POTATO COMPOSITION AND INGREDIENT FUNCTIONALITY

Potatoes USA

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INTRODUCTION

U.S. potato products have a well-earned reputation for unparalleled flavor, versatility and nutrition. That's why you'll find these operationally efficient, hardworking and naturally gluten-free potato ingredients in everything from soups and ready meals to baked goods and desserts.

Fresh, dehydrated and frozen potato ingredients bring value-added functionality to formulations across categories, adding flavor, improving texture, increasing yield, simplifying preparation and introducing delicious variety wherever they appear.

To get the most out of any potato ingredient, product developers need to know which options best fit their applications. By familiarizing yourself with some potato basics, you'll be prepared to make the right choice for your products.

SET CLEAR SPECIFICATIONS

Before choosing a potato ingredient, it's important to remember that potatoes are living, nature-made foods. As such, no two potatoes are alike.

Environmental conditions during growth, harvest and storage, soil type, water levels, nitrogen application, pest-control interventions, and the presence or absence of disease all influence the quality, composition and performance of the potato—which, in turn, influence the ingredients made from them.

Given so much potential for variability, formulators must establish procurement specifications that clearly state the properties they require of their dehydrated potato ingredients. This is the best way to achieve desirable finished-product characteristics—from texture, color and viscosity to salt content and cooked potato quality.

Moreover, clear and measurable ingredient specifications improve efficiency, product uniformity and a range of process parameters while ultimately increasing customer satisfaction and profits.

Know which specifications you require before selecting your potato ingredients.

POTATO COMPOSITION, CHEMISTRY AND NUTRITION

Potatoes come in many varieties, shapes, sizes and colors.

Despite being more than 75% water, fresh skin-on potatoes are complex carbohydrates; they supply 3 grams of protein and 8% of the daily value for fiber per 5.3-ounce potato; and they're fat, sodium and cholesterol free. They contain multiple vitamins and minerals and qualify as an excellent source of vitamin C and a good source of potassium and vitamin B6.

A common misperception about potato nutrition is that all the nutrients are in the skin. Yet while the skin contains approximately half the total dietary fiber, the majority of the nutrients are found within the potato itself.

As with most vegetables, processing affects the bioavailability of certain potato nutrients, particularly the water-soluble vitamins and minerals. Nutrient loss appears to be greatest when cooking involves water, as with boiling, or extended time at high temperatures, as with baking.[1] Vitamin C is probably the nutrient most affected, as it's not only water soluble but also heat and oxygen labile.[2,3]

Potato ingredients, though produced from fresh potatoes, vary slightly in nutritional composition, as outlined in the following chart.

COMPOSITION OF POTATOES AND POTATO PRODUCTS PER 100G EDIBLE PORTION[4]

Product Type	Water %	Calories	Protein (g)	Fat (g)	Carbohydrte (g)	Calcium (mg)	Vitamin C (mg)
Raw potato	79.8	76	2.1	0.1	17.1	7	20
Baked in skin	75.1	93	2.6	0.1	21.1	9	20
Boiled in skin	79.8	76	2.1	0.1	17.1	7	16
French fried	44.7	274	4.3	13.2	36.0	15	21
Fried from raw	46.9	268	4.0	14.2	32.6	15	19
Dehydrated shreds, rehydrated overnight	54.2	229	3.1	11.7	29.1	12	9
Mashed, milk and fat added	79.8	94	2.1	4.3	12.3	24	9
Canned, solids and liquid	88.5	44	1.1	0.2	9.8	0	13
Dehydrated mashed, granules, water, milk, fat	78.6	96	2.0	3.6	14.4	32	3
Frozen cooked, hash browned	56.1	224	2.0	11.5	29.0	18	8
Frozen, French fried heated	52.9	220	3.6	8.4	33.7	9	21
Frozen, mashed, heated	79.3	93	1.8	2.8	15.7	25	4
Potato chips	1.8	568	5.3	39.8	50	40	16
Potato flour	7.6	351	8.0	0.8	79.9	33	19

Table 1

POTATO MACRONUTRIENTS

CARBOHYDRATES

Potatoes are a great source of nutrient-dense carbohydrates—the body's main fuel. These include complex carbohydrates like starches, simple sugars and the non-starch polysaccharides soluble and insoluble fiber.

