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Research Paper

# Total and resistant starch from foodstuff for animal and human consumption in Costa Rica

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ABSTRACT

Starchy ingredients are a key source of carbohydrates and have an essential role in a healthy diet. Starch amount in foodstuffs is paramount as it allows diet professionals to base their formulations on scientific data. Herein, the total (TS) and resistant starch (RS) content, in a selection of typical starchy foods available on the Costa Rican market, for both human and animal consumption, is reported. The major types of starch, including physically encapsulated starch, were determined using *in vitro* methods AOAC OMA$^{SM}$ methods 996.11, 2014.10, 996.11, 2002.02 and AACC 76–13.01 and 32–40.01. Samples were collected during 5 years as part of national surveillance plans. For feedstuffs, $n = 252$ feed ingredients (e.g., cornmeal and wheat products), $n = 103$ feeds (e.g., dairy and beef cattle), and $n = 150$ feed ingredient samples (selected based on their usage in feed formulations) were assessed for RS. In food commodities, sample numbers ascended to $n = 287$ and $n = 371$ for TS and RS, respectively (e.g. bananas). Feed ingredients with higher TS values were cassava meal, bakery by-products, rice/broken, sweet potato, and cornmeal (93.37, 81.67, 72.33, 66.66, and 61.43 g/100 g, respectively). TS for beef and dairy cattle, pig, and calf feeds, ranged from 30.26 to 34.46 g/100 g. Plantain/green banana flour, as a feed ingredient, exhibited RS absolute and relative contributions of 37.04 g/100 g and 53.89%, respectively. Products with a higher TS content included banana flour, green plantain flour, japonica rice, and cassava flour (62.87, 63.10, 72.90, 83.37 g/100 g). The primary RS sources in the Costa Rican diet are, in absolute terms, green plantain and malanga (50.41 and 56.59 g/100 g). Depending on a person's food habits, these sources may contribute in the range of 20–30 grams of RS per day. TS and RS intake may vary considerably among ingredients, and the contribution of RS may be of nutritional importance for specific individuals.

## 1. Introduction

Starch is one of the most significant sources of energy in diets (Slavin and Carlsson, 2014). It is enzymatically hydrolyzed in the animal and human small intestine (McCleary et al., 2019; Slavin and Carlsson, 2014). As such, it is an essential nutrient that is monitored in feed and foodstuff. Starch is contained in many staple foods such as cereals, legumes, root vegetables, and fruits (Slavin and Lloyd, 2012). Starch consists in two structural components a 1,4-α-linked D-glucan and few 1,6-α-linked branch points polymer (i.e., amylose); and highly branched structure with a high proportion of 1,6-α-linked 1,4-α-D-glucan chains (i.e., amylopectin) (Sajilata et al., 2006).

Although in animal feed there is the possibility of using a wide range of raw materials in the formulation, only a few main starch suorces are selected as the feed's backbone. In Costa Rica, there is a dependence on corn and soybeans, as main ingredients in balanced feed for livestock, pigs and poultry (60% of inclusion) (Leiva and Granados-Chinchilla, 2020). However, the use of other raw materials with greater access (banana, cassava, sweet potato, among others) that generate good productive yields has been investigated (Montoya-López et al., 2014). Even so, both traditional and non-traditional raw materials may represent feasible TS and RS sources. It is of particular interest, that the RS fraction would provide several benefits for animal health, such as improving intestinal function, increasing the absorption of Ca and Fe, as well as lengthening the duration of satiety (Regassa and Nyachoti, 2018).

In terms of animal health, starch has been related to growth performance and meat quality in finishing pigs and broiler chickens (Khoddami et al., 2018; Wang et al., 2019), milk production in dairy cows (Sucak et al., 2017), and the modification of gastrointestinal microbial community in horses (Harlow et al., 2016) to name a few.

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Starch comprises a significant portion of many foods and feeds; hence, measuring starch in feedstuff is paramount to a nutritionist during diet formulation. So much so, that, several papers have reviewed the relevance and the peculiarities among the available methods for in animal feeds and feedstuffs (Hall et al., 2000; Hall 2015; McCleary et al., 2019).

On the other hand, several factors affect starch digestibility, including granule size, amylose/amylopectin ratio, the proportion of farinaceous and vitreous endosperm, presence of starch-lipid and starch-protein complexes, and the physical-chemical processing of the foodstuffs (Gómez et al., 2016).

RS is a low-calorie functional food component (Fuentes-Zaragoza et al., 2010). It resists hydrolysis by enzymatic digestion in the small intestine but it undergoes complete or partial fermentation in the colon and generates short-chain fatty acids (Topping and Clifton, 2001), and possesses prebiotic potential as it stimulates healthy gut microflora (Zaman and Sarbini, 2016).

RS has potential impacts on the prevention or therapy of certain metabolic diseases (Birt et al., 2013). Despite the possible benefits of RS, it is estimated that consumption levels are, on average, much lower than the recommended intake values (i.e., 20 g day$^{-1}$) (Lockyer and Nugent, 2017).

Four different subtypes of RS are accounted for (i.e., RS1-RS4, Fuentes-Zaragoza et al., 2010). In the case of this research, the first three will be mostly encountered. Starch fractions found in feed ingredients and most food commodities are type 1 (e.g., whole and partly milled grains and seed, legumes), type 2 (e.g., raw potatoes and high amylose starches) and type 3 (formed when certain starchy foods, including potatoes and rice, are cooked and then cooled), these will be found mostly in food commodities (Fuentes-Zaragoza et al., 2010; Regassa and Nyachoti, 2018), except for the case of green bananas and some legumes, that are occasionally used as a feed ingredient.

