# Technical Bulletin

## Ancient Grains:
### What's Old is New Again . . . Composition and Functionality

## Key Points

- Ancient grains fulfill the current trend for gluten-free, non-GMO ingredients.
- Some ancient grains are not grains but pseudo-cereals.
- Ancient grains differ in nutritional composition.
- Nutrient composition impacts starch gelatinization and water-holding capacity during processing.
- Water-holding capacity alters dough formation, viscosity, and final product characteristics.
- Understanding differences in nutrient composition and functionality is necessary when using ancient grains to replace traditional grains or other ancient grain sources.

The use of ancient grains in pet foods and treats continues to grow in popularity as more pet owners seek products that do not contain traditional grains, gluten, or genetically modified ingredients. Despite rising popularity, little information is available on the nutritional composition, processing properties, or animal utilization of most ancient grains. Awareness is needed within the pet industry to understand that differing nutritional composition of popular ingredients can significantly affect their functionality for extrusion and baking. These nutritional and functional differences must be recognized when manufacturers consider replacing traditional ingredients in pet foods and treats with on-trend ingredients like ancient grains.

## Taxonomic classification

A variety of ingredients are frequently referenced as ancient grains, but many of these ingredients are not grains at all. True cereal grains belong to the *Poaceae* (grass) family because their seeds store energy as starch. Examples of cereal-based ancient grains include barley, sorghum, millet, and oat groats. Another group of ancient grains are considered pseudo-cereals. None of these pseudo-cereals are classified in the *Poaecae* family. They look and function like cereal grains but some do not produce starch-containing seeds. Chia and flax are pseudo-cereals that produce oil-containing seeds whereas quinoa, buckwheat and amaranth are starch-containing pseudo-cereals.

Ancient grains provide a number of consumer-desired benefits when used in pet foods and treats. Most are not genetically modified because they have not been subjected to modern plant breeding and production practices, allowing them to retain characteristics of their wild ancestors. The most primitive ancient grains are sourced from Central and South America, Africa, and India. Common varieties of ancient grains are generally sourced from North America. Many ancient grains are also gluten-free which contributes to their growing popularity. All pseudo-cereals and some cereal grains are gluten-free. The gluten-free cereal grains include corn, rice, millet, and sorghum. Cereal grains that contain gluten include wheat, barley and oats.

> The differing nutritional composition of popular ancient grains can significantly affect extrusion and baking.

## Composition

The typical nutritional composition varies among the different ancient grains (Table 1). Grouping ingredients based on their typical composition illustrates their nutritional