Not only do potato carbohydrates supply important energy, they're critical to potato products' functionality in formulations, too.

STARCH

Potato starch resides primarily in the starch granules found in potato cells. These granules are semicrystalline in structure and quite large compared to those found in grains such as wheat and corn.[5]

The granules contain a mix of straight-chain amylose and branched-chain amylopectin starch molecules, with roughly 75% of the starch in the waxier amylopectin form—which releases less glucose into the bloodstream upon metabolism—and the remainder as the starchier, more easily digested amylose.

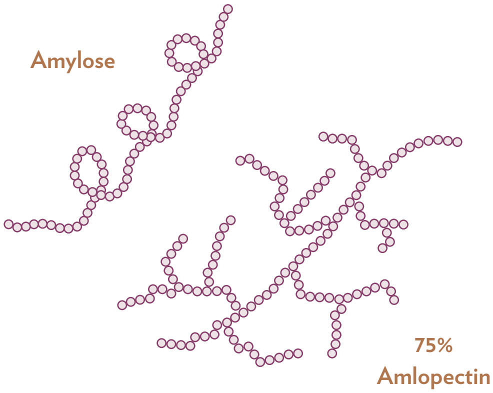

Figure 1

When a potato is cooked in water, its starch undergoes a gelatinization process in which the starch granules dissolve—amylose at a temperature of about 158°F (70°C) and amylopectin at 194°F (90°C)—to form a gel. This gel can be quite viscous relative to gels formed from other types of starch, like tapioca, corn and wheat (see chart 2).[6]

When gelatinized potato starch cools, it reassociates into its crystalline structure in a process called retrogradation. The retrogradation that takes place during sequential cooking and cooling increases the proportion of starch that resists breakdown by human digestive enzymes, thus decreasing the potato's glycemic index.[7] Retrograded potato flour has more resistant starch and less digestible starch than a hot boiled potato.[8]

Resistant starch acts like dietary fiber, aiding in the proliferation of the good bacteria in the gut microbiome. And because resistant starch slows glucose absorption into the bloodstream, it helps moderate spikes and dips in blood sugar.

From a food-processing standpoint, starch retrogradation also reduces oil penetration, making dehydrated potato ingredients preferable for use in snack foods.

Another reason that starch solids are important to potato ingredient performance is their contribution to specific gravity. Specific gravity is a measure of the dry-matter content of potatoes and is expressed as a ratio of dry matter to water; the higher the ratio, the higher the specific gravity. Specific gravity is an important driver of texture and appearance, influences time and energy requirements for cooking and is generally considered a key indicator of product quality.[9]

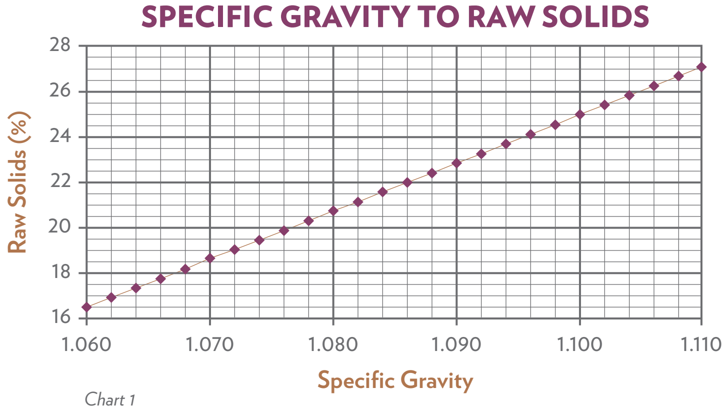

Chart 1

SG INFLUENCES COOK TIME		
SG	Solids	Blanch Time
1.073	≅19.5%	~8 minutes
1.084	≅22.0%	~7 minutes
1.101	≅25.3%	~6 minutes

Table 2

The specific gravity that a formulator will require of a potato ingredient will depend on the application in which that ingredient will appear. A potato with a specific gravity on the high side—equal to or greater than 1.080, or about 20.7% solids—cooks faster with less energy input, produces a lighter and mealier texture and is best for fries, chips and dehydrated products, as well as for mashed and baked applications (although a higher specific gravity does indicate a potential to slough). Russets, white and yellow potatoes characteristically have higher specific gravities.

