

Introduction

Starch is a plant polysaccharide stored in roots and seeds of plants, and in the endosperm of a grain kernel. It provides humans with energy (4 cal/g), and is hydrolyzed into glucose, supplying the glucose that is necessary for brain and central nervous system functioning.

Starch grains, or *granules*, contain long-chain glucose polymers and are *insoluble* in water. Unlike the small molecules of salt and sugar, the larger starch polymers do *not* form a true solution. Instead, starch granules form a *temporary suspension* when stirred in water. As *uncooked* granules, each may swell slightly when it absorbs water. However, once starch is *cooked*, the swelling is *irreversible* and the starch leaches out. This characteristic of starch granules enables starch to be used as a thickener.

Overall, the characteristics of a finished starch food product are determined by several factors: the source of starch, concentration of starch used in a formulation, the temperature and time of heating, and other components used with the starch, such as acid and sugar. There are many types of starch and modified starches. These thicken, prevent curdling, and stabilize cooked salad dressings, dips, gravies, desserts, and more.

Intermediate, shorter chain products from starch breakdown, known as dextrins, may be used to simulate fat in salad dressings and frozen

desserts. For example, wheat, potato, and tapioca maltodextrins may be used as fat replacers. These provide the viscosity and mouthfeel of fat in a food product, yet, with reduced calories compared to fat.

Starch Sources in the Diet

Starch sources are numerous, with common ones derived from cereal grains such as wheat, corn, or rice. Wheat yields a cloudy, thick mixture, while cornstarch produces more clear mixtures such as gravies or sauces. Vegetables, roots and tubers, including the root of cassava, and potatoes, are frequently used in the preparation of gluten-free foods, where persons with wheat allergies or intolerances do not use any wheat as a thickener. Specialty starches are available commercially and some may be available to the consumer, perhaps purchased through specialty food stores.

Another source of starch is legumes such as soybeans or garbanzo beans. As well, *sago* is a powdery starch obtained from the stems and trunks of the sago palm in tropical Asia. Sago may be used as a food thickener as well as a fabric stiffener. Fruits such as bananas may also be sources of starch.

Thus it may be seen that starch may come from a variety of sources. Depending on the source, starches may also have different crystalline structures.

Starch Structure and Composition

The starch *granules* from various grains differ in *size*, ranging in size from 2 to 150 μm . The *shape* of starches may also vary—being round or polygonal, as seen in the photomicrographs of corn, wheat, and waxy maize in Figs. 4.1, 4.2, and 4.3.

Starch is made up of two molecules, *amylose* and *amylopectin*, whose parts are connected by glycosidic linkages (see Chap. 3). **Amylose** molecules typically make up approximately one-quarter of starch. Amylose is a long linear chain composed of thousands of glucose units with attachment of the carbon 1 and carbon 4 of glucose units, and therefore contains α -1,4 glycosidic linkages. It forms a three-dimensional network when molecules associate upon cooling, and is responsible for the gelation of cooked, cooled starch pastes.

While those starches with a *high* amylose content are able to gel, or hold their shape when molded, starches *without* amylose thicken, although do *not* gel. Examples of the amylose content of various starch sources include:

Cereal grains—26–28 % amylose
Roots and tubers—17–23 % amylose
Waxy varieties of starch—0 % amylose

Amylopectin molecules (Chap. 3) constitute approximately three-quarters of the polymers in a starch granule. The glucose chain of amylopectin contains α -1,4 linkages, similar to amylose, however, with α -1,6 branching at every 15–30 glucose units of the chain. There is a linkage between the carbon 1 of the glucose and carbon 6 of the branch in amylopectin. The chains are highly branched and bushy (however less branched and less bushy than the *animal* storage form of carbohydrate, which is glycogen, *not* starch).

Starches with a high percentage of amylopectin will *thicken* a mixture, although cannot form a *gel* because, unlike amylose, amylopectin molecules do not associate and form chemical linkages. The greater the amylopectin content, the more viscous the starch paste (not a gel), while the greater the amount of amylose, the stronger the *gel*.

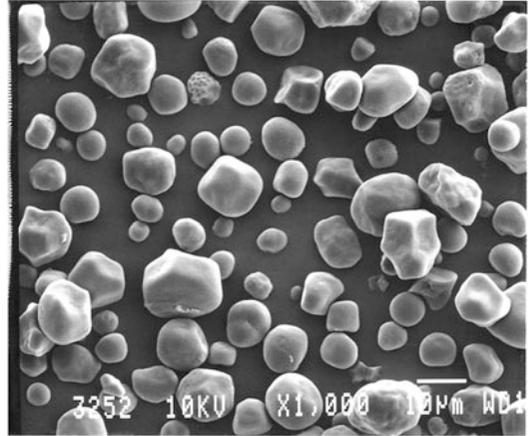


Fig. 4.1 Scanning electron micrograph of common corn cereal grains magnified 2,000 times (Source: Purdue University—Whistler Center for Carbohydrate Research)

