are, respectively, synthetically manufactured or obtained from natural sources. Synthetic color additives “certified” by the Food and Drug Administration are designated FD&C (Food, Drug, and Cosmetic) and are traditionally termed primary colors. These colors are shades of red, yellow, blue, and green. Secondary colors are blends of certified primary colors, with or without diluents. Table 3 lists the physical and chemical properties of the certified food colors.

Those acceptable food colors not designated “certified” are designated “approved” and consist of natural organic and synthetic inorganic colorants used in certain applications (see Table 4). Colors are available in powders, liquids, granules, pastes, and other forms. Colorant determination includes desired hue, water solubility, and stability. The following groupings are used to illustrate different color groups.

Table 3 Physical and Chemical Properties of Certified Food Colors

FDA Name (Chemical Class)	Hue Range	Tinctorial Strength	Stability to:			Compatibility with Food Components
			Light	Oxidation	pH Change	
FD&C Red #3 (erythrosine)	Bluish-pink	Very good	Fair	Fair	Poor	Poor
FD&C Red #40	Yellowish-red	Very good	Very good	Fair	Good	Very good
FD&C Yellow #5 (tartrazine)	Lemon yellow	Good	Moderate	Fair	Good	Moderate
FD&C Yellow #6 (sunset yellow FCF)	Reddish	Good	Moderate	Fair	Good	Moderate
FD&C Green #3 (fast green FCF)	Bluish-green	Excellent	Fair	Poor	Good	Good
FD&C Blue #1 (brilliant blue FCF)	Greenish-blue	Excellent	Fair	Poor	Good (unstable in alkali)	Good
FD&C Blue #2 (indigotine)	Deep blue	Poor	Very poor	Poor	Poor	Very poor

Source: Food Colors (National Academy of Sciences, 1971)

Table 4 Physical and Chemical Properties of Some Noncertified Colors

FDA Name (Chemical Class)	Hue Range	Tinctorial Strength	Stability to:				Compatibility with Food Components
			Light	Oxidation	pH Change	Microbial Attack	
Annatto extract (carotenoid)	Yellow to peach	Good	Moderate	Very good	Very good	—	Very good
Beets, dehydrated (anthocyanin)	Bluish-red <pH 6	Good	Good	Excellent	Good	Good	Excellent
Caramel	Brown >pH 6						
Beta-carotene (carotenoid)	Yellowish to tan Yellow to orange	Fair Good	Good Fair	Good Poor	Good Good	Fair Poor	Good Good
Cochineal extract; carmine	Orange red to wine red	Fair	Good	Good	Poor	Poor	Good
Grape skin extract	Red-blue-green	Poor	Poor	Poor	Poor	Fair	Good
Turmeric extract and oleoresin	Bright yellow to greenish- yellow	Good	Poor	Moderate	Poor	—	Good

Source: Food Colors (National Academy of Sciences, 1971)

Artificial Coloring

Water-soluble colors are designated as FD&C, followed by the color name and number designation, for example, FD&C Blue #2. They have a corresponding common name, for example, indigotine. The colors vary in hue, solubility, and other properties, which relates to the intended application. The water-soluble colors include FD&C Blue #1, Blue #2, Green #3, Red #40, Yellow #5, and Yellow #6.

Water-insoluble colors are termed FD&C aluminum lakes. Lakes are prepared by the absorption of a certified dye on an insoluble substrate, aluminum hydroxide, and as such include the standard colors. Lakes are used to color dry ingredients, increase stability, and reduce color migration. Lakes can be used to color foods with a high oil or fat content, in dry mixes and coated candies, and for other purposes.

Natural Coloring

Natural colors are usually extracted from botanical sources and often contain several pigments and, as such, are not used as direct replacements for FD&C colors. The colors have low tinctorial strength due to a low quantity of pigment present and thus are used at higher levels than FD&C colors. These colors generally have poor stability in that their color and rate of degradation are affected by pH, temperature, and other conditions. Some natural colorings are:

- Annatto—The pigment bixin found in the coating of the annatto seed. The color hue ranges from yellow to reddish-orange.
- Turmeric—Contains curcumin obtained from turmeric root. The color hue varies from greenish-yellow to yellow-orange.
- Paprika—Produces a red to red-orange color.
- Beet—Produced from red beets and has a deep reddish-purple color.

CORN SWEETENERS

Corn sweeteners are the products made by using mild conversion techniques to produce starch hydrolysates, that is, dextrin, maltodextrin, and corn-syrup solids. These carbohydrates vary according to

sugar composition, which accounts for their differences in properties. They are classified in terms of dextrose equivalent (DE), a standard that expresses the level of reducing sugar calculated as dextrose (see Table 5). Complete conversion of cornstarch yields dextrose, also termed corn sugar, which has a DE of 92. When the reaction is stopped at the intermediate stage, corn syrup, consisting of dextrose, maltose, and polysaccharides, is obtained. It can be manufactured to have the desired DE based on desired properties. A common distribution is 28–38 DE (low conversion) to 58–68 DE (high conversion). Partial hydrolysis of cornstarch commercially produces maltodextrins of DE ranging from 13 to 22 and dextrin, with a DE range of 7–12. In high-fructose corn syrup, a fraction of the dextrose has been converted enzymatically to fructose, thus making a sweeter syrup.