By contrast, potatoes with a lower specific gravity—1.070 or less, or about 18.6% solids—take more time and energy to cook, but develop a firm, sturdy texture suited to canning, salads and grilled foods.[9] Waxier potato varieties such as red potatoes fall into this category.

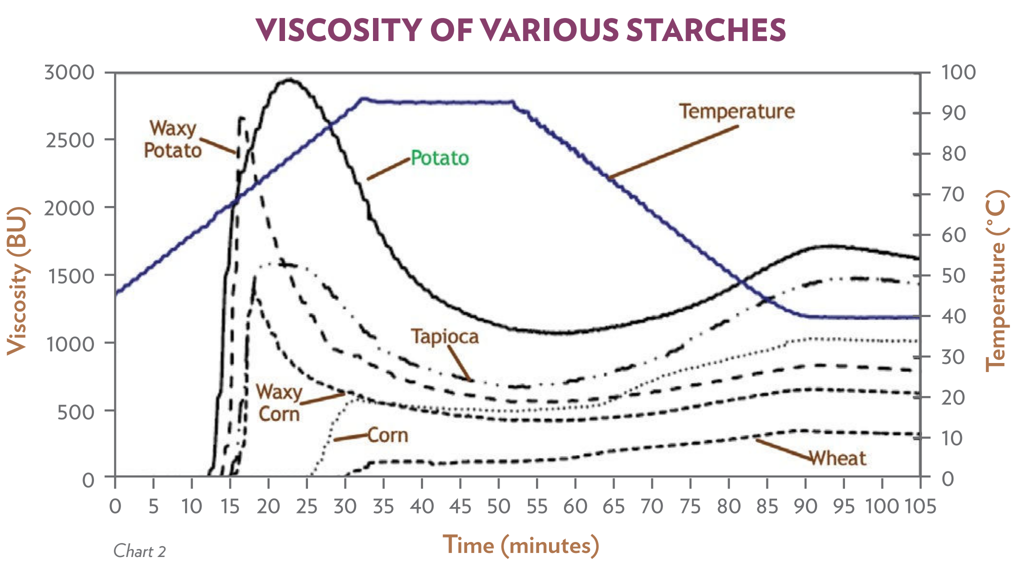

Chart 2

SUGARS

The sugar content of potato ingredients varies depending on the type, maturity and physiological state of the raw tuber. That said, the main sugars in potatoes are sucrose, glucose and fructose.

As monosaccharides, glucose and fructose are reducing sugars. That means that their structure bears a free aldehyde group capable of reducing other compounds. The reduction of other compounds leaves the reducing sugars themselves oxidized.

Reducing sugars are critical in food processing because they participate in the Maillard reaction. The Maillard reaction—a form of non-enzymatic browning—occurs when reducing sugars react with amino acids at high temperatures to yield brown, caramelized colors and aromatic flavors associated with grilling, roasting and frying, as seen in figure 2.

Maillard reaction products are generally desirable, but too much of them isn't always a good thing. For example, most formulators in the snack and baking industries want to avoid excessive browning in their products; thus, they prefer potato ingredients with lower levels of reducing sugars.

Typically, processors look for potatoes with reducing-sugar levels below 2%, although levels below 1.5% are even more preferable. Higher reducing-sugar levels may not be a drawback when using potato ingredients to make rehydrated products like mashed potatoes; nevertheless, levels above 3% both contribute to excessive browning and can make the finished product sweeter.

The upshot: Formulators must consider the optimal level of Maillard browning when specifying the reducing-sugar content of their potato ingredients.

Also, as raw potatoes grow and mature, the ratio of reducing sugars to sucrose—a non-reducing sugar—and to starch increases, as does the ratio of fructose to glucose.[10] This happens because respiration within the potato gradually converts starches and even disaccharides like sucrose to the reducing monosaccharides glucose and fructose. Keeping a close eye on storage temperatures and conditions can help control this reaction.