## **Table 1.** Typical nutrient composition of select ancient grains expressed on DM basis

| Ancient Grains | | Cereal Grains | | | | Pseudo-cereals | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Barley (hulled) | White Milet (proso) | Oat Groats (hulled) | Sorghum (cracked) | Amaranth (hulled) | Buckwheat (whole) | Quinoa (hulled) | Chia Seed (whole) | Flaxseed (whole) |
| Proximate Analysis | Moisture, % | 11.9 | 10.0 | 10.5 | 12.4 | 11.2 | 12.4 | 10.7 | 6.3 | 6.2 |
| | Protein, % | 12.0 | 12.1 | 14.3 | 9.7 | 16.6 | 13.0 | 12.0 | 17.6 | 23.6 |
| | AH-Fat, % | 3.0 | 5.3 | 7.4 | 4.4 | 6.4 | 3.8 | 4.5 | 31.4 | 40.0 |
| | Ash, % | 1.5 | 3.8 | 2.3 | 1.4 | 2.7 | 1.9 | 1.9 | 5.1 | 3.7 |
| Energy | Gross energy, kcal/g | 4.4 | 4.6 | 4.6 | 4.5 | 4.7 | 4.6 | 4.6 | 6.4 | 6.9 |
| | Metabolizable, kcal/g | 3.5 | 3.5 | 3.7 | 3.6 | 3.5 | 3.0 | 3.6 | 3.7 | 4.7 |
| Fiber | Insoluble fiber, % | 6.5 | 10.4 | 6.9 | 8.9 | 12.6 | 23.5 | 7.5 | 35.0 | 16.6 |
| | Soluble fiber, % | 4.1 | 0.6 | 3.2 | 1.0 | 0.0 | 0.3 | 0.7 | 1.0 | 5.8 |
| | Total dietary fiber, % | 10.6 | 11.0 | 10.1 | 9.9 | 12.3 | 23.8 | 8.2 | 36.1 | 22.4 |
| Soluble Carbohydrates | Starch, % | 60.5 | 60.4 | 58.5 | 67.1 | 57.4 | 57.9 | 59.3 | <0.1% | <0.1% |
| | Amylose, % total starch | 15.0 | 16.0 | 30.3 | 26.5 | 9.6 | 26.6 | 15.2 | <0.1% | <0.1% |
| | Amylopectin, % total starch | 83.5 | 84.5 | 71.4 | 72.8 | 89.7 | 73.4 | 84.8 | <0.1% | <0.1% |
| | Oligosaccharides, % | 0.3 | 0.1 | 0.2 | 0.1 | 0.6 | 0.0 | 0.2 | 0.2 | 0.3 |
| | Disaccharides, % | 1.4 | 0.3 | 0.4 | 0.8 | 1.2 | 0.1 | 0.8 | 0.2 | 1.6 |
| | Monosaccharides, % | 1.7 | 3.2 | 2.4 | 2.5 | 5.6 | 2.2 | 5.4 | 1.3 | 1.2 |
| Free Sugars | Glucose, % | 1.2 | 2.8 | 1.8 | 2.1 | 5.2 | 1.8 | 4.9 | 0.7 | 1.1 |
| | Fructose, % | 0.5 | 0.4 | 0.6 | 0.4 | 0.5 | 0.4 | 0.4 | 0.5 | 0.2 |
| | Sucrose, % | 0.4 | 0.0 | 0.1 | 0.0 | 1.1 | 0.0 | 0.7 | 0.2 | 1.6 |
| | Lactose, % | 0.0 | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Maltose, % | 0.9 | 0.2 | 0.3 | 0.7 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| | Raffinose, % | 0.3 | 0.0 | 0.1 | 0.0 | 0.4 | 0.0 | 0.1 | 0.0 | 0.3 |
| Hydrolyzed Sugars | Ribose, % | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.0 | 0.5 | 0.0 | 0.0 |