EMULSIFIERS

Emulsifiers are products that function to reduce the surface tension between two immiscible phases at their interface, allowing them to become miscible. The interface can be between two liquids, a liquid and a gas, or a liquid and a solid. Most emulsions involve water and oil or fat as the two immiscible phases, one being dispersed as finite globules in the other. The liquid as globules is referred to as the dispersed or internal phase, while the medium in which they are suspended is the continuous or external phase. There are two types of emulsions depending on the composition of the phases. In an oil-in-water emulsion such as milk and mayonnaise, the water is the external phase and the oil is the internal phase. In a water-in-oil emulsion such as butter, the oil is the external phase and the water is the internal phase. By use of the proper emulsifier, the two phases will mix and separation is prevented or delayed.

Table 5 Comparison of Properties Relative to Dextrose Equivalent (DE)

<i>DE</i>	<i>Product</i>	<i>Solubility</i>	<i>Sweetness</i>	<i>Viscosity</i>	<i>Bodying Agent</i>
0	Starch	4	4	1	1
6–20	Maltodextrin	3	3	2	2
20–58	Corn syrup	2	2	3	3
100	Corn sugar (dextrose)	1	1	4	4

Range: 1 = greatest; 4 = least

The emulsifier consists of a hydrocarbon chain which has affinity for fats and oils (lipophilic group) and a polar group which is attracted to water or aqueous solutions (hydrophilic group). The emulsifier tends to concentrate at the interface between two immiscible liquids, with the hydrophilic portion in the water and the lipophilic portion in the oil. In such fashion, the surface properties are altered by the orientation of the emulsifiers at the interface which reduces the resistance of the two substances to combine. They are frequently used as blends for obtaining the most stable emulsion system. Emulsifiers have the following major functions:

- Complexing—Reaction with starch in bakery products which retards the crystallization of the starch, thus retarding the firming of the crumb which is associated with staling.
- Dispersing—The reduction of interfacial tension which creates an intimate mixture of two liquids that normally are immiscible, an example being oil-in-water emulsions such as salad dressing.
- Crystallization control—Control of crystallization in sugar and fat systems, i.e., chocolate, where it allows for brighter initial gloss and prevention of solidified fat on the surface.
- Wetting—Allows the surface to be more attracted to water, such as powders, i.e., coffee whitener, in which the addition of surfactant aids the dispersion of the powder in the liquid without lumping on the surface.
- Lubricating—Functions as a lubricant, such as in caramels, by reducing their tendency to stick to cutting knives, wrappers, and teeth.

Emulsifiers are also classified according to their solubility, being hydrophilic (water-loving) or lipophilic (oil-loving). The HLB, or hydrophilic/lipophilic balance, is a measure of the emulsifier's affinity to oil or water. The HLB range is 0–20, where 0 indicates completely lipophilic and 20 indicates completely hydrophilic. The behavior of emulsifiers in water according to the HLB range is shown in Table 6.

Table 7 lists the FDA names of food-grade emulsifiers and the Title 21 Code of Federal Regulations reference number for each.

FATS AND OILS

Fats and oils belong to a group of substances classified as lipids which consist of the higher fatty acids and compounds associated with them. Lipids are characterized by their solubility in fat solvents, their

Table 6 Behavior of Emulsifiers in Water According to HLB Range

<i>Behavior When Added to Water</i>	<i>HLB Range</i>
Insoluble	1–4
Poor solubility	3–6
Milky dispersion after vigorous agitation	6–8
Stable milky dispersion	8–10
Translucent-to-clear dispersion	10–13
Clear solution	13+

HLB hydrophilic/lipophilic balance

Table 7 FDA Names of Food-Grade Emulsifiers and the Title 21 Code of Federal Regulations References

<i>Emulsifier</i>	<i>Reference No.</i>
Acetylated monoglycerides	172.828
Calcium stearyl-2-lactylate	172.844
Diacetyl tartaric acid esters of mono- and diglycerides	184.1101
Dioctyl sodium sulfosuccinate	172.810
Ethoxylated mono- and diglycerides	172.834
Fatty acids	172.860
Glyceryl-lacto esters of fatty acids	172.852
Hydroxylated lecithin	172.814
Lactylated fatty acid esters of glycerol and propylene glycol	172.850
Lactylic esters of fatty acids	172.848
Lecithin	184.1400
Mono- and diglycerides	184.1505
Monosodium phosphate derivatives of mono- and diglycerides	184.1521
Polyglycerol esters of fatty acids	172.854
Polyoxyethylene (20) sorbitan tristearate	172.838
Polyoxyethylene (20) sorbitan monostearate	172.836
Polyoxyethylene (20) sorbitan monooleate	172.840
Propylene glycol mono- and diesters of fats and fatty acids	172.856
Sodium lauryl sulfate	172.822
Sodium stearyl-2-lactylate	172.846
Sodium stearyl fumarate	172.826
Sorbitan monostearate	172.842
Succinylated monoglycerides	172.830
Succistearin (stearyl propylene glycol hydrogen succinate)	172.765

insolubility in water, and their greasy feel. Fats and oils are of similar chemical structure but differ physically in that at ordinary temperatures, fats are solids and oils are liquids. They are complex mixtures of predominantly mixed triglycerides, which are the compounds formed by combining one molecule of glycerol with three molecules of fatty acids. The fatty acids may be the same, two different fatty acids, or all different. Fatty acids are composed of a chain of carbon with hydrogen atoms, terminating in a carboxyl group. Fatty acids contain carbon chain lengths ranging from 4 to 24 and are identified according to the number of carbon atoms and whether they are saturated or unsaturated. Saturated fatty acids contain only single-bond carbon linkages and cannot accept additional hydrogen; unsaturated fatty acids have one or more double bonds and thus fewer hydrogen atoms and can accept hydrogen. Mono-unsaturated indicates that hydrogen can be accepted at one double-bond site; polyunsaturated indicates that hydrogen can be accepted at more than one double-bond site. The most highly unsaturated fats are oils, while fats of low unsaturation tend to be solids at room temperature. Hydrogenation (chemical addition of hydrogen to the double bond of unsaturated fatty acids) of a fat makes it firmer and more plastic, raises the melting point, and slows the development of rancidity by reducing the rate of reaction with oxygen. These fats are termed hydrogenated or partially hydrogenated oils. Fats and oils are composed of varying percentages of fatty acids which account for their respective properties. Some useful properties to consider in determining a suitable fat or oil include:

- Iodine value—An expression of the degree of unsaturation, which can serve as a guide in evaluating fat stability.
- Melting point—The temperature at which a solid changes to a liquid when heated.
- Solid fat index—A number indicating the proportion of solid to liquid present in the fat at a given temperature, which will reflect the consistency.

Fats and oils are used by themselves or as components of a food. Some examples of nomenclature are:

- Shortenings—Usually solid fats instead of oils used in baked goods to impart tenderness, soft crumb, etc.
- Spreads—Usually butter or margarine, which contains 80% or more fat.
- Salad oils—Oils which include olive, corn, cottonseed, soybean, sunflower.

- Cooking fat—Any edible fat or oil.
- Frying fat—A bland-flavored fat or oil of high smoking temperature to allow for heating to 400°F without smoking.
- Confectionary fat—A fat that is hard at room temperature and soft at body temperature, such as hydrogenated coconut oil or cacao butter.

Table 8 lists fats and oils with their principal component fatty acids.

FLAVORS

Flavors are classified into the major groups of spices, natural flavors, and artificial flavors. A spice is an aromatic vegetable substance in a whole, broken, or ground form which is used as a seasoning. Natural flavors are flavor constituents derived from plant or animal sources. Artificial flavors are flavorings containing all or some portion of non-natural materials.

Table 8 Fats and Oils and Their Principal Component Fatty Acids

<i>Fats and Oils</i>	<i>Approximate Percentage of the Principal Fatty Acids</i>
Butter fat	32 Oleic, 25 palmitic
Cocoa butter	37 Oleic, 35 stearic, 25 palmitic
Coconut	48 Lauric, 18 myristic
Corn	58 Linoleic, 26 oleic
Cottonseed	54 Linoleic, 24 palmitic
Lard	46 Oleic, 23 palmitic
Olive	68 Oleic, 14 palmitic, 12 linoleic
Palm	47 Palmitic, 38 oleic
Palm Kernel	50 Lauric, 16 myristic
Peanut	46 Oleic, 31 linoleic
Rapeseed	31 Oleic, 23 erucic, 19 linoleic
Safflower	75 Linoleic
Sesame	43 Linoleic, 42 oleic
Sorghum	52 Linoleic, 31 oleic
Soybean	50 Linoleic, 25 oleic
Sunflower	68 Linoleic, 20 oleic
Tallow, beef	44 Oleic, 35 palmitic
Tallow, mutton	43 Oleic, 30 stearic

Materials that can be used for flavorings can be grouped as follows: spices and herbs; essential oils and their extracts; fruits and fruit juices; and aliphatic, aromatic, and terpene compounds. Spices and herbs consist of dried plant products that exhibit flavor and aroma. They are derived from true aromatic vegetable substances from which the volatile and flavoring principles have not been removed. Essential oils and their extracts are odorous oils obtained from plant material and have the major odor that is characteristic of that material. Most have poor water solubility and most contain terpenes (hydrocarbons of formula $C_{10}H_{16}$ and their oxygenated derivatives $C_{10}H_{16}O$ or $C_{10}H_{18}O$) which contribute to the poor water solubility as well as possibly contributing to the off-flavor. Examples are essential oils of bitter almond, anise, and clove. Terpeneless oils are extensions of concentrated essential oils in which the unwanted terpenes are removed. These oils are usually more concentrated and of increased stability and water solubility. Common oils in the terpeneless form are citrus oil, spearmint, and peppermint. Fruit and fruit juices are natural flavorings obtained from fruits. Whole, crushed, or pureed fruit may be used, but, more commonly, the juice or concentrate is used. Fruit extracts are made by extraction with a water-alcohol mixture. Aliphatic, aromatic, and terpene compounds refer to synthetic chemicals and isolates from natural materials. This classification encompasses the largest group of flavoring materials.

Flavors can be quite complex and the number of available flavors is extensive. Flavor is that property of a substance that causes a sensation of taste. Four basic tastes are perceived by taste buds on the tongue: sweet, salty, sour, and bitter. The flavors used are natural, artificial, or combinations and exist in liquid or dry form. General flavor types available include fruit, dairy, meat, vegetable, beverage, and liquor.

FLOUR

Flour, also referred to as white flour, wheat flour, and plain flour, is the food prepared by grinding and bolting cleaned wheat other than durum wheat and red durum wheat (Code of Federal Regulations). Flour from other sources is available, identified according to its grain source. The properties of wheat flour vary according to the type of wheat, milling procedures, and treatment applied after milling.

Flour milling involves the separation of the endosperm, which is about 83% of the kernel, from other parts of the kernel, that is, bran

and germ. The processing involves tempering, grinding, and sifting the large chunks of endosperm or “middlings” to yield the flour which, in the USA, will represent about 72% of the wheat kernel. By processing, size classification is achieved as flour streams. The streams include:

1. Straight flour—All the flour that can be milled from a wheat blend, or 72% of the wheat kernel which equates to 100% separation.
2. Long patent flour—90–95% separation.
3. Medium patent flour—80–90% separation.
4. Short patent flour—70–80% separation.
5. Short family or first patent flour—60–70% separation.
6. Extra short or fancy patent flour—40–60% separation.
7. Clears—Portion of straight flour remaining after removal of patent streams.