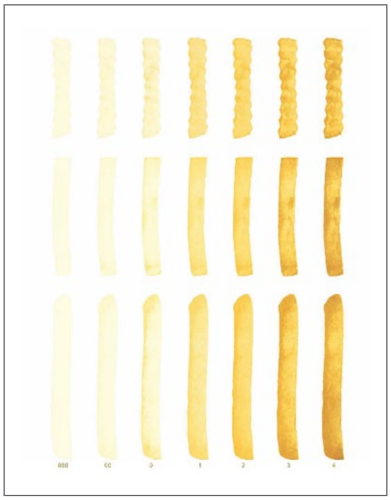

Figure 2: Munsell USDA Frozen French Fry Color Standard

NON-STARCH POLYSACCHARIDES (FIBER)

Non-starch polysaccharides such as cellulose, hemicellulose, pentosans and pectic substances compose a potato's crude fiber and are found in the potato cell wall and intercellular substances.[10] These naturally occurring polysaccharides are often added to commercial foods as thickening agents.

PROTEIN

The 3 grams of protein found in the average potato appear throughout the tuber in cellular membranes, cytoplasmic structures and enzymes. Common protein fractions include albumin, globulin, glutelin, prolamine and others.[10] After dehydration, potato products contain approximately 8% to 10% protein by weight.[11]

Protein quality is often expressed in terms of its biological value (BV), which takes into account the protein's amino acid profile and it's a common misperception that plant proteins lack essential amino acids. Potatoes contain all nine essential amino acids in a well-balanced profile that's comparable to other vegetable proteins. Potatoes also have lower levels of the sulfur-containing amino acids, which have been shown to increase calcium excretion and may impair bone mineral density.[13] Meanwhile, the leucine present in potatoes at levels similar to those in animal protein stimulates muscle protein synthesis.[8]

LIPIDS

Lipids occur at very low levels in potatoes (<0.2%) and appear as free fatty acids, fats (triglycerides) and phospholipids in the cytoplasmic membrane of the potato cell, where they're thought to regulate membrane permeability. Most of the fatty acids are unsaturated and, therefore, can undergo oxidation, which can be important when storing and manufacturing with dehydrated potato products.[10]

POTATO MICRONUTRIENTS

VITAMINS

Fresh potatoes with the skin are excellent sources of vitamin C, providing 45% of the daily value, or 27 mg per serving. Some vitamin C is lost during processing, but even after dehydrating, vitamin C remains in the dried potato. For example, mashed potatoes made from dehydrated granules contain 9.7 grams of vitamin C per 100 grams.[14]

Fresh potatoes with the skin are also a good source vitamin B6, providing 11% of the daily value, and contain trace amounts of several other essential vitamins per 148-gram serving: B1 (0.12 mg), B6 (0.2 mg), niacin (1.6 mg) and folate (24 mcg).[11]

MINERALS

Minerals make up about 1% of the potato and vary by variety, soil and growing conditions. The most abundant are potassium (1,400–2,500 mg), phosphorous (120–600 mg), chlorine (45–800 mg), sulfur (40–400 mg) and magnesium (45–220 mg) per 100 grams of tuber dry matter.[10] Potatoes also contain calcium (10–130 mg) and iron (2.5–72 mg) per 100 grams of tuber dry matter.[10]

Because potatoes are high in compounds that promote mineral bioavailability, such as vitamin C, organic acids, beta carotene and polypeptides, their mineral content is more bioavailable than that of other plant food sources.[15]

PHYTONUTRIENTS

Potatoes contain a variety of phytonutrients—most notably carotenoids and phenolic acids[2,16]—and are the largest contributor of vegetable phenolics to the American diet.[17]

Carotenoids, such as lutein, zeaxanthin and violaxanthin, are found mostly in yellow and red potatoes, though small amounts appear in white potatoes.[16] Total potato carotenoid content ranges widely from 35 µg to 795 µg per 100 grams fresh weight.[18]

Anthocyanins are phenolic compounds that impart colors ranging from red shades to blue and purple.[2] The potatoes that supply the most anthocyanins are, not surprisingly, the purple and red varieties.[2,16]

Chlorogenic acid, a polyphenol, constitutes up to 90% of the total phenolic content of potatoes.[2] And quercetin is a flavonoid found most prominently in red and russet potatoes and has demonstrated anti-inflammatory properties in animal studies and a limited number of human clinical trials.[19]

POTATO INGREDIENT FUNCTIONALITY

Potato ingredients display a wide range of functionalities, from low water absorption in the case of native starch to high water absorption in the case of dehydrated potato flakes, flour and granules. The high water-holding capacity of a dehydrated potato ingredient's starch contributes to these functionalities.