| | Glucose, % | 10.6 | 8.5 | 7.2 | 5.8 | 5.4 | 3.9 | 6.0 | 0.2 | 0.8 |
| | Galactose, % | 0.8 | 0.5 | 0.8 | 1.0 | 1.0 | 1.3 | 1.0 | 1.1 | 0.8 |
| | Mannose, % | 1.7 | 1.3 | 1.2 | 2.2 | 1.3 | 0.0 | 1.6 | 0.8 | 1.2 |
| | Arabinose, % | 0.2 | 0.1 | 0.3 | 0.2 | 0.3 | 0.0 | 0.9 | 0.4 | 0.5 |
| | Xylose, % | 0.1 | 0.1 | 0.1 | 0.2 | 0.0 | 0.0 | 0.7 | 0.2 | 0.0 |
| | Stachyose, % | 0.0 | 0.0 | 0.1 | 0.1 | 0.2 | 0.0 | 0.1 | 0.1 | 0.0 |
| Minerals | Calcium, % | 0.1 | 0.0 | 0.1 | 2.2 | 0.2 | <0.1% | <0.1% | 0.7 | 0.2 |
| | Phosphorus, % | 0.4 | 0.3 | 0.5 | 46.6 | 0.5 | 0.3 | 0.4 | 0.9 | 0.7 |
| | Magnesium, % | 0.1 | 0.2 | 0.1 | 20.6 | 0.3 | 0.2 | 0.2 | 0.4 | 0.4 |
| | Potassium, % | 0.5 | 0.5 | 0.4 | 56.5 | 0.5 | 50.0 | 0.7 | 0.7 | 0.9 |
| | Copper, ppm | 8.8 | 15.0 | 6.7 | 8.0 | 3.0 | 5.0 | 4.0 | 9.0 | 18.8 |
| | Iron, ppm | 85.2 | 78.9 | 81.6 | 43.0 | 47.0 | 29.0 | 52.0 | 56.0 | 221.0 |
| | Manganese, ppm | 18.2 | 33.0 | 33.5 | 14.0 | 20.0 | 19.0 | 16.0 | 30.0 | 81.8 |
| | Selenium, ppm | 37.7 | 5.4 | 0.3 | 0.5 | 18.7 | 8.3 | 8.5 | 0.6 | 25.4 |
| | Zinc, ppm | 19.3 | 34.0 | 44.7 | 17.0 | 3.0 | 8.0 | 24.0 | 36.0 | 100.6 |
| Amino Acids | Arginine, % | 0.7 | 0.4 | 1.1 | 0.4 | 1.2 | 1.1 | 0.9 | 2.4 | 2.5 |
| | Histidine, % | 0.3 | 0.2 | 0.4 | 0.2 | 0.4 | 0.3 | 0.2 | 0.7 | 0.5 |
| | Isoleucine, % | 0.5 | 0.5 | 0.6 | 0.4 | 0.7 | 0.4 | 0.3 | 0.8 | 0.1 |
| | Leucine, % | 0.9 | 1.3 | 1.1 | 1.3 | 1.0 | 1.6 | 0.6 | 1.3 | 1.6 |
| | Lysine, % | 0.5 | 0.3 | 0.6 | 0.3 | 0.8 | 0.7 | 0.5 | 1.1 | 1.0 |
| | Methionine, % | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 | 0.2 | 0.2 | 0.6 | 0.5 |
| | Phenylalanine, % | 0.7 | 1.2 | 0.7 | 0.6 | 0.6 | 0.5 | 0.5 | 1.3 | 1.2 |
| | Threonine, % | 0.4 | 0.5 | 0.5 | 0.4 | 0.6 | 0.5 | 0.4 | 0.9 | 1.0 |
| | Tryptophan, % | 0.1 | 0.2 | 0.2 | 0.1 | 0.2 | 0.2 | 0.0 | 0.5 | 0.2 |
| | Valine, % | 0.7 | 0.7 | 0.8 | 0.5 | 0.8 | 0.6 | 0.6 | 1.2 | 1.2 |
| Fatty Acids | Linoleic acid 18:2, % | 0.9 | 2.0 | 2.7 | 1.3 | 2.7 | 1.0 | 3.0 | 5.8 | 5.6 |
| | Linolenic acid 18:3, % | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.3 | 17.6 | 23.6 |
| | Total Omega-6, % | 1.0 | 2.0 | 2.4 | 1.3 | 2.7 | 1.0 | 3.0 | 5.8 | 17.8 |
| | Total Omega-3, % | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.3 | 17.6 | 63.3 |