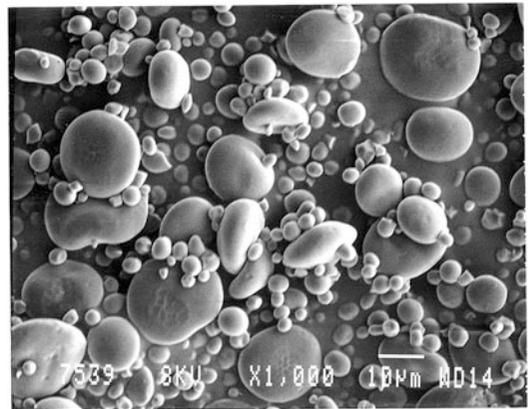


Fig. 4.2 Scanning electron micrograph of wheat magnified 600 times (Source: Purdue University—Whistler Center for Carbohydrate Research)

Gelatinization Process in Cooking

Steps in the process of becoming gelatinized will be enumerated in the following text. Starch in its *uncooked* stage is *insoluble* in water. Thus it cannot be referred to as “going into solution,” or “dissolving.” It forms a temporary *suspension* of large granules/particles, which are *undissolved* in the surrounding medium, and these particles will settle to the bottom of a container of liquid unless it is continuously stirred or otherwise agitated.

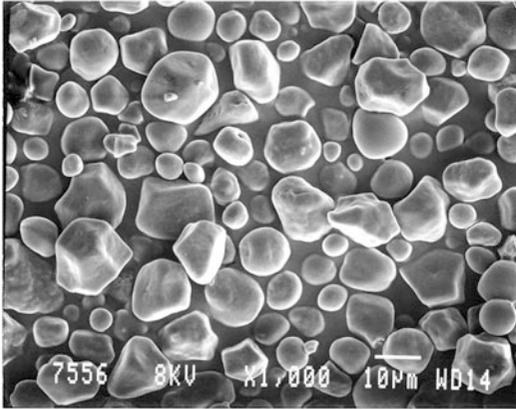


Fig. 4.3 Scanning electron micrograph of waxy maize magnified 1,000 times (Source: Purdue University—Whistler Center for Carbohydrate Research)

In a suspension, the starch particles may imbibe a small amount of water; however, generally, a suspension offers minimal change to the starch. Any uptake of water by the starch granule is reversible if starch is dried while still in the *uncooked* state.

Another feature of the *uncooked* starch molecule is that it exhibits a Maltese cross formation, or *birefringence* on the granule when it is viewed under polarized light with an electron microscope. This is due to the fact that it is a highly ordered crystalline structure, and light is refracted in two directions (Fig. 4.4).

Once cooking has begun when the starch is heated in surrounding water there occurs *imbibition*, or the taking of water into the granule. This first occurs in *less*-dense areas, and subsequently in the *more* crystalline regions of the starch molecule. At this *initial* point this is still a *reversible* step in the gelatinization process. However, as heating continues, starch granules take up more water *irreversibly* and swell; some short chains of amylose come out of the granules. This process, known as *gelatinization*, is responsible for the thickening of food systems. The gelatinized starch mixtures are opaque and fragile, and the ordered crystalline structure of starch is lost.

As starch leaches out of swollen granules in the gelatinization process, the water–starch mixture becomes a *sol*. A sol is a colloidal two-phase system containing a liquid continuous phase and

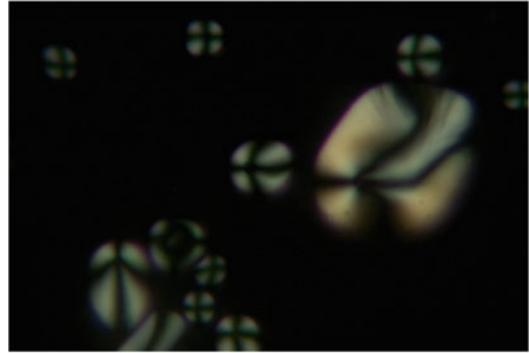


Fig. 4.4 Graph of the thickening of various starches (Source: Schoch TJ. Starches in foods. In: *Carbohydrates Their Roles*, Schultz HW, Cain RF, Wrolstad RW, eds. Westport, CT: AVI Publishing Company, 1969. With permission)

a solid dispersed phase. This *solid-in-a-liquid* is pourable and has a low *viscosity* or resistance to flow.



Gelatinization may be synonymous with *pasting*, although the two terms may also be reported as sequential occurrences (Freeland-Graves and Peckham 1996). Whether a separate process or the continuation of gelatinization, *pasting* occurs with the continued heating of already gelatinized starch grains. The process involves a *loss* of the ordered crystalline structure in starch, which is observed as the *disappearance* of the Maltese cross formation when starch is viewed under polarized light with an electron microscope.