Why do dehydrated potato ingredients hold so much water? Because they've been precooked to about 160°F to 165°F to gelatinize their starch. At this point, the starch granules within the potato cells absorb water and swell in size, but not to the point of breaking the cell walls. Subsequent cooling retrogrades, or shrinks, the swollen starch granules, relaxing the tension on the potato cell walls and effectively toughening them so that they're less susceptible to rupture during cooking and drying. This cooling step is critical to producing potato flakes that can be reconstituted into mashed potatoes with the expected dry, mealy texture.

Another benefit of precooking potatoes for use in potato ingredients is that the process breaks down the potato's intercellular materials, facilitating the separation of the cells so that they can form a mash that processors can later dry. Heat processing also causes potato proteins to partially unfold and solubilize; this exposes water-binding sites that were unavailable in the native unheated protein. Soluble proteins are more functional, as they interact with ions, water and other compounds to form emulsions and provide other functionalities. Dehydrated potato products generally retain their protein.

A potato ingredient's water-absorption profile will vary significantly depending on base potato. Viscosity increases as particle size decreases. Increasing the cook time decreases viscosity slightly. Lower-solids potatoes have a high peak viscosity. With extended mixing, the viscosity decreases more rapidly. Precooking and cooling significantly decrease the peak viscosity. Continued mixing helps to retain absorption properties longer. Viscosity increases as ash, sodium, potassium and phosphorous concentration increase. Viscosity decreases as calcium concentration increases.

The potato starch granule is substantially larger than other starch granules. This, too, accounts for potato ingredients' water-holding capacity.

Potato variety, processing conditions and grind size (in the case of flour) also influence ingredient functionality.

DEHYDRATED POTATO SPECIFICATIONS AND TYPES

POTATO GRANULES

Potato granules are made from a spray-dried slurry of cooked potato. The granules comprise precooked individual potato cells, most of which are still surrounded by cellular material. The cells are relatively strong and don't readily break during reconstitution, which results in less starch damage. They're highly absorbent with low water-holding capacity and relatively low viscosity. They have less gelling capacity and hold water with little cohesion, similar to wet sand. Mixing granules with other ingredients can help absorb this water later.

STANDARD POTATO FLAKES

Standard potato flakes are precooked flaked layers of individual potato cells with some broken cellular material, which allows some starch to escape. The goal in standard flake production is to minimize cell damage, reduce the amount of free starch and produce a product that holds water to make mashed potatoes of a good consistency that isn't sticky. Because they're cooked, cooled and cooked again, their starch retrogrades, becoming less sticky. The cells remain more intact unless or until the resulting product is overmixed. Potato flakes have moderate water-holding capacity with moderate viscosity. The water-holding capacity increases if the flakes are ground. When used in snack production, standard flakes absorb and hold water lightly but do not contribute much to expansion.

LOW-PEEL/LOW-LEACH POTATO FLAKES

Low-peel/low-leach potato flakes (LP/LL) undergo similar processing as standard flakes but with strategic differences to enhance potato flavor. First, potatoes intended for LP/LL flakes spend less time under steam in the peeler and get less spraying or brushing afterward; this leaves more peel on the potato during drying, leaving more of the peel's strong potato flavor in the finished flake. LP/LL production also eliminates standard flaking's precooking and cooling steps to maintain flavor volatiles in the finished flake that would otherwise leach into the cooking water. LP/LL flakes have more cell damage and thus more free starch, hold water more aggressively and form a more sticky viscous material. Mixed with water and perhaps starches and flavorings, LP/LL flakes create a cohesive yet non-sticky dough ideal for use in fabricated potato snacks, where they generally give up water more slowly and contribute more to expansion.

POTATO FLOUR

Potato flour consists of precooked flaked layers of individual cells with a very high level of broken cells and released free starch. Potato flour has very high water-holding capacity and high viscosity, creating a stickier dough and the most expansion in snack production. Note that potato granules are not potato flour. Potato granules typically behave more like standard flakes.