Flour properties depend upon the type of wheat, which is classified as hard or soft. Hard wheats are high in protein and the resulting flours have a high protein content and form a tenacious, elastic gluten with good gas-retaining properties and high water absorption capacity which makes it suitable for yeast-leavened bread. Soft wheats are low in protein and the resulting flour has poor gas-retaining properties and low water absorption capacity which makes it suitable for chemically leavened cakes and pastries.

The protein content of the flour is important because it forms the protein complex termed *gluten* when water and flour are kneaded together. The gluten formed accounts for the mixing and dough-handling characteristics as well as in the formation of the framework of the baked product.

Different flours are used for different purposes. Some of these include:

- Bread flour, which generally contains in excess of 10.5% protein and is obtained from straight or long patent flours, has high absorption and good mixing tolerance.
- Cake flour, which generally contains less than 10% protein and is generally short patent flours, is low in absorption, and has short mixing time and tolerance.
- All-purpose (family) flour, which is intermediate between bread and cake flour.
- Pastry flour, which is obtained from soft wheat and can be straight or clear flour grades because color is not an essential requirement.

- Cracker flour, which generally contains 9–10.5% protein obtained from long patent or straight flours, is of low absorption, and has short mixing requirements.

Flours can be modified by various treatments to alter characteristics such as color, nutritional value, and baking qualities. Some of these modified flours include:

- Enriched flour—Flour that has been enriched by the inclusion of vitamins and minerals.
- Bromated flour—Potassium bromate has been added for improvement of baking qualities.
- Phosphated flour—Monocalcium phosphate has been added for improvement of baking qualities.
- Bleached flour—Flour in which the yellow carotenoid pigment has been converted to a nearly colorless product.

Other specific grain flours are obtained, with the term *flour* referring to that degree of grinding and sifting which results in a fine, powdery substance. The grain flours in Exhibit 1 are designated according to the grain from which they are obtained and include corn, rye, and durum flours.

Exhibit 1 Cereal Flours Listed in the Code of Federal Regulations Part 137

Flour	Whole durum flour
Bromated flour	White corn meal
Enriched bromated flour	Bolted white corn meal
Enriched flour	Enriched corn meals
Instantized flours	Degerminated white corn meal
Phosphated flour	Self-rising white corn meal
Self-rising flour	Yellow corn meal
Enriched self-rising flour	Bolted yellow corn meal
Cracked wheat	Degerminated yellow corn meal
Crushed wheat	Self-rising yellow corn meal
Whole wheat flour	Farina
Bromated whole wheat flour	Enriched farina
White corn flour	Semolina
Yellow corn flour	Enriched rice
Durum flour	

GUMS

Gums are classified by source according to the following principal groupings: plant exudates, which include arabic, tragacanth, karaya, ghatti; seaweed extracts, which include agar, alginates, carrageenan, furcelleran; plant seed gums, which include guar, locust bean, tara, tamarind, psyllium, quince; plant extracts, which include pectin and arabinogalactan; fermentation gums, which include xanthan gum, gellan gum, and dextran; and cellulose derivatives, which include carboxymethyl cellulose, hydroxypropylmethyl cellulose, microcrystalline cellulose. Gum derivatives include propylene glycol alginate and low-methoxy pectin. Galactomannans are polysaccharides consisting of a mannose backbone with galactose side groups. Included in this family are guar gum, tara gum, locust bean gum with respective mannose:galactose ratios 2:1, 3:1, 4:1, with the higher amounts of galactose resulting in more solubility. Starches and gelatin function as water-control agents but are not included in this grouping.

The selection of a gum is based on the desired function and food application. By thickening or gelling the water, gums perform numerous roles such as stabilizers, film formers, binders, suspending agents, whipping agents, coating agents, and crystallization inhibitors. The gums perform these functions by themselves or in combination with other gums. Food properties considered in selecting a gum include pH, shelf stability, ingredient compatibility, texture, processing requirements, and ultimate consumer method of preparation. The differentiating properties of gums include viscosity, compatibility, pH stability, gel-forming capabilities, temperature stability, flow properties, and solubility. Within the same family of gums, there may be differences relative to salt type which will have an effect on its functional characteristics, that is, solubility, dispersibility, gel-forming capabilities, flow properties, and stability. Tables 9 and 10 list, respectively, comparative and relative properties of gums.

PRESERVATIVES

Preservatives are antimicrobial agents. The preservatives most widely used are the benzoates (sodium benzoate), sorbates (sorbic acid and potassium sorbate), and the propionates (sodium or calcium propionates), which are organic acids or their salts (see Table 11).