Herein, a five-year historical account of TS and RS content of food and feedstuff (ingredients and compound feeds) samples available in Costa Rica were investigated. This research is expected to serve as a repository of collected data for future reference during routine food/feed quality analysis and as a guideline for new researchers in the field of starch analysis in the food and feed industry. Additionally, this research is expected to represent a resource in the selection of RS-rich foodstuffs, and to provide information for the scientific community of starch values for raw ingredients and crops such as ours.

## 2. Materials and methods

### 2.1. Feedstuffs: sampling

Animal feedstuffs were collected according to the procedure described in the Association of American Feed Control Officials (AAFCO, 2014). Sampling was performed from 2015 to 2018 for a total of $n = 252$ feed ingredients (responding to cornmeal [26.2%], wheat shorts [15.5%], wheat middlings [9.1%], banana [8.7%], cassava meal [7.5%], sorghum [6.3%], rice/broken [6.3%], corn dried distillers grains [6.0%], bakery by-products [3.6%], forage [3.2%], soy protein concentrate [2.0%], sweet potato [2.0%], wheat/durum [1.6%], total mixed ration [0.8%], pelletized pineapple crown [0.4%], wheat distillers grains [0.4%], and garlic meal [0.4%]) and $n = 103$ feeds (beef and dairy cattle [36.9 and 29.1%, respectively], pig [27.2%], horse [1.9%], calf [1.9%], and heifer feed [1.9%], and cat food [1.0%]).

Additionally, $n = 150$ (i.e., 15 for each matrix) feed ingredient samples were assessed for RS, i.e., corn, bakery by/products, banana meal/slightly ripe, plantain/green banana meal, rice/broken, sorghum, sweet potato, wheat middlings, wheat shorts, and wheat/durum.

### 2.2. Feedstuffs: starch analyses

All samples were quartered and sieved at 1 mm particle size using an ultracentrifuge mill (Retsch, ZM200, Haan, Germany). Fresh material was oven-dried at 55 °C according to NFTA Forage Analyses method 2.2.1.1. All starch analyses were performed according to the method previously described (Salazar-Murillo and Granados-Chinchilla, 2018) based on AOAC OMA$^{SM}$ methods 996.11 and 2014.10. The former process involves a step of dispersion and solubilization of unavailable amylose using dimethyl sulfoxide (Radosta et al., 2001).

### 2.3. Feedstuffs: mixed rations

Several mixtures between forage and starch sources were prepared, and TS assessed. These physical mixtures from shrubs forage and some legumes were evaluated as they may have a great potential to improve ruminant production systems, especially in subhumid areas in the tropics (Vandermeulen et al., 2017). Inclusion percentages varied from 0 to 45 g starch source per 100 g mixture.

### 2.4. Food commodities: sampling

Samples were obtained from 2013 to 2019 as part of a food quality assessment program. As not all samples were tested for both TS and RS, sample numbers differ. TS and RS samples ascend to $n = 287$ and $n = 371$, respectively. Food collection, for TS, resulted as it follows: banana [21.6%], banana puree [1.6%], cornflour [6.6%], malanga flour [5.9%], rice [5.2%], sweet potato flour [3.8%], green plantain [3.8%], dairy solid preparations [3.5%], quinoa [3.5%], green banana [2.8%], bread crumbs, banana chips, and purple corn [2.4%, each], corn germ flour and dried palm roots [2.1%, each], mucilage, banana flour, and pineapple stems [1.7%, each], purple corn products [1.4%], japonica rice, cassava flour, coffee leaves, and white bread, potatoes [1.0%, each], pinolillo and tapioca [0.7%, each], nontraditional starches and flours [0.3%, each].

On another hand, for RS the sample distribution was presented as follows: banana [14.3%], malanga flour [8.4%], green plantain [7.3%], banana puree [5.9%], corn flour [5.7%], potato starch, rice, musaceae [4.0%], corn starch [3.5%], purple corn [2.7%], green banana, malanga root, cassava flour, square banana flour [2.2%, each], green plantain and banana chips [1.9%, each], corn germ flour and dried palm roots [1.6%], pineapple stems [1.3%], mucilage [1.1%], pinolillo, white bread, sweet potato flour, coffee leaves [0.8%], nixtamalized corn flour [0.5%], nontraditional starches and flours [0.5%, each].

### 2.5. Food commodities: starch analysis

Fresh materials were freeze-dried (Freezone 2.5 L Plus System, LABCONCO™, Kansas City, MO, USA), the particle size was reduced using a knife mill (Grindomix GM200, Retsch) and sieved to a particle size of 1 mm. For grains and seeds, particle size was dwindled using a cyclone mill (TWISTER, Retsch). Both TS and RS were measured using the Megazyme starch assay kit based on AOAC OMA$^{SM}$ methods 996.11 and 2002.02 and AACC International methods 76–13.01 and 32–40.01, respectively.

### 2.6. Statistical analysis

Mann-Whitney *U* tests were applied to medians to assess differences among matrices in starch values. In all cases, results were considered significantly using an $\alpha$ threshold of 0.05; statistical analysis performed using SPSS® Statistics 23 (IBM, Armonk New York, USA).