DEHYDRATED POTATO SLICES, DICES AND SHREDS

Dehydrated potato slices, dices and shreds are convenient and versatile ingredients that deliver potato flavor and nutrition without the need to wash, peel, slice, dice or shred fresh potatoes. Once rehydrated, they cook up to the firm texture and identifiable potato flavor and appearance that consumers expect from fresh.

CHARACTERISTICS OF VARIOUS DEHYDRATED POTATO INGREDIENTS

Type	Free Starch	Viscosity	Water Absorption	Cell Damage
Standard Flakes	Moderate	Low-moderate	Low-moderate	Low-moderate
Standard Flakes – Ground	Moderate-high	Moderate-high	Moderate-high	Moderate-high
LP/LL Flakes	High	High	High	High
Flour – Granular and Fine	Very high	High	High	High-very high
Granules	Low	Low	Low	Low
Slices, Dices and Shreds	Varies	N/A	Varies	Very low

Table 3

POTATO INGREDIENT ADDITIVES AND WHY WE USE THEM

Processors use several additives in the production of dehydrated potato ingredients. The additives are blended with water and pumped into the mash, then distributed through the mix.

EMULSIFIERS

Emulsifiers—typically monoesters of oleic or stearic acid, or monoglycerides—serve as processing aids, easing the release of the dried potato sheet from the drum dryer and improving the texture of the rehydrated potato, reducing its stickiness.

SODIUM ACID PYROPHOSPHATE (SAPP)

SAPP helps preserve potatoes' white color by chelating metal ions in the potato, such as iron, that would otherwise oxidize and discolor the potato during processing and later reconstitution.

CITRIC ACID

Citric acid preserves potato color by tying up metallic ions and preventing their oxidative discoloration.

CALCIUM CHLORIDE

Calcium chloride is a preservative that helps the potato taste salty without adding excess sodium. It firms the potato, reduces sloughing and reduces the formation of acrylamide.

SULFITES

Sulfites are inorganic salts commonly used as preservatives. They increase the rate of dehydration, protect the potato from non-enzymatic browning, slow product deterioration during storage and delay spoilage.

FUNCTIONALITY OF POTATO INGREDIENTS IN SOME COMMON APPLICATIONS

BAKED GOODS

Potato ingredients bring considerable functionality to baked goods, thanks primarily to their ability to bind available water and impede moisture migration. Other benefits owe to the composition of the specific ingredient, including the sugars and micronutrients.

CRUMB SOFTENING, MOISTURE ENHANCEMENT, SHELF-LIFE EXTENSION, ANTI-STALING

The water-holding capacity of potato flour, flakes and granules can forestall staling and extend shelf life in baked goods. Precooked amylopectin may also crosslink with gluten to help retard starch crystallization and rotation, also reducing staling. It's important to note, however, that increasing the moisture content of baked goods can entail increasing the risk of mold growth in the bread or bakery product.

IMPROVED CRUST COLOR, IMPROVED TOASTING PROPERTIES

Baked goods made with potato ingredients develop a rich, even brown color during baking, primarily because of the reducing sugars and amino acids in the potato ingredients required for Maillard browning.

IMPROVED FERMENTATION

Potato ingredients also serve as a good fermentation starter for yeast. Because potatoes contain valuable minerals like potassium, magnesium and phosphorus—all of which stimulate yeast growth—they help activate a vigorous and complete sugar fermentation.[8] Less-volatile substances remain in the final loaf and contribute to flavor and aroma. Overall, the addition of potato flour to a dough provides a more complete fermentation and greater bloom and flavor intensity than occurs in a bread made without.

IDEAL POTATO PRODUCTS

- **Ground standard flakes: can be used across many baked good applications.**
- **LP/LL flakes: add texture, nutrition and flavor to cookies, biscuits, crackers, pizza dough.**
- **Granular or fine flour: softens biscuits, pancakes, breads, muffins.**

FUNCTIONAL ADVANTAGES

- **Reduced staling**
- **Crumb softening**
- **Shelf-life extender**
- **Color enhancer**
- **Yield improver**
- **Moistness enhancer**
- **Improved toasting properties**
- **Improved fermentation**

BREADINGS AND COATINGS

Potato ingredients work well in breading and coating systems thanks to potatoes' ability to bind available water and impede moisture migration. Other benefits owe to the composition of the individual potato ingredient, specifically sugars and micronutrients.