Table 9 Comparative Properties of Gums

Gums	Cold Water Solubility	Hot Water Solubility	Gel Former	Acid Stability
Agar	No	Yes	Yes	Between pH 4.5 and 9.0
Alginate, sodium	Yes	Yes	Yes	Gels at pH 3.5 depending on calcium content
Arabic (Acacia)	Yes	Yes	No	pH 4–10
Carboxymethyl cellulose	Yes	Yes	No	Best between pH 7 and 9, below pH 5 get reduction in viscosity
Carrageenan	No, except lambda and sodium salts	Yes	Yes, except lambda	Solution undergoes hydrolysis at acid pH (3.5); gel is stable
Furcelleren	No	Yes	Yes	Heating below pH 5 causes hydrolysis and gel degradation
Gelatin	No swells	Yes	Yes	Stable, gradual decline in gel strength with acidification
Gellan gum, high acyl	No	Yes	Yes	Stable in acid pHs
Gellan gum, low acyl	No	Yes	Yes	Stable in acid pHs
Ghatti	Yes	Yes	No	Opt. viscosity at pH 8, drops on both sides
Guar	Yes	Yes	No	Between pH 3.5 and 10.5, gradual decline with acidification
Hydroxypropyl cellulose	Yes	No, insoluble above 45°C	No	Between pH 3 and 10, opt. pH 6–8
Hydroxypropyl methylcellulose	Yes	No	Yes, at elevated temp. depending on type	pH 3–11
Karaya	Yes, swells	Some	No	Viscosity decreased by acids or electrolytes
Locust bean gum	Swells, requires heat	Yes	No	Between pH 5 and 8, at higher or lower values get considerable variation
Low-methoxy pectin	Yes, depends on methoxy content	Yes	Yes	Form gels between pH 2.5 and 6.5 depending on system
Methylcellulose	Yes	No	Yes, at elevated temp	pH 3–11

	Insoluble, dispersible	Insoluble, dispersible	No	Insoluble, resistant
Microcrystalline cellulose	Yes	Yes	No	
Pectin	Yes	Yes	Yes	Gel below pH 3.6
Psyllium	Yes	Yes	Yes, at high conc.	Between pH 2 and 10
Quince	Yes	Yes	No	Between pH 4 and 10
Tragacanth	Yes, swells	Yes	No	Between pH 4 and 6
Xanthan gum	Yes	Yes	No	Between pH 2 and 12

Table 10 Relative Properties of Gelling Gums

Property	Agar	Carraegeenan	Furcelleran	Gelatin	Gellan gum, high acyl	Gellan gum, low acyl	LM Pectin	Pectin	Sodium Alginate	Xanthan Gum/ Locust Bean Gum
Solubility	>90°C	Kappa 50–60°C	70–80°C	70°C	70–80°C, swells initially	75–90°C	Room temperature	Room temperature	Room temperature	70°C
Gelling temperature	Set 32–39°C	Kappa, iota — set and melt temperature are 10°C apart, vary with solute; lambda; nongelling	Set 40°C	Set 20°C	Set/melt — at high temperature with some ion affect	Set — room temperature to 50°C, depending on ion concentration	At some fixed temperature depending on system	Set 50–99°C	Room temperature	49–55°C
Melt	>85–90°C		Melt 50°C, vary with solute	Melt 30°C		Melt >80°C, depending on ion concentration		Melt 70–100°C + depends on type of pectin, pH, soluble solids, etc.		
Mechanism	Cooling	K, Ca ions	Cooling	Cooling	Ca ions, cools	Ca ions, cooling	Ca ions	Cooling; pH/soluble solids	Ca ions	Cooling

Table 11 Preservatives

<i>Preservative Category</i>	<i>Activity</i>	<i>Use Level (%)</i>
Benzoates (sodium benzoate)	Yeasts, molds, and bacteria, but usually not recommended for bacterial control because of restricted use level and lower activity at higher pH; best activity at pH 2.5–4.0	0.01–0.10
Sorbates (sorbic acid, potassium sorbate)	Yeasts and molds, least activity against bacteria and on a selective basis; best activity up to pH 6.5	0.03–0.10
Parabens	Yeasts and molds, less active against bacteria, especially gram-negative; effective up to pH 8.0	0.10 range
Propionates (propionic acid, Ca, Na propionate)	Molds, slightly antibacterial action except against "rope"; effective up to pH 6.0	0.20–0.50

The activity of preservatives is due to the undissociated form of the molecule and thus pH is a major factor in their effectiveness. Increasing the acidity of foods is a method of controlling the growth of microorganisms. The survival and proliferation of microorganisms depend in part upon the pH of the food. Foods with a pH below 4.6 are considered acidic, and many bacteria will not proliferate in acidic foods. Acidulants are used to reduce the pH and thus provide a means of controlling microorganism growth. Acidulants used include acetic acid, adipic acid, citric acid, fumaric acid, lactic acid, and phosphoric acid. Greater effectiveness is achieved in acidic systems. Sorbic acid and potassium sorbate have the best activity up to pH 6.5, calcium and sodium propionate up to pH 5.0, and sodium benzoate up to pH 4.5.

Sorbic acid and potassium sorbate are effective against yeast and mold inhibition with little activity against bacteria. Common uses are in cheese, sausage, and baked goods not including yeast-raised goods. Sorbic acid has low solubility in water which increases with increasing temperature, while potassium sorbate is readily soluble in water. Potassium sorbate has the same antimycotic properties as sorbic acid and on an equivalent weight basis has 74% of the activity of sorbic acid. Thus, higher concentrations are required to obtain the same yeast and mold-inhibiting effects (four parts potassium sorbate equal three parts sorbic acid).

Calcium and sodium propionate are effective against molds and have slight antibacterial action and little action on yeasts. Application

areas include baked goods and processed cheese. Because they have little action against yeasts, they can be used in yeast-baked goods and are the most common preservative in baked goods.

Sodium benzoate is effective against yeasts and slightly effective against bacteria and molds. The most effective range is pH 2.5–4.0 with a maximum pH of 4.5. It is used in acidulated beverages, jams, jellies, and relishes.

Parabens, which are esters of *para*-hydroxybenzoic acid, are related to benzoic acid but are effective over a wider pH range. They are active against yeasts and molds and are used in baked goods and beverages.