## 3. Results

### 3.1. Starch in feedstuff

In general, the TS values varied from 0.26 to 93.37 g/100 g, for protein concentrate and cassava meal, respectively (Table 1). From the collection of feed ingredients tested; cassava meal, bakery by-products,

**Table 1**
Total Starch determined in Feedstuffs, Raw Ingredients, and Compound Feed from Costa Rica.

| Concentration g/100 g | | | |
|---|---|---|---|
| Mean ± SD | Median | Max | Min |
| *Feed Ingredients* | | | |
| Corn Meal ($n = 66$) | | | |
| 66.66 ± 5.01 | 66.76 | 77.42 | 54.24 |
| Wheat Shorts ($n = 39$) | | | |
| 32.42 ± 8.12 | 29.66 | 52.48 | 22.96 |
| Wheat Middlings ($n = 23$) | | | |
| 26.55 ± 3.47 | 26.29 | 34.19 | 19.39 |
| Banana (*Musa* spp. in dry weight basis, $n = 22$) | | | |
| 41.73 ± 21.84 | 27.30 | 80.17 | 20.19 |
| Cassava Meal ($n = 19$) | | | |
| 93.37 ± 4.62 | 92.55 | 104.92 | 78.02 |
| Rice, Broken ($n = 16$) | | | |
| 72.33 ± 21.48 | 77.10 | 99.39 | 32.92 |
| Sorghum ($n = 16$) | | | |
| 40.84 ± 11.11 | 36.18 | 65.34 | 31.23 |
| Corn Dried Distillers Grains ($n = 15$) | | | |
| 4.58 ± 0.66 | 4.51 | 6.05 | 3.38 |
| Bakery By-products ($n = 9$) | | | |
| 81.67 ± 24.36 | 91.43 | 116.23 | 41.23 |
| Forage (corn for silage in dry weight basis, $n = 8$) | | | |
| 0.52 ± 0.15 | 0.48 | 0.73 | 0.30 |
| Sweet Potato ($n = 5$) | | | |
| 61.43 ± 15.48 | 51.99 | 82.45 | 44.57 |
| Wheat, Durum ($n = 4$) | | | |
| 45.24 ± 11.53 | 47.17 | 57.51 | 29.12 |
| Total Mixed Ration (in dry weight basis, $n = 2$) | | | |
| 20.18 ± 0.33 | 20.18 | 20.52 | 19.85 |
| Soy Protein Concentrate ($n = 5$) | | | |
| 0.28 ± 0.03 | 0.2 | 0.33 | 0.250.25 |
| Feed Ingredients with Only One Hit | | | |
| Matrix | | | Concentration g/100 g |
| Garlic Meal | | | 31.35 ± 1.55 |
| Wheat Distillers' Grains | | | 2.13 ± 0.11 |
| Pelletized Pineapple Crown | | | 2.06 ± 0.10 |
| *Compound Feed* | | | |
| Beef Cattle Feed ($n = 38$) | | | |
| 32.38 ± 6.70 | 31.35 | 51.89 | 22.25 |
| Dairy Cattle Feed ($n = 30$) | | | |
| 30.26 ± 6.52 | 27.28 | 46.38 | 21.71 |
| Pig Feed ($n = 28$) | | | |
| 33.94 ± 6.57 | 33.42 | 56.87 | 22.92 |
| Horse Feed ($n = 2$) | | | |
| 39.31 ± 4.04 | 39.31 | 43.35 | 35.27 |
| Calf Feed ($n = 2$) | | | |
| 34.46 ± 2.37 | 34.46 | 36.83 | 32.09 |
| Heifer Feed ($n = 2$) | | | |
| 41.56 ± 4.15 | 41.56 | 45.72 | 37.41 |
| Compound Feed with Only One Hit | | | |
| Matrix | | | Concentration g/100 g |
| Cat Food | | | 29.03 ± 0.87 |

rice/broken, sweet potato, and cornmeal were among the most tested TS-rich matrices (mean values of 93.37, 81.67, 72.33, 66.66, and 61.43 g/100 g, respectively, Table 1). On the low end of TS content, dried distillers, corn grains, forage, and soy protein concentrate are found (mean values of 4.58, 0.52, and 0.28 g/100 g, Table 1). In wheat products (i.e., durum, shorts, and middlings) it means TS values vary from 26.55 to 45.24 g/100 g, Table 1. Also, these were among the most tested matrices for TS ($n = 66/252$, 26.2% of the total of samples collected). From all tested samples, the banana TS values varied the most being the minimum and maximum values range from 20.19 to 80.17 g/100 g (Table 1). Finally, banana meal and sorghum (41.73 and 40.84, respectively) exhibited mean values of TS statistically similar to wheat/durum (45.24 g/100 g, $p < 0.05$, Table 1). In terms of TS input, garlic meal can be somewhat compared to wheat shorts with mean values of 31.55 and 32.42 g/100 g, respectively (Table 1). Finally, in relative terms, neither pelletized pineapple crowns nor wheat distiller's grains seem to be a relevant source of starch (2.06 and 2.13 g/100 g, Table 1).

In the case of compound feed, TS values ranged from 29.03 to 41.56 g/100 g for cat food and heifer feed, respectively (Table 1). Mean TS values for horse and heifer feeds (ranging from 39.41 to 41.56 g/100 g) are significantly higher ($p < 0.05$) than beef and dairy cattle, pig, and calf feeds (ranging from 30.26 to 34.46 g/100 g) (Table 1).