The temperature at which a starch loses its ordered crystalline structure, and gelatinizes, may actually be a *range* of temperatures specific to a starch. The granules within a starch will swell and thicken mixtures at slightly different temperatures, with the larger granules swelling earlier than smaller granules.

The **steps** in the gelatinization process are as follows:

- The gelatinization temperature is *reached*—approximately 140–160 °F (60–71 °C), depending upon the starch type, and is *completed* at 190–194 °F (88–90 °C), or higher.
- The kinetic energy of the hot water molecules breaks the hydrogen bonds between the starch

molecules. Hydrogen bond interchange occurs as starch forms hydrogen bonds with water molecules instead of other starch molecules. As hydrogen bonds are formed, water is able to penetrate further into the starch granule and swelling takes place. Sufficient water must be present to enter and enlarge the starch granule.

- Diffusion of some amylose chains occurs as they leach out of the starch granules.
- Birefringence and the ordered crystalline structure of the uncooked granule is lost. Increased translucency is apparent because the refractive index of the expanded granule is close to that of water.
- Granule swelling increases as the temperature increases. The larger starch granules are the first to swell.
- Swollen granules take up more space and the mixture thickens as the enlarged granules leach amylose and possibly amylopectin.
- The starch paste continues to become thicker, more viscous, and resistant to flow as it gelatinizes.
- The final step in the gelatinization involves the necessity of cooking the gelatinized starch mix—gravy, pie filling, and so forth—for 5 min or longer to develop flavor. Unnecessary overstirring thins the cooked starch mixture because the swollen starch granules implode, rupture, and lose some of the liquid held inside the enlarged granule.

Factors Requiring Control in Gelatinization

It is important to note that starches must first be *thoroughly* gelatinized in order to produce viscous pastes or strong gels. Several factors must be controlled during gelatinization in order to produce a high quality gelatinized starch mixture. (Starches that are not *thoroughly* gelatinized *cannot* produce viscous pastes or strong gels.)

These factors include the following:

Agitation: Agitation, or stirring both initially and throughout the gelatinization process, enables granules of starch to swell independently of one

another and creates a more uniform mixture, without lumps. Even so, as previously mentioned, excessive agitation after gelatinization is complete may rupture granules, and consequently thin starch mixtures.

Acid: Acid hydrolysis during cooking of starch granules results in fragmentation and the formation of *dextrins* or short chain polymers. Hydrolysis of the starch molecule results in less water absorption by the starch granule, thus a thinner *hot* paste and less firm *cooled* product. Therefore, the late addition of acid to a starch mixture is best, after starch has been gelatinized and begun to thicken. Acid is frequently added to starch sauces in the form of vinegar, tomatoes, fruit, or citrus juice

Enzymes: Starch may be hydrolyzed by the starch-splitting enzymes α -amylase, β -amylase, and beta-glucoamylase.

Endoenzymes such as α -amylase act anywhere on the starch chain and undamaged starch grains to degrade starch. The hydrolysis products of β -amylase are glucose, maltose, and dextrins, depending on the extent of hydrolysis that takes place, and this may be desirable in commercial breadmaking.

The *exoenzyme* β -amylase acts on α -1,4 glycosidic linkages from the nonreducing end, and on damaged amylose or amylopectin chains. This further hydrolyzes starch two glucose units at a time, thus producing maltose.

The β -amylase cannot hydrolyze starch beyond the branch points of amylopectin. The enzyme β -glucoamylase hydrolyses the α -1,4 link, producing glucose, and slowly hydrolyzes α -1,6 linkages in starch.

Fat and proteins: The presence of fat and protein (such as in meat drippings used to produce a meat gravy) initially coats or *adsorbs* to the surface of the starch granules causing a delay in hydration and viscosity. Fat “waterproofs” the starch granules so that water does not easily penetrate during the gelatinization process. Thus, with the presence of fat there is less granular swelling and less amylose exiting from the granule, resulting in a decreased viscosity of the starch paste and decreased gel strength.