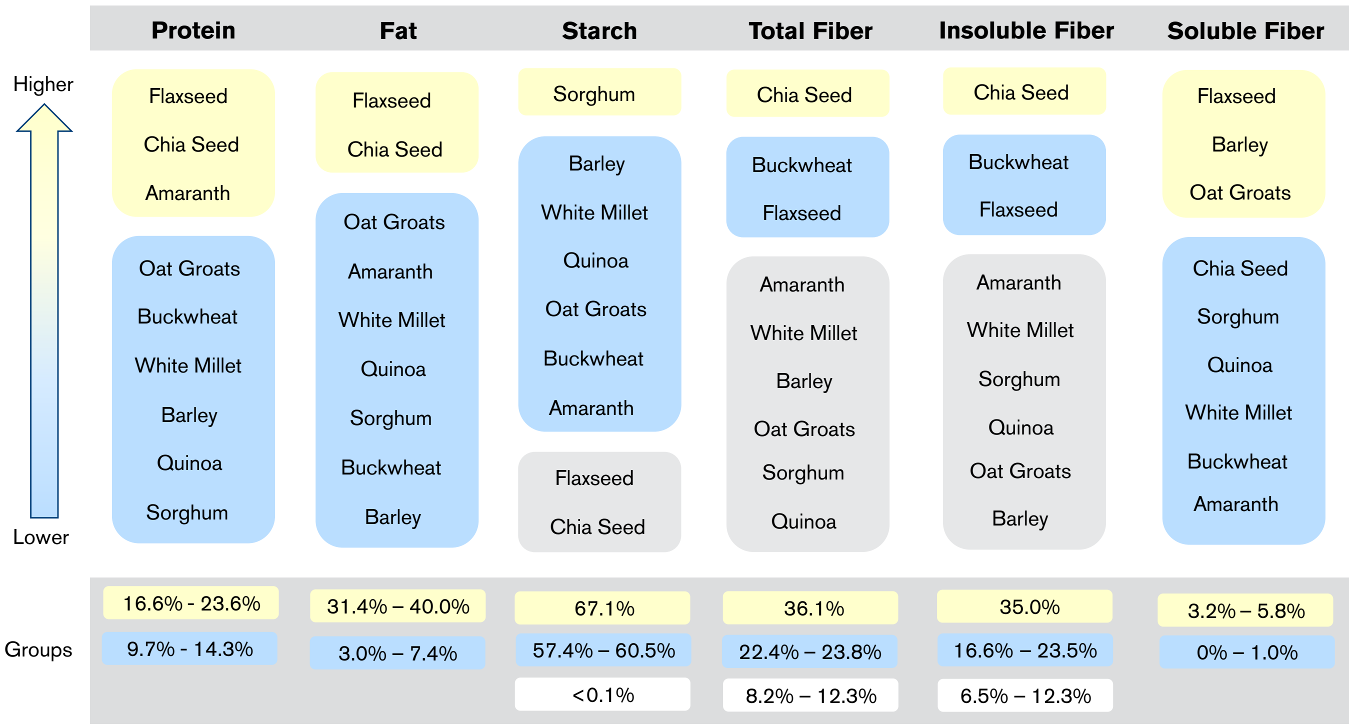



**Figure 1.** Subjective grouping of select ancient grains based on typical nutrient composition

similarities and differences (Figure 1). Chia and flaxseed are noticeably different in composition based on higher levels of protein (17.6, 23.6%), fat (31.4, 40.0%), total fiber (36.1, 22.4%), and insoluble fiber (35.0, 16.6%) and the absence of starch (<0.1, <0.1%), respectively. The remaining ancient grains are more similar in protein (9.7-16.6%), fat (3.0-7.4%), total starch (57.4-67.1%), total dietary fiber (8.2-12.3%), and insoluble fiber (6.5-12.3%). Buckwheat is different based on higher levels of total dietary fiber (23.8%) and insoluble fiber (23.5%). Levels of soluble fiber are highest in oat groats (3.2%) and barley (4.1%) while the other ingredients contain no more than 1% soluble fiber. For the starch-containing ingredients, total starch averages 60.2% with 20% as amylose and 80% as amylopectin. Oat groats have the highest amylose level (30.3%) with amaranth having the highest amylopectin level (71.4%).

Understanding differences in nutrient composition is useful to knowing which ancient grain to use in commercial applications.

Other starch-containing ingredients with more than 80% amylopectin include barley, white millet, and quinoa. In contrast, sorghum and buckwheat contain less than 80% amylopectin.

Comparing ancient grains with traditional grains shows amaranth, quinoa, sorghum, and white millet are similar in nutritional composition to corn and rice (Figure 2). The notable exception is their fiber content when compared with rice. These differences are attributed to the inherently low fiber content in rice. Ancient grains having a comparable nutrient profile as wheat include amaranth, barley, buckwheat, oat groats, quinoa, sorghum, and white millet.