Regarding starch sources and forages mixtures, as expected, the cassava meal constitutes a rich source of starch (mean values of 93.37, Table 1), it also needs lower inclusion rates to a forage (a naturally poor starch source) to reach similar amounts of starch (i.e., just 15 g/100 g inclusion to attain 14.82 g TS/100 g mixture, Table 2). Moreover, it is evident that a forage legume such as *C. argentea* can input almost tenfold the amount of starch than *E. poeppigiana* (3.99 versus 0.31 g/100 g, Table 2), another Fabaceae.

Feed ingredients tested vary prominently in terms of RS input. Overall, mean values ranged from 1.21 to 37.04 g/100 g (i.e., from sorghum to plantain/green banana flour, respectively, Table 3). Once more, the same pair of matrixes unveil extreme values concerning the RS/TS ratio 2.62 and 53.89%, respectively (Table 3). Wheat middlings and broken rice conveyed relatively elevated starch ratios (8.46 and 9.19, respectively), making them a relatively good source for feed RS (Table 3). A promising candidate for TS input was observed in sweet potato (i.e., mean values of 51.24, Tables 1 and 3). However, it showed to be a lesser promising candidate as RS mean values amounted to 1.94 (representing a mere 3.79% of the TS, Table 3). Wheat products varied between 1.91 and 3.15 g/100 g of RS (representing 5.35–8.46%, expressed in terms of the TS); in increasing order, shorts, middlings, and durum.

### 3.2. Starch in food commodities

Overall, the matrixes with more starch are in ascending order. This order corresponds to corn germ flour, cornflour, quinoa, sweet potato flour, purple corn, bread crumbs, malanga flour, banana flour, green plantain flour, japonica rice and cassava flour with mean values of 50.09, 50.57, 54.14, 54.93, 60.15, 62.27, 62.87, 63.10, 72.90, 83.37 g/100 g (Table 4).

Particular interest is given to banana starch as it accounts for 62.1% of the samples ($n = 101/287$, accounting fresh fruit and puree) for TS

**Table 2**
Total Starch Content in Forage and Starch Source Mixtures.

| Concentration g/100 g | | | | |
|---|---|---|---|---|
| Starch Source Inclusion | Mean ± SD | Median | Max | Min |
| Cassava Meal and Forage (*Cenchrus Purpureus* (Schumach.) Morrone) | | | | |
| 0 | Not detectable (<0.25 g/100 g) | | | |
| 6 | 7.43 ± 0.62 | 7.59 | 8.17 | 6.43 |
| 8 | 8.33 ± 0.66 | 8.38 | 9.60 | 7.24 |
| 10 | 8.66 ± 0.94 | 8.53 | 10.25 | 7.50 |
| 15 | 14.82 ± 9.25 | 9.82 | 32.24 | 8.18 |
| Banana (*Musa Acuminata x Balbisiana*, Group ABB) Meal and Forage (*Erythrina Poeppigiana* (Walp.) O.F. Cook) | | | | |
| 0 | 0.31 ± 0.12 | 0.25 | 0.52 | 0.24 |
| 15 | 2.5 ± 1.03 | 2.05 | 4.22 | 1.67 |
| 30 | 4.18 ± 1.88 | 3.43 | 7.34 | 2.53 |
| 45 | 12.23 ± 1.04 | 12.18 | 13.45 | 11.12 |
| Banana Meal and Forage (*Cratylia Argentea* (Desv.) Kuntze) | | | | |
| 0 | 3.99 ± 0.28 | 4.10 | 4.24 | 3.51 |
| 15 | 6.18 ± 1.56 | 5.50 | 8.84 | 4.89 |
| 30 | 6.94 ± 2.97 | 5.69 | 12.00 | 4.39 |
| 45 | 9.27 ± 1.32 | 9.57 | 10.78 | 7.15 |
| Pineapple Crown and Banana Meal | | | | |
| 0 | 1.00 ± 0.09 | 1.01 | 1.10 | 0.88 |
| 15 | 3.83 ± 1.56 | 3.83 | 6.55 | 2.00 |
| 30 | 5.23 ± 0.74 | 5.45 | 6.01 | 4.01 |
| 45 | 7.23 ± 0.03 | 7.25 | 7.26 | 7.18 |

**Table 3**
Starch Fraction (Total and Resistant) Content for Feed Ingredients Commonly used in Animal Feed Formulations in Costa Rica.