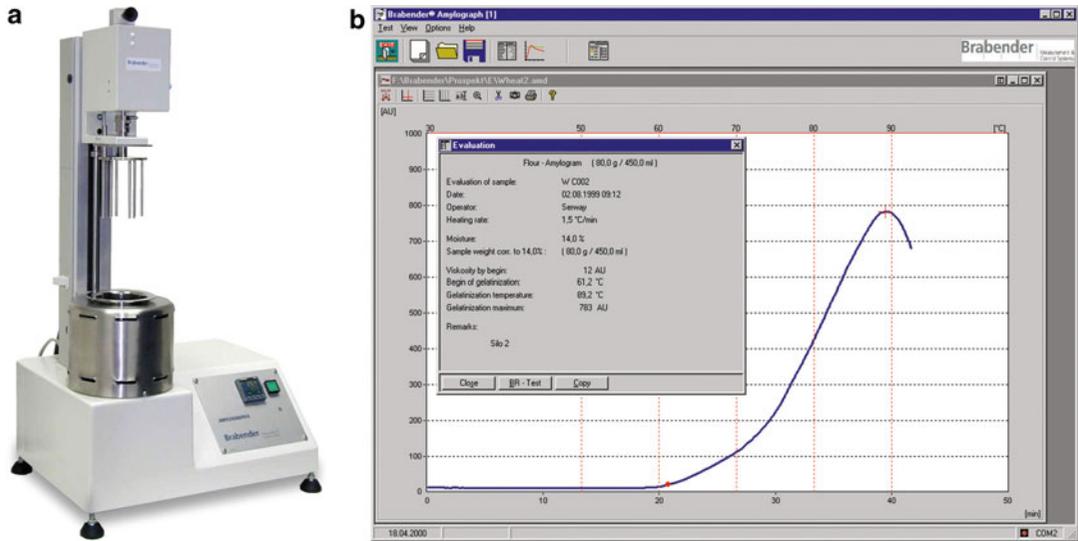


Fig. 4.5 Brabender amylograph and Brabender amylogram (Source: C.W. Brabender Instruments, Inc.)

Sugar: The addition of just moderate amounts of sugar, especially the disaccharides sucrose and lactose from milk, decreases starch paste viscosity, the firmness of the cooked and cooled starch product. Sugar competes with the starch for water and thus delays the absorption of water by starch granules. This prevents a speedy or complete swelling of the starch granule. Sugar also elevates the temperature required for gelatinization to occur.

As with acid addition, timing of sugar addition is significant. For a thicker mixture and gel, it is advised that a *partial* addition of sugar before the starch thickens and the remainder added later is best. Thus there is less sugar to compete with granule water absorption than if all of the sugar is added at the beginning of cooking.

If *both* acid and sugar are added to a starch mixture, there is less swelling due to the presence of sugar that competes with starch for water and there is less hydrolysis from acid, on the granule.

Salt: raises the temperature at which a starch mixture thickens.

Temperature: as previously mentioned, there is a range of temperatures, 190–194 °F (88–90 °C), that need to be met for gelatinization to occur.

The *completion* is up to 203 °F (95 °C), although starches vary in their gelatinization temperature.

Length of heating: Enough time is required for all the granules to swell (especially the large ones) but as the heating is lengthened, the finished mixture may be thinner due to possible overstirring and rupturing of enlarged granules. Alternatively, cooking for a long time in an uncovered double boiler may evaporate the water that would otherwise thin the mixture.

Type of heat: *Moist heat* is necessary for gelatinization to occur. *Dry heat* causes the starch to hydrolyze, forming shorter chain dextrans. Dry heat creates “browned” flour that imparts a slightly toasted flavor and brown color to a food mixture. This browning effect may be desired in many recipes.

Rate of heating: In general, the faster a starch–water dispersion is heated, the thicker it will be at an identical endpoint temperature.

It can be seen that many factors—many “if’s” must be controlled in the gelatinization process. For example, a desired three-dimensional starch structure forms IF gelatinization has occurred correctly, IF the starch is the correct type, IF

the concentration of starch is sufficient, IF the heat is correctly applied, IF inclusion of added substances is properly timed, and so forth!

The viscosity of a starch and water mixture is recorded on a moving graph as the mixture is tested and stirred (Fig. 4.4). The recording instrument portrays the thickness of starch mixtures during heating, gelatinization, and cooling. It may be used in order to show the effects of α -amylase on starch mixtures, or the thickness of various starches at different times and temperatures. Evidence of dextrinization may be seen.

Further discussion of specific times and temperatures of when various starches thicken or gel may be observed by reading data from a recording instrument or recording viscometer (Fig. 4.5). As illustrated in the graph in Fig. 4.4, *root* starches such as potato and tapioca, and *waxy cereal* starches thicken earlier and at lower temperatures than cereal starches.

Gelation or Setting of Gelatinized Starch Pastes During Cooling

Amylose

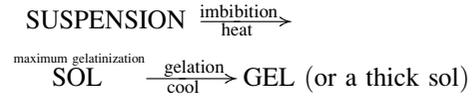
Further changes in the amylose component of starch pastes occur beyond the previously discussed process of gelatinization. During *cooling*, for example, the amylose “sets” and forms a *gel*—a process referred to as *gelation*. A gel forms a colloidal, elastic and solid, three-dimensional, two-phase system with a *solid* continuous phase of amylose polymers holding a *liquid* dispersed phase. This is in contrast to the *sol* it was beforehand.

The reason that the gel network forms is due to the fact that as the mixture cooled, energy is reduced. Subsequently, intermittent hydrogen cross-bonds formed among *amylose*, reassociating at random intervals of the amylose molecule, forming a *gel*.

Amylopectin

On the other hand, the highly branched *amylopectin* molecules do *not* readily form bonds or a gel.