SPICES

Spices consist of dried plant products that exhibit flavor and aroma. Spices are obtained from vegetable substances from which none of the volatile or other flavoring substances have been removed. Spices are grouped into (a) tropical spices such as pepper and cloves; (b) herbs, such as sage and rosemary; (c) spicy seeds such as mustard and anise; and (d) dehydrated aromatic vegetables such as onion and garlic.

Spices in the ground form have an increased surface area and consequently the oil glands are ruptured, causing the evaporation of the essential oil and loss of aroma. Spice flavor is also obtained by use of an extract or essential oil which carries the spice aroma in a concentrated form. These oils are volatile and as such do not contain the nonvolatile constituents. The compound containing both the essential oil and the non-volatile constituents is commercially known as oleoresins, which contain all the odorous and flavor principles of the spice. Oleoresins offer flavor uniformity, stability, freedom from bacteria, and flavor concentration.

Spices are used predominantly in prepared meats, luncheon meats, sauces, salads, soups, and dressings. Other important users are bakers, pickle packers, condiment manufacturers, and the canning industry.

A list of spices and other natural seasonings and flavorings, found in Title 21, Section 182.10, of the Code of Federal Regulations, is in Table 12.

STARCH

Starch, consisting of repeating glucose units, is separated into the polysaccharides amylose and amylopectin. Amylose consists of straight chains containing 200–2,100 glucose units, while amylopectin consists of

Table 12 Spices and Other Natural Seasonings and Flavorings

<i>Common Name</i>	<i>Botanical Name of Plant Source</i>
Alfalfa herb and seed	<i>Medicago sativa</i> L.
Allspice	<i>Pimenta officinalis</i> Lindl.
Ambrette seed	<i>Hibiscus abelmoschus</i> L.
Angelica	<i>Angelica archangelica</i> L. or other spp. of <i>Angelica</i>
Angelica root	<i>Angelica archangelica</i> L. or other spp. of <i>Angelica</i>
Angelica seed	<i>Angelica archangelica</i> L. or other spp. of <i>Angelica</i>
Angostura (cusparia bark)	<i>Galipea officinalis</i> Hancock.
Anise	<i>Pimpinella anisum</i> L.
Anise, star	<i>Illicium verum</i> Hook. f.
Balm (lemon balm)	<i>Melissa officinalis</i> L.
Basil, bush	<i>Ocimum minimum</i> L.
Basil, sweet	<i>Ocimum basilicum</i> L.
Bay	<i>Laurus nobilis</i> L.
Calendula	<i>Calendula officinalis</i> L.
Camomile (chamomile), English or Roman	<i>Anthemis nobilis</i> L.
Camomile (chamomile), German or Hungarian	<i>Matricaria chamomilla</i> L.
Capers	<i>Capparis spinosa</i> L.
Capsicum	<i>Capsicum frutescens</i> L. or <i>Capsicum annum</i> L.
Caraway	<i>Carum carvi</i> L.
Caraway, black (black cumin)	<i>Nigella sativa</i> L.
Cardamon (cardamon)	<i>Elettaria cardamomum</i> Maton.
Cassia, Chinese	<i>Cinnamomum cassia</i> Blume.
Cassia. Padang or Batavia	<i>Cinnamomum burmanni</i> Blume.
Cassia. Saigon	<i>Cinnamomum loureirii</i> Nees.
Cayenne pepper	<i>Capsicum frutescens</i> L. or <i>Capsicum annum</i> L.
Celery seed	<i>Apium graveolens</i> L.
Chervil	<i>Anthriscus cerefolium</i> (L.) Hoffm.
Chives	<i>Allium schoenoprasum</i> L.
Cinnamon, Ceylon	<i>Cinnamomum zeylanicum</i> Nees.
Cinnamon, Chinese	<i>Cinnamomum cassia</i> Blume.
Cinnamon, Saigon	<i>Cinnamomum loureirii</i> Nees.
Clary (clary sage)	<i>Salvia sclarea</i> L.
Clover	<i>Trifolium</i> spp.
Coriander	<i>Coriandrum sativum</i> L.
Cumin (cummin)	<i>Cuminum cyminum</i> L.
Cumin, black (black caraway)	<i>Nigella sativa</i> L.
Elder flowers	<i>Sambucus canadensis</i> L.
Fennel, common	<i>Foeniculum vulgare</i> Mill.
Fennel, sweet (finocchio, Florence fennel)	<i>Foeniculum vulgare</i> Mill. var. <i>duice</i> (DC.) Alex.
Fenugreek	<i>Trigonella foenum-graecum</i> L.
Galanga (galangal)	<i>Alpinia officinarum</i> Hance.
Geranium	<i>Pelargonium</i> spp.
Ginger	<i>Zingiber officinale</i> Rosc.
Grains of paradise	<i>Amomum melegueta</i> Rosc.