| | Concentration g/100 g | | | |
|---|---|---|---|---|
| | Mean ± SD | Median[a] | Max | Min |
| Plantain/Green Banana Flour *(n = 15)* | | | | |
| Total | 67.74 ± 8.26 | 68.88 | 77.78 | 55.44 |
| Resistant | 37.04 ± 2.40 | 37.12 [53.89] | 40.25 | 33.61 |
| Rice, Broken *(n = 15)* | | | | |
| Total | 78.91 ± 16.63 | 84.98 | 99.39 | 45.86 |
| Resistant | 7.52 ± 2.81 | 7.81 [9.19] | 11.30 | 2.95 |
| Wheat Middlings *(n = 15)* | | | | |
| Total | 28.86 ± 11.03 | 25.18 | 67.14 | 19.39 |
| Resistant | 1.98 ± 0.72 | 2.13 [8.46] | 3.29 | 0.52 |
| Wheat, Durum *(n = 15)* | | | | |
| Total | 42.94 ± 8.92 | 40.36 | 57.51 | 29.12 |
| Resistant | 2.95 ± 0.73 | 3.15 [7.80] | 4.06 | 1.23 |
| Banana *(n = 15)* | | | | |
| Total | 23.10 ± 4.28 | 23.78 | 28.92 | 12.43 |
| Resistant | 1.94 ± 0.88 | 1.74 [7.32] | 3.29 | 0.96 |
| Wheat Shorts *(n = 15)* | | | | |
| Total | 32.52 ± 7.24 | 29.79 | 47.94 | 22.96 |
| Resistant | 2.39 ± 1.27 | 1.91 [5.35] | 5.80 | 1.23 |
| Bakery By-products *(n = 15)* | | | | |
| Total | 79.04 ± 18.45 | 75.17 | 115.77 | 41.23 |
| Resistant | 3.24 ± 1.98 | 3.61 [4.80] | 5.89 | 0.18 |
| Corn *(n = 15)* | | | | |
| Total | 65.38 ± 5.37 | 66.08 | 76.7 | 54.24 |
| Resistant | 3.73 ± 2.50 | 2.94 [4.45] | 10.36 | 2.15 |
| Sweet Potato *(n = 15)* | | | | |
| Total | 56.17 ± 12.70 | 51.24 | 77.64 | 44.57 |
| Resistant | 2.19 ± 1.05 | 1.94 [3.79] | 3.87 | 0.99 |
| Sorghum *(n = 15)* | | | | |
| Total | 42.70 ± 12.61 | 36.18 | 65.34 | 31.23 |
| Resistant | 1.21 ± 0.54 | 0.95 [2.62] | 2.38 | 0.65 |

[a] Values in square brackets represent the amount of resistant starch relative to the total (i.e., resistant starch/total starch · 100). Data calculated based on median values.

analysis (Table 4). Additionally, other related samples included banana flour, banana chips, and green banana with variable mean values of TS (i.e., 63.10, 27.52, and 9.44 g/100 g, respectively) (Table 4). Noteworthy, as fruit processing requires ripe banana, the moisture is somewhat increased during pureeing (i.e., values as high as 90 g/100 g). The starch in the fruit puree diminishes significantly compared to the fruit (ca. 3 fold; mean values of 14.78 g TS/100 g in banana vs 4.73 g TS/100 g in the puree) (Table 4).

Corn, Malanga, and sweet potato flours are among the most studied, accounting for 16.4% ($n = 47/287$) of the total samples assayed for TS. These products represented one traditional and two nontraditional flours, respectively (Table 4).

Rice alone accounted for 5.2% of the samples with a considerable input in TS (i.e., not less than 29.78 g/100 g). Interestingly, japonica rice samples exhibited almost twice as much as TS than regular rice samples. Albeit, in comparison, a small number of the latter samples were assayed. A similar example can be found when comparing between the mean TS values of corn and purple corn. In comparison, there is a significant increase in TS for the latter (50.57 vs. 60.15 g/100 g, respectively, $p < 0.05$) (Table 4).

Conversely, potatoes exhibited, in fresh weight basis, as they are mostly consumed, a low input in TS of 15.10 g/100 g. As anticipated, coffee leaves and sorghum TS input is scanty 2.58 and 2.09 g/100 g, respectively (Table 4). However, unexpectedly, the TS input is higher in leaves gathered from a Rubiaceae [i.e., *Coffea arabica* L.] than that of a Poaceae [i.e., *Sorghum bicolor* (L.) Moench].

Nontraditional starches and flours were also assayed, most of them with a considerable contribution of TS. The TS content in the starches ranged from 46.92 (peach palm) to 71.40 (yam) g/100 g. However, the TS