Rather, amylopectin exhibits *less* tendency to re-associate or revert to a more crystalline structure than amylose. It remain a sol; however, it forms a *thick* sol upon cooling as shown below. This may be desirable in food items such as pie fillings.



Gels

Starches may be selected for use based on their gelling potential as identified in the following list:

Forms gel	Does not form gel
Cornstarch	Waxy cereals
Wheat starch	Tapioca
Wheat flour	

If gels are formed, mixtures are non-pourable and of high viscosity. It is significant to know that if an appropriate flour is utilized to yield a gel, gelling requires a quantity of two times the amount of flour as cornstarch because an equal amount of flour contains additional non-starch components, such as protein that will not gel.

Retrogradation

Retrogradation refers to the occurrence where starch reverts or retrogrades to a more crystalline structure upon cooling. Both amylose and amylopectin may participate in a textural change that makes them somewhat more “gritty” with time. Retrogradation is more likely to occur in a *high amylose* starch. This occurrence is noted in baked products that become “*stale*,” no longer “*fresh*” tasting or “*fresh*” handling (a “*fresh*” baked good indicates that the starch is still in existence as a gel form). It is also observed in leftover, long-grain rice. Due to its high amylose content, leftover rice gets hard.

Retrogradation Facts

Likely if gel has been formed improperly, the resulting amylose structures are fragile, readily losing entrapped water.

- The amylose retrogrades and recrystallizes.
- Retrogradation is likely when gel is exposed to the effects of freeze–thaw cycles, as the water is frozen and thawed. Water created from melted ice crystals is not able to reassociate with the starch, and water loss becomes apparent.

Included below are a few baking examples of retrogradation from the literature. They are used to better clarify the term.

“In baking, the starch present in bread dough and batters becomes gelatinized. During this process the starch goes from an ordered, crystalline state to a disordered, amorphous state. Upon cooling the disordered starch state begins to re-order (or retrograde), returning the starch back to its more rigid crystalline state, resulting in the firming of crumb texture in baked goods. Starch retrogradation is a time and temperature dependent process.” Available from: Tessier, J. Increasing Shelf-Life without Preservatives (Bakers’ Journal: July 2001)

“When the starch stays as a gel, a product is softer, and we say it is “fresh”. When the starch regains its crystalline form, the product becomes firmer, and we say it is “stale”. The technical term for this is starch retrogradation.” Available from: [Ingredients - Starch and Modified Starch](http://sci-toys.com/ingredients/starch.html) <http://sci-toys.com/ingredients/starch.html>

“Staling as a result of changes in the starch component (i.e., a change in the amylose and amylopectin starch molecules) of the bakery product is called starch retrogradation. Starch retrogradation begins as soon as baking is complete and the product begins to cool. Amylose retrogradation is mostly complete by the time the product has cooled to room temperature. Amylopectin retrogradation requires

more time than amylose retrogradation and as a result, is the primary factor resulting in staling. During the staling period, the amylopectin molecules revert back to their original firm state as rigid crystalline granules. As a result, the baked product loses moisture in the crumb, becoming firmer and less elastic.” Available from: Nadia Brunello-Rimando. Bakers’ Journal—Voice of the Canadian Baking Industry. May 2004. (Product and Process Development, *Consulting & Technical Services*) <http://www.gftc.ca/about-us>

Syneresis

Syneresis or “weeping” is water freed from a cooked, cooled starch gel. The process is a change following *gelatinization* and is caused by *gelation*. As a cooked, cooled starch gel stands, the gel ages, then further association of amylose occurs and the gel contracts, causing both water loss and shrinkage to become apparent. This is caused by retrogradation, and is the separation of a liquid from a gel, upon standing. The process is a change following *gelatinization* and is caused by *gelation*.

If cooled undisturbed, the gels remain strong, yet reassociation may be accompanied by the unacceptable water loss or *syneresis*. To control syneresis, modified starches (see “Modified Starches” section) or starches containing only non-gelling amylopectin are used in commercial products.

“Research has well established that the cooling conditions will impact the strength of the gel. Generally, if cooled too fast, the amylose will not have time to form the vital micelles necessary for the three dimensional structure. If cooled too slowly, the amylose fractions will have a chance to align too much and become too close together and the liquid portion will not be trapped in the micelles. In both instances there will be weeping and syneresis.” (Oregon State University) Available from: <http://food.oregonstate.edu/learn/starch.html>

Separating Agents and Lump Formation

Separating agents are used in food preparation in order to prevent lumps in a starch-thickened food item. A problem in the preparation of starch-thickened mixtures is the undesirable formation of lumps. Lumps are due to the unequal swelling or “clumping” together of individual starch granules. The granules must be allowed to swell independently; thus, it becomes important to “separate” the granules with a separating agent.