**Practical applications:**

Understanding differences in nutrient composition is useful when using ancient grains to replace traditional grains or other ancient grain sources. For example, chia and flaxseed are best used in formulations requiring higher levels of protein and fat. In contrast, buckwheat, barley, and oat groats may be more appropriate in applications requiring less fat and more fiber such as weight management, senior, and digestive health formulas.

Greater formulation flexibility is provided by white millet, sorghum, amaranth, and quinoa. Their similarities in nutrient composition allow them to be used interchangeably with minimal changes to the nutritional profile of finished products. In contrast, more comprehensive reformulations are warranted when barley, buckwheat, chia, flaxseed, or oat groats are used as replacements for corn or rice. Similarly, chia or flaxseed cannot replace wheat on a simple 1:1 basis without a substantial product reformulation due to differing nutrient profiles.

## Functionality

Carbohydrates are important food components because they supply dogs and cats with glucose for specific functions and energy to meet whole-body needs. Glucose and energy are derived from the digestible starch component of carbohydrates. This starch is stored in granules as linear and branched polymers of glucose called amylose and amylopectin, respectively. Dietary starch also contributes important functionality to the ingredient matrix during processing and production of foods and treats. It also helps to maintain the structural integrity of final products.
Starch functionality is characterized by measuring water-holding capacity and viscosity. These characteristics are critical to dough formation when carbohydrates are processed by extrusion or baking. The introduction of water and heat causes starch to gelatinize and form dough. During gelatinization, heat-induced disruption of hydrogen bonds allows water to enter the starch granule causing it to swell until it physically ruptures.

### Water-holding capacity:

The amount of amylose and amylopectin within a starch granule determines its ability and capacity to absorb and retain water. Amylose is free-floating within the starch granule and provides strong film-forming and gelling functions during dough formation due to its linear structure. In contrast, amylopectin is a structural component of the starch granule that provides greater water binding capacity due to its branched structure. Amylopectin creates more viscous dough than amylose due to higher water binding capacity and reduced gelling properties.

Water-holding capacity of starch-containing ancient grains ranges from 10% (oat groats) to 22% (quinoa) when samples are ground (Table 2). The percentage of amylose in these ancient grains is inversely related to their water-holding capacity (Figure 3). Conversely, water-holding capacity is positively correlated with amylopectin content. Water-holding capacity is highest for flaxseed (28%) and chia (80%) despite being devoid of starch. These observations demonstrate the influence of fiber, protein, fat, and other components on water-holding capacity, starch gelatinization, and dough formation. Fiber and protein are likely responsible for the higher water-holding capacity of chia and flaxseed.

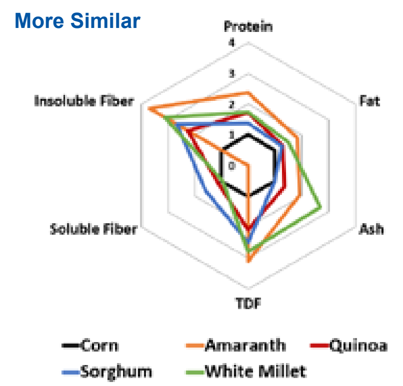
**Table 2.** Functional characteristics of select grain flours and cookies from standard baking test