**Table 4**
Total Starch content for Food Commodities from Costa Rica.

| Concentration, g/100 g | | | |
|---|---|---|---|
| Mean ± SD | Median | Max | Min |
| Ripe/Unripe Banana *(n = 62)* | | | |
| 14.78 ± 8.55 | 14.47 | 34.80 | 0.45 |
| Ripe Banana Puree *(n = 39)* | | | |
| 4.73 ± 5.49 | 2.92 | 29.63 | 0.22 |
| Corn Flour *(n = 19)* | | | |
| 50.57 ± 12.36 | 50.45 | 67.46 | 14.66 |
| Malanga [*Xanthosoma* sp.] flour *(n = 17)* | | | |
| 62.87 ± 8.18 | 65.60 | 73.88 | 43.93 |
| Rice *(n = 15)* | | | |
| 37.03 ± 4.29 | 35.01 | 44.57 | 29.78 |
| Sweet Potato [*Ipomoea batatas* (L.) Lam.] flour *(n = 11)* | | | |
| 54.93 ± 8.01 | 59.00 | 61.27 | 33.10 |
| Green Plantain *(n = 11)*, fresh weight basis | | | |
| 22.32 ± 1.45 | 22.55 | 24.30 | 19.84 |
| Dairy Solid Preparations with some Type of Cereal (*n* = 10) | | | |
| 11.72 ± 13.34 | 5.47 | 46.87 | 1.51 |
| White/Red/Black Quinoa [*Chenopodium quinoa* Willd.] (*n* = 10) | | | |
| 54.14 ± 3.41 | 54.70 | 59.00 | 48.30 |
| Green Banana (*n* = 8) | | | |
| 9.44 ± 0.96 | 9.82 | 10.42 | 7.81 |
| Bread Crumbs (*n* = 7) | | | |
| 62.27 ± 4.37 | 64.10 | 66.50 | 53.20 |
| Banana Chips (*n* = 7) | | | |
| 27.52 ± 1.50 | 27.79 | 28.86 | 24.07 |
| Pujagua/Puxauac/Purple corn (*n* = 7) | | | |
| 60.15 ± 9.26 | 59.83 | 73.88 | 42.70 |
| Quinoa based products [Burger, pizza bread, and brownie mix, pudding and flan] *(n = 7)* | | | |
| 49.79 ± 24.89 | 49.11 | 69.00 | 20.60 |
| Corn Germ Flour (*n* = 6) | | | |
| 50.09 ± 10.32 | 50.52 | 68.60 | 34.09 |
| Dried Palm Root (*n* = 6) | | | |
| 0.59 ± 0.11 | 0.56 | 0.77 | 0.44 |
| Coffee Mucilage (*n* = 5), Dry Weight Basis | | | |
| 23.86 ± 0.46 | 24.00 | 24.34 | 23.13 |
| Banana Flour (*n* = 5) | | | |
| 63.10 ± 11.98 | 62.33 | 79.90 | 49.56 |
| Pineapple Stems (*n* = 5) | | | |
| 7.69 ± 5.98 | 4.17 | 15.31 | 0.67 |
| Purple Corn Products [Atole/Atolli/Atol/Chicheme] (*n* = 4) | | | |
| 2.98 ± 1.04 | 2.85 | 4.40 | 1.80 |
| Japonica Rice (*n* = 3) | | | |
| 72.90 ± 0.71 | 73.25 | 73.54 | 71.91 |
| Green Plantain Flour (*n* = 3) | | | |
| 64.39 ± 6.22 | 62.40 | 72.81 | 57.96 |
| Cassava Flour (*n* = 3) | | | |
| 83.37 ± 3.32 | 82.50 | 87.80 | 79.80 |
| Coffee Leaves (*n* = 3) | | | |
| 2.58 ± 0.53 | 2.24 | 3.33 | 2.18 |
| White Bread (*n* = 3) | | | |
| 40.84 ± 11.96 | 32.83 | 57.04 | 32.64 |
| Potatoes (*n* = 3) | | | |
| 15.10 ± 1.53 | 15.70 | 16.60 | 13.00 |
| Sorghum (*n* = 3) | | | |
| 2.09 ± 0.07 | 2.06 | 2.19 | 2.02 |
| Pinolillo [Beverage prepared mainly from white corn flour, cocoa powder, and spices (especially cinnamon)] (*n* = 3), powdered instant beverage mix | | | |
| 34.73 ± 1.28 | 34.50 | 36.40 | 33.30 |
| Casssava Starch/Tapioca *(n = 2)* | | | |
| 66.62 ± 2.91 | 66.62 | 69.53 | 63.71 |
| *Food Commodities with Only One Hit/Nontraditional Starches* | | | |
| Sweet potato | | 66.86 ± 3.84 | |
| Yam | | 71.40 ± 4.13 | |
| Peach-Palm | | 46.92 ± 2.69 | |
| Taro (*Colocasia esculenta* (L. Scott)) | | 60.97 ± 3.50 | |
| *Food Commodities with Only one Hit/Nontraditional Flours* | | | |
| Turmeric | | 10.62 ± 0.61 | |
| Unripe Square Banana | | 71.09 ± 4.08 | |
| Ginger | | 21.42 ± 1.23 | |
| Peach-Palm | | 58.80 ± 3.38 | |
| Taro | | 59.80 ± 3.43 | |

content in the flours ranged from 58.80 (peach palm) to 71.09 (unripe square banana) g/100 g, respectively (Table 4). Turmeric and ginger exhibited considerably lower TS inputs, with mean values 10.62 and 21.42 g/100 g, respectively (Table 4).

In absolute terms, products exhibiting more RS input were, in ascending order, green plantain (fresh weight basis), sweet potato starch, corn starch, yam starch, unripe square banana flour, green plantain flour, potato starch, and Malanga with RS contributions of 23.36, 26.68, 35.45, 41.06, 45.28, 50.41, 50.50, and 56.59 g/100 g, respectively.

On the other hand, in relative terms (i.e., RS relative to TS), RS input was higher for the following commodities, again, in ascending order, corn germ flour, rice, banana chips, green plantain flour, ripe/unripe banana, and Malanga with 26.60, 31.85, 48.36, 77.40, 78.09, and 89.68% (Table 5).

Some of the products assayed exhibited considerable variations in their TS content. This was especially true for milled products such as Malanga flour that ranged from 32.32 to 71.00 g/100 g (Table 3 vs. Table 5). Additionally, as expected, operation units such as fruit bleaching drastically modified RS, for example, banana puree and ripe bananas exhibited significantly different mean values for RS, i.e., 1.92 and 11.59 g/100 g respectively (Table 5).

Interestingly, RS is also significantly increased in purple corn when compared to corn flour ($p < 0.05$). Mean values of RS both in absolute and relative terms reach 3.52 [5.88%] and 2.33 [4.58%] g/100 g, respectively.

Overall, Tables 3 and 5 indicate an evident variation in the RS content dependent on processing. Maceration and heat treatment can modify the RS values considerably, when compared to the fresh produce. Meanwhile, the production of snacks or flours increases the RS content up to fourfold. For example, ripe/unripe banana relative RS content is ca. 78%. This ratio is reduced to values as low as ca. 10% (mashed banana). The banana is commonly used to produce snack foods, in this case, during the processing, a considerable amount of resistant starch is lost (its value decreases to ca. 47%), possibly due to the enzymatic treatment.