For product success, one of the three *separating agents* such as fat, cold water, and sugar must be used. They should be added to *just* the starch/flour ingredient in order to physically *separate* the grains *prior* to its addition to a recipe. The correct use of any of these agents produces a desirable smooth-textured mixture as opposed to a lumpy mixture.

Fat. *Fat* is a separating agent. When stirred into the flour, fat forms a film around the individual starch granule allowing each granule to swell independently of other granules. Thus, a *lump-free* sauce or gravy is obtained when liquid is added and cooking occurs. Oftentimes a *roux* is made—flour is browned and then separated by agitation with liquid fat during heating.

A roux may range in color from light brown to almost black (Cajun cooking). As a starch is heated and becomes darker, the starch progressively loses its thickening ability as it undergoes dextrinization from heating. An added benefit of adding flour to *hot* meat fat drippings is that α -amylase (which thins) is destroyed.

Cold water. *Cold water* may be used to physically separate starch granules. When mixed with insoluble starch, water puts starch granules in a suspension known as a “*slurry*.” The cold water–starch suspension is then slowly mixed into the hot liquid for thickening.

Cold water as a separating agent may be desirable if the product is to remain fat-free or sugar-free. *Hot* water is not a successful separating agent as hot water partially gelatinizes the starch.

Sugar. *Sugar* is a common separating agent used for a sweetened mixture. It is mixed with starch, prior to incorporation into the liquid,

so that starch granules remain physically separate to allow individual swelling without lump formation.

Once starch is separated, so that the granules do not “clump together,” forming lumps, the separated starch mixture is added to the other recipe ingredients. Sauces must be heated slowly and/or **stirred constantly** in order to be free of lumps. Extensive or harsh stirring after maximum gelatinization has occurred will rupture starch granules, causing the mixture to be thin.

CULINARY ALERT! Many cookbook recipes do not specify the use/proper use of a separating agent and the result is a mixture with lumps! The choice of which separating agent to use is dependent upon the desired end product—e.g., sweetened, fat-free.

Modified Starches

Natural starches may be *modified* chemically to produce physical changes that contribute to shelf stability, appearance, convenience, and performance in food preparation. Some “natural” starches are *not* modified chemically which may be a “plus” for concerned consumers and processors. Various examples of modified starches used in food manufacturing are described in the following text.

Pregelatinized starch is an instant starch that has been gelatinized and then dried. It subsequently swells in liquid without the application of heat. Pregelatinized starch appears in many foods, including instant pudding mixes.

Some properties of a pregelatinized starch include the following:

- Dispersible in cold water; it can thicken without heat being applied
- Can be cooked and dried, yet is able to reabsorb a lot of water in preparation without cooking the food (instant pudding)

- Undergoes irreversible change and *cannot* return to its original ungelatinized condition after treatment
- A greater weight of starch is required to thicken a liquid because some rupturing and loss of starch granule contents occurred during gelatinization and drying

Cold water-swelling (CWS) starch is an instant starch that remains as an *intact granule*. It offers convenience, stability, clarity, and texture. CWS starches may be gelling or non-gelling. They may be used in no-cook or cold-process salad dressings providing the thick, creamy mouthfeel in no-fat salad dressings.

Cross-linked starches are those that undergo a molecular reaction at selected hydroxyl (—OH) groups of two adjoining, intact, starch molecules. The purpose of cross-linking is to enable the starch to withstand such conditions as low pH, high shear, or high temperatures. The cross-linked starch becomes less fragile and more resistant to rupture than the original unmodified starch. Although it is more tolerant of *high* temperatures, it is *not* more tolerant of *cold* temperatures. These starches are used in many foods, especially acid food products such as pizza sauce or barbecue sauce because the modified starch is *more acid-resistant* than an unmodified starch. As a result of cross-linking, a starch swells less and is less thick.

Stabilized (substituted) starches are used in frozen foods and other foods stored at cold temperature in order to prevent gelling and subsequent syneresis. The main types of substitutions include hydroxypropylated, hydroxyethylated, and so forth. These starches prevent molecular associations and cause ionic repulsion. The stabilized starch produces pastes able to withstand several freeze–thaw cycles before syneresis occurs. This is value to the frozen food industry, and also to foods such as sauces and gravies stored at cold temperatures. Stabilized starches are *not* appropriate for foods that

require prolonged *heating*. However, starches may be modified by a combination of both cross-linking and stabilization treatments. Such modification ensures that the starches are acid-, heat-, and freeze–thaw-stable. Stabilized starches have a wide range of uses in food products.

Acid-modified starch is starch that is subject to treatment in an acid slurry. A raw starch and dilute acid are heated to temperatures less than the gelatinization temperature. Once the starch is mixed into a food product, it appears less viscous in *hot* form, although it forms a strong gel upon *cooling*. More about Modified Starches as follows: <http://food.oregonstate.edu/learn/starch.html>

Non-food uses for Modified Starches include glue in cardboard manufacture and glue on postage stamps

Waxy Starches

Waxy starches are derived from some natural strains of barley, corn, rice, and sorghum. They *do not* contain amylose, begin to thicken at *lower* temperatures, become *less* thick, and undergo *less* retrogradation than non-waxy varieties. *Waxy* cornstarch, for example, does not have the same gel forming properties as regular cornstarch. It contains *no* gel producing *amylose*, and only *amylopectin*.