(continued)

Table 12 (continued)

<i>Common Name</i>	<i>Botanical Name of Plant Source</i>
Horehound (hoarhound)	<i>Marrubium vulgare</i> L.
Horseradish	<i>Armoracia lapathifolia</i> Gilib.
Hyssop	<i>Hyssopus officinalis</i> L.
Lavender	<i>Lavandula officinalis</i> Chaix.
Linden flowers	<i>Tilia</i> spp.
Mace	<i>Myristica fragrans</i> Houtt.
Marigold, pot	<i>Calendula officinalis</i> L.
Marjoram, pot	<i>Majorana onites</i> (L.) Benth.
Marjoram, sweet	<i>Majorana hortensis</i> Moench.
Mustard, black or brown	<i>Brassica nigra</i> (L.) Koch.
Mustard, brown	<i>Brassica juncea</i> (L.) Coss.
Mustard, white or yellow	<i>Brassica hirta</i> Moench.
Nutmeg	<i>Myristica fragrans</i> Houtt.
Oregano (oreganum, Mexican oregano, Mexican sage, organ)	<i>Lippia</i> spp.
Paprika	<i>Capsicum annuum</i> L.
Parsley	<i>Petroselinum crispum</i> (Mill.) Mansf.
Pepper, black	<i>Piper nigrum</i> L.
Pepper, cayenne	<i>Capsicum frutescens</i> L. or <i>Capsicum annuum</i> L.
Pepper, red	<i>Capsicum frutescens</i> L. or <i>Capsicum annuum</i> L.
Pepper, white	<i>Piper nigrum</i> L.
Peppermint	<i>Mentha piperita</i> L.
Poppy seed	<i>Papayer somniferum</i> L.
Pot marigold	<i>Calendula officinalis</i> L.
Pot marjoram	<i>Majorana onites</i> (L.) Benth.
Rosemary	<i>Rosmarinus officinalis</i> L.
Saffron	<i>Crocus sativus</i> L.
Sage	<i>Salvia officinalis</i> L.
Sage, Greek	<i>Salvia triloba</i> L.
Savory, summer	<i>Satureia hortensis</i> L. (Satureja).
Savory, winter	<i>Satureia montana</i> L. (Satureja).
Sesame	<i>Sesamum indicum</i> L.
Spearmint	<i>Mentha spicata</i> L.
Star anise	<i>Illicium verum</i> Hook. f.
Tarragon	<i>Artemisia dracuncululus</i> L.
Thyme	<i>Thymus vulgaris</i> L.
Thyme, wild or creeping	<i>Thymus serpyllum</i> L.
Turmeric	<i>Curcuma longa</i> L.
Vanilla	<i>Vanilla planifolia</i> Andr. or <i>Vanilla tahitensis</i> J. W. Moore.
Zedoary	<i>Curcuma zedoaria</i> Rosc.

Note: Spices and other natural seasonings and flavorings are listed in Title 21. Section 182.10 of the Code of Federal Regulations

branched chains containing 20–25 glucose units each. A visible difference is that amylose is more soluble and less viscous than amylopectin and facilitates gel formation. Starches vary in their amylose content.

Waxy starches, so termed because the cut endosperm resembles hard, opaque wax, contain mostly amylopectin, while ordinary cornstarch consists of about 24% amylose and 76% amylopectin. The waxy starches form thick, clear pastes but gel only at high concentrations such as 30%, while 4–5% cornstarch will form a gel. The paste viscosity of the waxy maize starch remains the same hot or cold. High-amylose starches contain 50–70% amylose and have unique properties for functioning as film formers, oxygen and fat barriers, quick-setting stable gels, and binders.

Starch is not soluble in cold water, but forms a suspension. Upon heating the suspension to the gelatinization temperature (60–70°C), the starch granules suddenly swell, the opaque suspension slowly becomes translucent upon continued heating, and the viscosity increases to the thickness of a boiled starch paste. Most starches require heating to 90°C in order to obtain a firm gel upon cooling, when the viscosity increases and may form a gel depending on the type of starch. During storage of a starch paste or gel, the molecules become less soluble and tend to aggregate and partially crystallize; the change is termed *retrogradation*, which is the opposite of gelatinization. The starch gel shrinks and some of the liquid separates from the gel. Retrogradation does not occur in waxy starches because they do not contain amylose.

Starches can be modified (they are then termed *modified starches*) by chemical modification or cross-linking, to provide desired properties not found in natural starch. By the production of cross-links or bridges from one starch molecule to another, starch can be made more resistant to hydrolysis, thus preventing the loss of viscosity. The resistance of starch to shear or mixing is directly proportional to the degree of cross-linking. Other properties obtained include viscosity control, freeze–thaw stability, heat resistance, and acid resistance. These starches find application in sauces, gravies, pie filling, frozen foods, and other products where specific properties are required.

Pregelatinized starch is a starch processed to swell to some degree in cold water unlike regular starch, which requires heating. The most common method involves heating a starch paste to its gelatinization temperature, drying on a drum dryer, and grinding the dried starch to a powder. Upon reconstitution with water, the pregelatinized starch has less thickening power and tendency to gel than pastes of the parent starch. This starch is used in applications requiring more rapid

hydration or room temperature preparation, such as instant desserts, puddings, and soups. Based on abundance and cost, cornstarch is the most commonly used. Other available starches include grain sorghum, rice, wheat, potato, tapioca, arrowroot, and waxy varieties.

SWEETENERS

Sweeteners can be classified as natural or artificial. The natural sweeteners are carbohydrates consisting of molecules of carbon, hydrogen, and oxygen. The simplest form of carbohydrate is the monosaccharide or simple sugar and includes glucose (dextrose), fructose (levulose), and galactose, which are six-carbon (hexose) sugars.

The combination of two monosaccharides forms a disaccharide sugar, which can also be formed by the breakdown of longer-chain carbohydrates termed *polysaccharides*. The following combinations of monosaccharides form the respective disaccharides: glucose+fructose=sucrose; glucose+galactose=lactose; glucose+glucose=maltose.

A trisaccharide consists of three monosaccharides, such as raffinose which consists of galactose, glucose, and fructose. A tetrasaccharide such as stachyose consists of four monosaccharides. These more complicated sugars are not digestible so they are not used as sweeteners. A polysaccharide is a longer-chained carbohydrate which exists in digestible and nondigestible forms. The digestible forms are starch, a polymer of glucose units from which corn sweeteners are obtained, and glycogen, a polymer of glucose which is the carbohydrate reserve of animals. The nondigestible form includes cellulose, lignin, and gums such as pectin and algin.