## 4. Discussion

### 4.1. Starch in feedstuffs

In terms of TS, with the exception of corn distillers, for which reported values, reach as high as 11.5 g/100 g starch, most feed ingredients (3.8, 64.5, 77.1, and 81.2 g/100 g for wheat distillers, sweet potato/dried, rice/broken, and cassava, respectively) are in line with those reported elsewhere (Sandoval-Aldana and Fernández-Quintero, 2013; Institut National de la Recherche Agronomique INRA, 2004). As Costa Rican feed is mostly based on maize and soybean meal, cornmeal is amongst the most tested feed ingredients for starch. However, soybean is less likely to be assessed (in this context), as it can be considered a relatively poor starch source (Bednar et al., 2001). TS values obtained for corn, are in line with those reported elsewhere as carbohydrates (Institut National de la Recherche Agronomique INRA, 2004; Rouf Shah et al., 2016). Cornmeal RS values as high as 13% of the TS have been reported (Bednar et al., 2001). However, the authors also described 84.3 g/100 g TS for the same matrix. These values may be highly variable as they depend on particle size (Fuentes-Zaragoza et al., 2010). If it is assumed that most of the RS present in cornmeal to be type 1, milling will diminish RS content (Fuentes-Zaragoza et al., 2010). Carvahlo and Teixeira et al., (2016) also demonstrated that RS in sorghum vary greatly (0.31–65.65 g/100 g) and the researchers suggested that genotypes with low RS values might be useful as a feed ingredient. Previously, whole grain wheat has been reported to contain RS as high as 14 g/100 g, while milled wheat flour may contain ca. 2 g/100 g (Bednar et al., 2001). Reported RS values for wheat are in line with our data as wheat/durum has the higher amount of RS, followed by middlings, and lastly, shorts (AAFCO, 2021).

In fruits, the situation differs drastically as ripening will modify not only TS but also fractions. The reported values for ripe, unripe, dried, or dehydrated (flour) banana are 21.8, 28.7, 63.0, and 82.1 g/100 g, respectively (Aurore et al., 2009). In the case of plantain pulp, it shows

**Table 5**
Resistant Starch Content for Food Commodities from Costa Rica.

| Concentration, g/100 g | | | |
|---|---|---|---|
| Mean ± SD | Median[a] | Max | Min |
| Ripe/Unripe Banana ($n = 53$) | | | |
| 11.59 ± 6.99 | 11.30 [78.09] | 26.60 | 0.04 |
| Malanga [*Xanthosoma* sp.] flour ($n = 31$) | | | |
| 56.59 ± 7.92 | 58.83 [89.68] | 71.00 | 32.32 |
| Green Plantain, Fresh Weight Basis ($n = 27$) | | | |
| 23.26 ± 4.33 | 23.90 | 34.90 | 12.60 |
| Ripe Banana Puree ($n = 22$) | | | |
| 1.92 ± 2.77 | 0.29 [9.93] | 9.34 | 0.02 |
| Corn Flour ($n = 21$) | | | |
| 2.33 ± 1.20 | 2.13 [4.58] | 4.75 | 0.45 |
| Potato Starch ($n = 15$) | | | |
| 50.50 ± 20.32 | 61.94 | 70.81 | 9.01 |
| Rice ($n = 15$) | | | |
| 10.55 ± 2.84 | 11.15 [31.85] | 14.25 | 1.01 |
| *Musa* sp. ($n = 15$) | | | |
| 6.66 ± 4.54 | 8.90 | 12.30 | 0.20 |
| Corn Starch ($n = 13$) | | | |
| 35.44 ± 15.81 | 44.50 | 51.53 | 11.80 |
| Pujagua/puxauac/Purple corn ($n = 10$) | | | |
| 3.52 ± 2.26 | 3.50 [5.85] | 7.40 | 0.93 |
| Green/Unripe Banana ($n = 8$) | | | |
| 7.82 ± 15.81 | 44.50 | 51.53 | 11.80 |
| Malanga [*Xanthosoma* sp.] root-tuber ($n = 8$) | | | |
| 12.29 ± 2.31 | 11.30 | 16.07 | 9.98 |
| Cassava Flour ($n = 8$) | | | |
| 1.26 ± 0.67 | 1.13 [1.37] | 2.48 | 0.47 |
| Unripe Square Banana Flour ($n = 8$) | | | |
| 45.28 ± 9.34 | 48.22 | 52.44 | 25.46 |
| Green Plantain Flour ($n = 7$) | | | |
| 50.41 ± 6.13 | 48.30 [77.40] | 58.65 | 42.07 |
| Banana Chips ($n = 7$) | | | |
| 13.59 ± 0.21 | 13.44 [48.36] | 13.92 | 13.40 |
| Corn Germ Flour ($n = 6$) | | | |
| 13.59 ± 0.21 | 13.44 [26.60] | 13.92 | 13.40 |
| Palm Dried Roots ($n = 6$) | | | |
| 0.015 ± 0.009 | 0.013 [2.32] | 0.034 | 0.005 |
| Pineapple Stems ($n = 5$) | | | |
| 0.58 ± 0.36 | 0.43 [10.31] | 1.21 | 0.21 |
| Coffee Mucilage ($n = 4$) | | | |
| 0.38 ± 0.07 | 0.38 [1.58] | 0.45 | 0.30 |
| Pinolillo [Beverage prepared mainly from white corn flour, cocoa powder, and spices (especially cinnamon)] ($n = 3$), powdered instant beverage mix | | | |
| 4.63 ± 2.74 | 2.90 [8.40] | 8.50 | 2.50 |
| White Bread ($n = 3$) | | | |
| 0.78 ± 0.07 | 0.79 [2.40] | 0.87 | 0.69 |
| Sweet Potato Flour ($n = 3$) | | | |
| 1.29 ± 0.60 | 1.20 [2.03] | 2.06 | 0.60 |
| Coffee Leaves ($n = 3$) | | | |
| 0.25 ± 0.05 | 0.23 [10.27] | 0.32 | 0.20 |
| Nixtamalized Corn Flour ($n = 2$) | | | |
| 1.12 ± 0.08 | 1.12 | 1.20 | 1.04 |
| Breadfruit/Jackfruit Flour ($n = 2$) | | | |
| 10.11 ± 0.29 | 10.11 | 10.40 | 9.83 |
| Peach-Palm Flour ($n = 2$) | | | |
| 0.62 ± 0.06 | 0.62 [1.05] | 0.68 | 0.56 |
| Palm Hearts Flour ($n = 2$) | | | |
| 0.27 ± 0.04 | 0.27 | 0.32 | 0.23 |
| Yam Starch ($n = 2$) | | | |
| 41.06 ± 16.34 | 41.06 | 57.40 | 24.72 |
| Bean Starch ($n = 2$) | | | |
| 3.28 ± 0.09 | 3.28 | 3.37 | 3.18 |
| Sweet Potato Starch ($n = 2$) | | | |
| 26.68 ± 18.8 | 26.68 | 45.55 | 7.80 |
| Peach-Palm Starch ($n = 2$) | | | |
| 12.22 ± 6.73 | 12.22 | 18.95 | 5.49 |