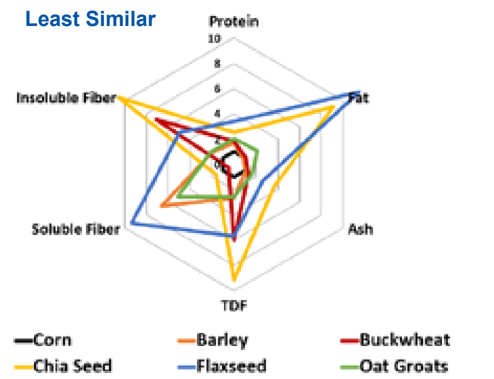
| Grain flour | Water-Holding Capacity (%) | Pasting Temperature (°C) | Peak Viscosity (cP) | Final Viscosity (cP) | Cookie Diameter | Cookie Stack Height | Cookie Spread Ratio |
|---|---|---|---|---|---|---|---|
| Wheat | 7.2 | 50.0 | 4,900 | 4,116 | 7.4 | 3.5 | 2.1 |
| Buckwheat | 20.1 | 76.8 | 3,630 | 8,615 | 6.5 | 5 | 1.3 |
| Amaranth | 16.6 | 94.8 | 1,744 | 2,066 | 6.1 | 5.9 | 1.0 |
| Sorghum | 12.4 | 87.5 | 1,120 | 2,511 | 6.0 | 5.7 | 1.1 |
| Chickpea | 18.0 | 78.2 | 55 | 89 | 5.0 | 7.6 | 0.7 |
| Quinoa | 21.9 | 92.0 | 4,338 | 7,060 | 4.9 | 8.6 | 0.6 |
| Chia | 80.5 | 50.0 | 2,815 | 760 | 9.4 | 2.1 | 4.5 |
| Barley | 17.4 | 92.2 | 1,582 | 3,960 | n/a | n/a | n/a |
| White millet | 13.8 | 82.7 | 1,159 | 2,120 | n/a | n/a | n/a |
| Oat groats | 9.9 | 92.0 | 2,671 | 3,343 | n/a | n/a | n/a |
| Flaxseed | 28.0 | 50.9 | 165 | 442 | n/a | n/a | n/a |

**Figure 2.** Subjective grouping of select ancient grains based on similarities and differences of typical nutrient content relative to corn (A), rice (B) and wheat (C)

**A**

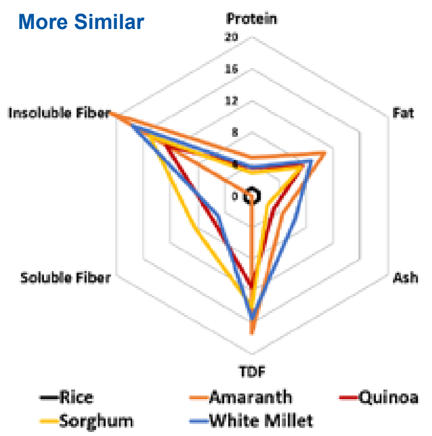
| Nutrient (%DMB) | Protein | Fat | Ash | Total Fiber | Insoluble Fiber | Soluble Fiber |
|---|---|---|---|---|---|---|
| Corn | 7.0 | 3.5 | 1.4 | 3.9 | 3.3 | 0.6 |

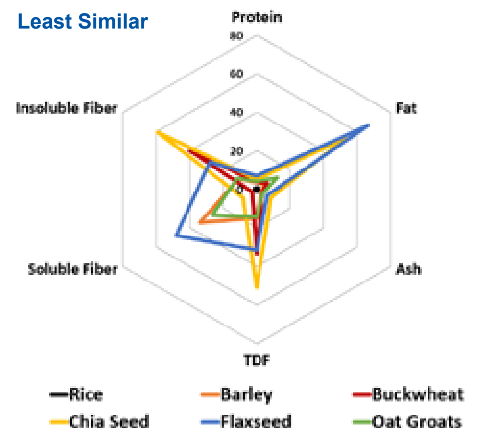



**B**

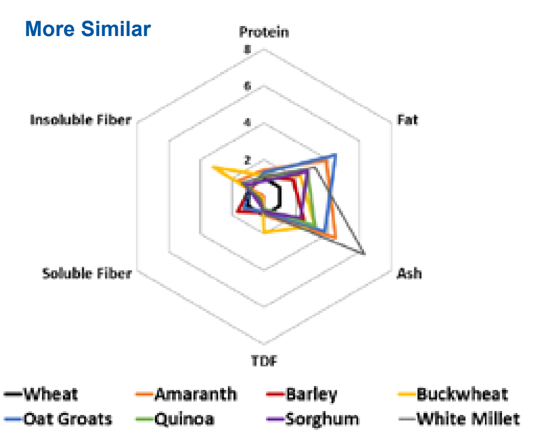
| Nutrient (%DMB) | Protein | Fat | Ash | Total Fiber | Insoluble Fiber | Soluble Fiber |
|---|---|---|---|---|---|---|
| Rice | 3.4 | 5.9 | 0.6 | 0.7 | 0.6 | 0.1 |