Polyhydric alcohols (polyols) in foods consist of glycerine, sorbitol, mannitol, propylene glycol, and xylitol. When used at low levels, the taste of the polyols is of minor consequence; but when used as a major ingredient, such as in sugarless chewing gum, the polyol is the major source of sweetness.

Sucrose is the most widely used natural sweetener and is usually the reference relative to sweetness, taste profile, and cost. Corn sweeteners, fructose, and high intensity sweeteners are other widely used sweeteners.

Sweeteners are also grouped as nutritive and non-nutritive. Nutritive sweeteners include sucrose, fructose, dextrose, lactose, maltose, honey, high fructose corn syrups, and polyols. Non-nutritive sweeteners (artificial sweeteners) include saccharine, aspartame, acesulfame-K, sucralose, neotame, and rebaudioside A.

Table 13 Nutritive Sweeteners Sweetness Relative to Sucrose

Levulose	173
Fructose	150
Honey (dry basis)	100–150
Invert sugar	130
<i>Sucrose</i>	100
High fructose corn syrup	70–80
Dextrose (glucose)	70
Corn syrup	40–70
Maltose	30–35
Galactose	32
Lactose	15–20

Table 14 Polyols Sweetness Relative to Sucrose

<i>Sucrose</i>	100
Xylitol	100
Maltitol	90
Erythritol	60–70
Sorbitol	60
Isomalt (palatinit)	50–60
Mannitol	50
Lacticol	30–40

The relative sweetness of sweeteners relative to sucrose can vary according to concentration, temperature, etc. (Table 13).

Polyols (polyhydric alcohols, sugar alcohols) are produced by hydrogenating the corresponding reducing sugars, for example, sorbitol – hydrogenated from glucose. They provide the bulk and texture of sucrose but have less kilocalories/gram. Polyols include sorbitol, mannitol, xylitol, erythritol, lacticol, maltitol, and isomalt (Table 14).

High-Intensity Sweeteners

High-intensity sweeteners are products intended to imitate the taste of sucrose and function as non-nutritive replacements; they provide basically 0 cal. Saccharin, discovered in 1878, has the longest history of food use.

Table 15 High-Intensity Sweetness Relative to Sucrose

Sucralose	600
Saccharin	300
Acesulfame-K	200
Aspartame	200
Sucrose	100

Note: Relative sweetness can vary according to concentration and temperature

The properties of high intensity sweeteners vary according to source, relative sucrose sweetness, taste profile, solubility, stability to temperature and pH, synergies, and applications. These sweeteners are used singly or in combination to maximize the beneficial properties of each (Table 15).

VITAMINS

Vitamins are organic compounds that are essential for normal body growth and maintenance. They are classified into groups: fat-soluble vitamins – vitamins A, D, E, and K; and water-soluble vitamins – vitamins B and C. Vitamins are measured in very low concentrations, such as 1–100 mg. Through biochemical action, they perform various functions in such processes as cell growth, normal digestion, manufacture of red blood cells, and absorption of calcium and phosphorus. Inadequate vitamin intake can be the result of food deficiency, increased vitamin requirements, and increased vitamin loss. The vitamins of determined importance include A (retinol), B₁ (thiamine), B₂ (riboflavin), B₅ (pantothenic acid), B₆ (pyridoxine), B₁₂ (cyanocobalamin), C (ascorbic acid), D₂ (calciferol), E (tocopherol), K, niacin, folic acid, and biotin.

Table 16 describes the functions and provides sources for fat- and water-soluble vitamins.

Table 16 Vitamin Functions and Sources

<i>Vitamins</i>	<i>Function</i>	<i>Sources</i>
<i>Fat Soluble</i>		
Vitamin A (retinol)	Necessary for cell growth, healthy skin; prevents night blindness	Green and yellow fruits and vegetables; eggs, butter, cheese
Vitamin D ₂ (calciferol)	Necessary for bone and teeth growth; deficiency causes rickets	Fish, liver, oil, vitamin D milk, sunshine
Vitamin E (tocopherol)	Functions as antioxidant, preventing the oxidation of unsaturated fatty acids and protecting vitamins such as vit. A	Legumes, meat, eggs, whole grains
Vitamin K	Essential for blood clotting	Green leafy vegetables, liver, soybeans
<i>Water Soluble</i>		
Vitamin B ₁ (thiamine)	Necessary for growth, fertility, lactation; deficiency causes beriberi	Pork, fish, cereal, beans, peas
Vitamin B ₂ (riboflavin)	Necessary for growth; acts as coenzyme	Milk, cheese, eggs, poultry
Vitamin B ₆ (pyridoxine hydrochloride)	Functions as coenzyme; involved in utilization of protein	Meat, corn, lima beans
Vitamin B ₁₂ (cobalamin)	Necessary for normal functioning of cells	Meat, liver, dry milk
Niacin	Necessary for healthy cells and tissues; prevents pellagra	Meat, liver, enriched bread
Pantothenic acid	Necessary for several bodily functions	Whole grain cereal, meat, fish
Biotin	Necessary in metabolism	Peanuts, beans, eggs, meat
Folic acid	Necessary in metabolism; helps manufacture red blood cells	Leafy green vegetables, yeast, liver
Vitamin C (ascorbic acid)	Essential for healthy bones and teeth; contributes to resistance to infection; deficiency causes scurvy	Fresh fruit and vegetables