- Waxy cornstarch—contains NO amylose, is all amylopectin, and does NOT gel
- Ordinary *cornstarch*—contains 27 % amylose and forms a gel
- *High amylose cornstarch*—contains 55 % amylose and forms a gel

Waxy varieties of starch are commonly used in the preparation of pie fillings to *thicken*, however, *not gel*. They may also be cross-linked for better function.

Starch Uses in Food Systems

Starches have many uses in food preparation and are very versatile and oftentimes inexpensive. They may be introduced into foods primarily because of their *thickening* ability. For example, pureed, cooked, or instant potatoes, or pureed cooked rice may be undetectable, however, useful as thickeners. A white sauce may be added during the preparation of a tomato and milk-based soup, in order to thicken and stabilize. It aids in the control of milk protein precipitation caused from the addition of tomato acid. Starch may also be useful as a water binder and gelling agent.

Another use of starch is as a *fat replacer* in food systems. Molecularly, the amylose chains form helical or spherical shapes, holding water and providing bulk. This confers the satisfying “mouthfeel” attributes on starch. Intermediate length polymers of D-glucose, called *maltodextrins*, are formed from the hydrolysis of starches such as tapioca, potato, and wheat. Maltodextrins simulate the viscosity and mouthfeel of fats/oils and are used to reduce the fat content of some foods.

With the use of ordinary cross-breeding procedures, new starches are being discovered that have various applications in food systems. Baking, microwave cakes, frozen sauces, fat replacers, breadings, snacks, and gelled candies are some of the uses of starch (American Maize-Products Company, Hammond, IN). For example, **pea starch** may offer an alternative to other modified starches used in the food industry as it provides a very high viscosity *immediately* upon agitation. It is available in pregelatinized form for use in cold processed products such as dessert creams, dressings, instant soups, and sauces (Feinkost Ingredient Company, Lodi, OH). Pea starch may also be environmentally friendly as a biodegradable food packing material introduced in landfill sites.

New food starches and their uses are continually being developed. Food starches are commercially manufactured and available

for use in products such as baked food, beverages, canned, frozen, and glassed foods, confections, dairy products, dry goods, meat products, and snack foods (National Starch and Chemical Company—Food Products Division, Bridgewater, NJ).

CULINARY ALERT! A starch chosen for use in food systems may involve a choice by habit, or convenience. Consumers may actually use less than the best because “it’s what mom always used, so I’ll use it too,” or “it’s here in the kitchen, so I’ll use it!”

Cooking with Starch

Several of the applications of cooking with starch appear below. Cooking with the appropriate starch, in the proper concentration, timing of addition, and so forth as previously discussed are factors crucial to the success of any starch-thickened product.

Appearance

The appearance of a cooked, cooled starch mixture is influenced by the choice of starch. For example, *cereal* starches in general produce *cloudy*, thickened mixture upon cooling. Within the group of cereals, *flour* produces a *more* cloudy thickened mixture than *cornstarch* because the wheat flour contains additional non-starch ingredients not present in cornstarch. A *clear gel* is produced using cornstarch.

A *clear, thickened mixture* is also produced by other non-gelling starch sources such as Arrowroot. Non-gelling may be a desirable feature of pie fillings.

Use of a Double Boiler

Cooking *over boiling water* (such as with a double boiler for household preparation) promotes

temperature control and a more even gelatinization than would occur with *direct heat* cooking. A disadvantage of this cooking method is that it requires cooking for a longer time period to reach the thickening stage than a direct heat cooking method.

Tempering

Tempering involves the technique of *slowly* adding small amounts of hot starch to eggs in a recipe, in order to gradually raise the temperature thus slowly exposing eggs to heat without the danger of coagulation. In this manner, the eggs do not curdle and produce an unacceptable consistency. To achieve the desired consistency and texture of a recipe containing hot starch *and* raw eggs (in sauces, cream puffs, etc.), the process of *tempering* is used.

White Sauce

White sauces have widespread applications in cooking. The *concentration* of starch used in a formulation varies. For example, a white sauce of flour, fat, and milk may be thickened to various consistencies, for croquettes, sauces, and so forth. The concentration of flour may be as follows:

White Sauces

Thin—1 tablespoon of flour/cup of liquid

Medium—2 tablespoons of flour/cup of liquid

Thick—3 tablespoons of flour/cup of liquid

Liquid

The use of liquid type varies in starch mixtures. *Water or fruit juice* is incorporated into some foods dictated by need for clarity or flavor. Milk is usually used in a starch-thickened sauce such as white sauce. Since milk easily curdles at high temperatures, it may be made less likely to curdle if it is first thickened with flour prior to recipe addition.