**C**

| Nutrient (%DMB) | Protein | Fat | Ash | Total Fiber | Insoluble Fiber | Soluble Fiber |
|---|---|---|---|---|---|---|
| Wheat | 11.4 | 1.7 | 0.6 | 12.2 | 7.4 | 2.5 |



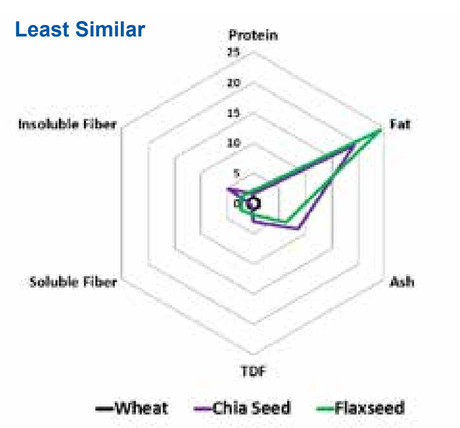



**Figure 3.** Functional water-holding capacity of select ancient grains relative to typical nutrient content


Similarly, the higher fiber content of buckwheat may explain greater water-holding capacity compared with oats groats and sorghum considering they all contain similar levels and types of starch.

### Viscosity:

Pasting or dough thickening is the physical response of starch to moisture, heat, and gelatinization. It is reflected in viscosity changes measured by Rapid Viscosity Analysis (RVA) under standardized conditions of moisture, time, and temperature. This method records the temperature of the initial change in viscosity as the starch granule begins to swell in the presence of water and increasing heat. It represents the pasting, gelatinization, or cook temperature. Peak viscosity is recorded at maximal swelling of starch granules when they physically rupture dispersing amylose and amylopectin. Final viscosity is recorded after the dough cools and starch molecules re-align through a process of retrogradation or set-back.

Viscosity results show wheat flour, chia, and flaxseed are more sensitive to heat based on lower pasting temperature (≤50°C) than other grain sources. Amaranth, quinoa, barley, and oat groats are least-sensitive based on pasting temperatures ≥90°C. Heat-sensitivity of buckwheat, sorghum, pre-cooked chickpea, and white-millet is intermediate based on pasting temperatures between 76.8 and 87.5°C. There is no obvious correlation between pasting temperature and peak viscosity for these ingredients. Peak viscosity is highest for wheat flour, buckwheat, and quinoa (≥3,630 cP) and lowest for pre-cooked chickpea and flaxseed (≤165 cP). Peak viscosity for all other ancient grains ranges from 1,120 to 2,815 cP. Upon cooling, final viscosity was markedly higher for buckwheat and quinoa (≥7,060 cP) compared with pre-cooked chickpea, chia, and flaxseed (≤760 cP). For all other ingredients, final viscosity ranges between 2,066 and 4,116 cP but with two distinct groupings. Wheat, barley, and oat groats range from 3,343 to 4,116 cP while amaranth, sorghum, and white millet range from 2,066 to 2,511 cP.

**Baking test:**

The impact of flour source on dough formation and the resulting physical characteristics of finished products can be assessed using a standardized cookie baking test. In this test, flour source is the only variable ingredient in a standard cookie recipe. Indices of dough spread and rise are based on measurements of individual cookie diameter and height of four stacked cookies, respectively. These characteristics reflect ingredient transformations occurring during the baking process. As dough temperature rises, water within the dough is converted to steam and trapped by the dough matrix. Trapped water increases internal cookie pressure causing dough expansion. This expansion is impacted by the water-holding capacity and viscosity of the starch during baking. Higher viscosity produces more rise and less spread while lower viscosity causes greater spread and less rise.