The water-holding capacity and cohesiveness of the pregelatinized starch found in many potato ingredients are advantageous in battering systems. Increased viscosity from potato flour may permit the use of fewer solids in a mix or help hold other materials in suspension. Potato flakes can make a crispy breading layer that adheres well.

Potato ingredients' increased moisture-absorbing capacity contributes to a breading system's ability to cling to the food being breaded, too.

These coating systems develop rich color during frying or baking primarily because potato ingredients contain the reducing sugars and amino acids that promote the Maillard reaction.

IDEAL POTATO PRODUCTS

- **Granules: breading and coatings with added texture and crunch.**
- **Granular and fine flour: breading to coat fried foods.**

FUNCTIONAL ADVANTAGES

- **Crispy texture**
- **Color enhancer**

FILLERS, BINDERS, THICKENERS

Potato ingredients are superior fillers, binders and thickeners in a range of applications. Why? Because they're excellent at absorbing moisture. As potato flour is precooked, its starch is gelatinized and solubilized. This allows it to absorb more water—and absorb it more quickly—than wheat flour, rice flour or cornstarch, all of which require cooking to thicken.[20,21] Further, the proteins in potato flour are mostly soluble because of their partial unfolding during processing, which exposes additional sites to bind yet more water. Finally, potato flour is lighter, which increases finished-application volume and improves texture.

As such, potato ingredients are frequent binders in both animal- and plant-based systems, where their water-holding capacity helps them cling to each base's respective proteins. Potato ingredients' ability to hold moisture also increases finished-product yield by extending the base ingredient—whether meat or vegetable—and decreasing drip loss during cooking. Best of all, potato ingredients' neutral flavor doesn't interfere with the flavor of the meat or plant product.

The use of potato ingredients as fillers, binders and thickeners in gluten-free applications can also be an advantage. Potato flour has a less gritty texture than some other gluten-free ingredients, such as rice flour.[22]

IDEAL POTATO PRODUCTS

- Flour: adds moisture and volume to meat products and non-meat alternatives.
- Granules: increases yield in animal- and plant-based systems.

FUNCTIONAL ADVANTAGES

- Binds meat proteins
- Binds moisture
- Extends meat
- Reduces drip loss

FROZEN MEALS AND PREPARED FOODS

As ingredients in frozen meals, reconstituted dehydrated potatoes—granules especially—tolerate and remain stable during the freeze-thaw cycling that occurs in frost-free freezers. Additionally, less moisture loss (or syneresis) takes place when foods made with dehydrated potatoes are frozen, thawed and reheated than in products made with fresh potato. In frozen mashed potatoes, the formulator can tailor their dehydrated ingredient choice to a specific finished-product solids content.

From an operational standpoint, dehydrated potatoes enjoy a longer shelf life, reduce storage space and reduce preparation time by eliminating the need for cleaning, peeling, precooking and more.

IDEAL POTATO PRODUCTS

- Granules: soups, frozen dinners.
- Dehydrated slices: frozen and boxed entrées.
- Dices and shreds: canned soups, stews.

FUNCTIONAL ADVANTAGES

- Uniform shape in soups
- Freeze-thaw stability
- Flexibility in achieving finished product characteristics

SHEETED AND EXTRUDED SNACKS

The advantage of using dehydrated potato ingredients in sheeted and extruded snacks lies in potatoes' ability to absorb moisture and lighten snack dough texture. By contrast, other flours can make a snack dough dense. The flavor of extruded snacks made with potato ingredients is neutral, offering formulators flexibility in finished-product profiles. Finally, because extruded snacks made with potato ingredients can obtain a very small pore structure, formulators can experiment with different expansion characteristics.

IDEAL POTATO PRODUCTS

- **LP/LL leach flakes**
- **Standard granules**

FUNCTIONAL ADVANTAGES

- **Neutral or potato flavor**
- **Light texture**
- **Uniform shape in chips**
- **Small pore structure**
- **Cohesive, easily handled dough**

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