CULINARY ALERT! Flourless sauces are thickened by reduction of the stock/liquid. Portions of the starchy ingredients of a soup recipe may be saved out and pureed, and then added back to the soup in order to thicken and flavor it.

Nutritive Value of Starch

Nutritive value is provided by starches. Starches are a complex carbohydrate containing 4 cal/g, and traces of protein and fat. Short chain maltodextrins derived from the hydrolysis of starch may be used in foods to partially replace fat. Maltodextrins simulate the taste of fat, and offer less calories per gram than the 9 cal/g in fat.

Not all starch is capable of carrying calories or being digested. A “*resistant starch*” is dietary fiber, with an example being whole cooked beans. Resistant starches offer benefits to the colon, namely, “roughage.” Also, intestinal bacterial flora use fiber, producing vitamins such as vitamin K.

Whole grains that are *ground* to make flour are different than the whole grain from which they came. For example, they have a higher *glycemic index* than *unground* grains. This is due to the ease of absorbing the starch into the blood as sugars.

Special nutritional needs may require a dietary restriction of wheat that may lead to use of non-wheat starches for those individuals following gluten-free diets. Assorted alternatives to wheat are corn, potato, or rice starch. Packages of potato “flour” indicate on the finer print of the label that the contents are solely potato *starch* (Ener-G Foods, Inc., Seattle, WA). A gluten-free addition of starch or even fiber may be utilized in product development (Hazen 2012).

Safety of Starches

Starches are one of many white powders used in food handling and production operations. Proper storage, including separation from other dangerous

chemicals, is crucial. If used in bulk quantities, labeling of both the container and its lid (if removable) better assures safety of starches in the workplace.

CULINARY ALERT!

Conclusion

Starch is a plant polysaccharide that is the storage form of carbohydrate in roots, seeds, and tubers. It may be derived from cereals such as corn, wheat, rice, or oats, or legumes such as soybeans, or from vegetable roots and tubers such as potatoes or arrowroot. In its uncooked stage, starch is insoluble in water. As it is heated and undergoes gelatinization, factors such as acid, agitation, use of enzymes, fat, proteins, sugar, and temperature require control. A separating agent prevents lumps in a starch mixture.

The source of starch and its concentration determine the thickening, gelling, retrogradation, and clarity of the finished product. Flour and cornstarch may be used to form gels; waxy varieties of starch do not gel. Syneresis may occur as the cooked, cooled starch mixture ages. Modification of starch granules allows starches to be used successfully in a variety of food applications. Starch may be added to foods in order to provide thickening, or product stability, or potentially, to carry flavors.

Notes

Glossary

Adsorb Surface adherence of gas, liquids, or solids onto a solid.

Amylose Long, linear chain composed of thousands of glucose molecules joined by an α -1,4-glycosidic linkage.

Amylopectin Branched chains of glucose units joined by α -1,4 linkages, with α -1,6 branching occurring every 15–30 units.

Birefringence A Maltese cross appearance on each uncooked crystalline starch granule when viewed under a polarizing microscope due to light refraction in two directions.

Dextrin Glucose polymers; a product of the early stages of starch hydrolysis.

Gel Elastic solid formed upon cooling of a gelatinized starch paste; a two-phase system that contains a solid continuous phase and a liquid dispersed phase.

Gelatinization Starch granules take up water and swell irreversibly upon heating, and the organized granular pattern is disrupted.

Gelation Formation of a gel upon cooling of a gelatinized starch paste.

Granule Starch grain of long-chain glucose polymers in an organized pattern; granule shape is particular to each starch type.

Imbibition Starch granules taking up water and swelling as it is exposed to moist heat.

Maltodextrin Starch hydrolysis derivative that may be used to simulate fat in formulations.

Modified starch Specific chemical modification of natural starches to physically create properties that contribute to shelf stability, appearance, convenience, and performance in food preparation.

Retrogradation Reverting back, or reassociation of amylose as the gelatinized starch

once again forms a more crystalline structure upon cooling.

Separating agent Prevents lump formation in a starch mixture. Physically separates starch grains and allows their individual swelling.

Sol A two-phase system with a solid dispersed in a liquid continuous phase.

Spherical aggregate Open, porous starch granules with spaces that can be filled and used to transport materials such as flavor, essences, and other compounds.

Starch Carbohydrate made up of two molecules—amylose and amylopectin.

Suspension Large particles undissolved in the surrounding medium. Particles are too large to form a solution or a sol upon heating.

Syneresis “Weeping” or water loss from a cooked, cooled gel due to excessive retrogradation or improper gel formation.

Viscosity Resistance to flow of a liquid when force is applied. A measure of how easily a liquid will flow. Thin liquids have a low viscosity. Thick liquids or gels have a high viscosity and flow slowly.

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