**Figure 4.** Cookies from the standardized baking test.


Flours evaluated using the cookie bake test included sorghum, chia, amaranth, quinoa, buckwheat, pastry wheat, and pre-cooked chickpea (Figure 4). Using pastry wheat flour as a control, cookies baked with this flour were 7.4 cm in diameter and 3.5 cm in stack height. With the exception of chia, cookies made with ancient grain flours exhibited less spread and more rise than pastry wheat flour. The inverse relationship between dough spread and rise was noted for these ancient grain flours. Quinoa had the smallest diameter (4.9 cm) and greatest stack height (8.6 cm) while chia had the largest diameter (9.4 cm) and lowest stack height (2.1 cm). These extreme response of chia can be attributed to its high fiber content and absence of starch, resulting in extremely high water-holding capacity and low viscosity. These unique characteristics result in cookies that fail to rise but spread maximally during baking.

The impact of flour source on dough formation is also expressed in the calculated spread ratio (diameter/height) for chia (4.5) and quinoa (0.6). Excluding chia, the spread ratio of pastry wheat flour (2.1) was greater than other flours. If pastry wheat flour represents an ideal flour source when baking cookies, then dough spread should be twice the height of dough rise to produce ideal cookies using ancient grain flours. Spread ratios for buckwheat (1.3), sorghum (1.1), and amaranth (1.0) show these flours provide more spread than rise, but not to the extent of wheat flour. In contrast, the spread ratios for pre-cooked chickpeas (0.7) and quinoa (0.6) show these flours contribute more rise than spread during processing. These relationships demonstrate the differential effects of ingredients and their nutrients on the trapping of air and moisture by cookie dough during the baking process. Importantly, these results demonstrate how formulation and selection of ingredients can significantly influence the baking properties and appearance of foods.

**Practical applications:**
Ancient grains can supply substantial formulation flexibility when designing products to meet consumer expectations. However, manufacturers must consider the impact of these changes on cook and dough expansion during processing. Reduced dough expansion is likely with flax whereas other ancient grains will likely cause more dough expansion compared with traditional grains like wheat. Quinoa and pre-cooked chickpeas are appropriate for applications requiring more dough expansion. Chia, buckwheat, and amaranth can be used in applications needing more spread and less rise. Opportunities also exist to combine ancient grain flours of varying characteristics to deliver optimal dough and product formation. These combinations require additional evaluations to determine their impact on the physical characteristics of baked and extruded products. The possibility also exists to leverage these data to predict the processing response of other ancient grains based on their individual nutritional profile.

## Summary

Dogs and cats have a dietary requirement for nutrients and not ingredients. Similarly, there is no specific dietary requirement for carbohydrates. Nevertheless, carbohydrates are important food components because their starch component supplies required glucose and energy for the body. Carbohydrates are also important in manufacturing pet foods and treats because starch provides processing functionality and structural integrity of the final product.

It is important to understand differences in the nutrient composition and functional properties of carbohydrate sources for use in pet foods and treats. Historically, extruded dog and cat foods relied primarily on corn, wheat, and rice as carbohydrate sources along with the occasional use of barley, sorghum, millet, or oats. Many pet owners are now avoiding these traditional ingredients by feeding grain-free foods. These foods are not carbohydrate-free due to the use of alternative starch-containing ingredients such as potato, peas, beans, lentils, and tapioca. Today, there is a growing trend by pet owners to avoid genetically modified ingredients in foods and treats. Manufacturers are responding to this consumer need by offering foods and treats with more primitive and novel ingredients like ancient grains. Ancient grains have existed for centuries, but this research demonstrates there is still new knowledge and experiences to be gained as more ancient grains are used in foods and treats for today's dogs and cats. ■