[a] Values in square brackets represent the amount of resistant starch relative to the total (i.e., resistant starch/total starch · 100). Data calculated based on median values.

less variation as it has been reported since it ranges from 63 to 65 g/100 g (unripe and ripe fruit, respectively) (Aurore et al., 2009). Additionally, it has already been reported that starch values vary among varietals of banana (da Mota et al., 2000).

Herein the TS and RS of vegetable sources were described. Most starch is storage starch form non-photosynthetic plant structures (Pfister and Zeeman, 2016). Additionally, structures such as phytoglycogen are also assessed during the starch analysis (McCleary et al., 2019; Pfister and Zeeman, 2016). In the case of compound feed, since vegetable sources are majoritarian, animal protein sources, and even yeast and bacteria can be deliberately added as feed supplements due to their probiotic and antimicrobial activities (Hatoum et al., 2012). Due to this, dietary starch might be the appropriate term when referring to starch from compound feed (AAFCO, 2021). In Costa Rica, the majority of feeds tested for TS, during the surveillance program, are for ruminants. This represents an intuitive result since unchecked amounts of starch, in feed for such species, can trigger ruminal acidosis (Gómez et al., 2016). However, in monogastric animals, feed formulations based on RS-rich ingredients have already proven to improve parameters such as growth promotion hinting as a possible alternative to in-feed antibiotics (Regassa and Nyachoti, 2018).

Even though the input of starch for forage is relatively modest, starch values do fluctuate considerably, depending on the growing season and hybrid selection. Starch analyses in forages (Abijaudé et al., 2000) and silages (Van Vureen et al., 1999) are of prime importance as it may significantly affect how ruminants respond to a ration. For example, diets with a low forage-to- concentrate ratio, containing rapidly degraded starch, have increased feed intake, ruminal acidity, and milk yield in goats (Abijaudé et al., 2000).

As an example, Table 6 shows the theoretical formulation of balanced feed for dairy cattle (in the lactation and dry stages), as well as for swine (primary and substitute feed). In the case of dairy farming, the dry cow phase (i.e., having no milk yield and being in transition stage) allows a broader use of by-products (wheat shorts and middlings). Although corn is predominant in the diets, the contribution of resistant starch on the part of wheat by-products allows better digestion and a decrease in cases of ruminal acidity (Salfer et al., 2018).

In the case of pig feeding, during the production stage, two feeds were formulated theoretically, one using a standard formulation and the other with the inclusion of a less traditional ingredient (banana). It should be remembered that 55% of the energy in pig feed comes from starch; however, the calculation is made with total starch, and the contribution of each of its fractions is not taken into account (Fouhse and Zijlstra, 2018). Even so, by making the substitution in the formulation, it allows to decrease the use of distillers grains and wheat middlings, that is, to lower costs and take advantage of the benefits to intestinal health of increasing the contribution of RS in the diet (Wang et al., 2018).

Several of the starch sources reported here is used worldwide. However, some products may be restricted to certain regions, usually due to availability and costs. For example, in contrast to the type of starch sources reported herein for pet food formulation, some USA states, such as Illinois, use legumes as a traditional feed ingredients (e.g., lentils, peas and beans) (Bednar et al., 2001). Similarly, grain-based food products (e.g. spaghetti or macaroni; Bednar et al., 2001) are not exploited as animal feed ingredients in Costa Rica, however, as stated above, bakery sub products is.

Other countries such as Iran use barley as a base ingredient for ruminant diet formulation with good results as barley has more protein than other grains such as corn (Nikkhah, 2012). In Japan, Holstein cows have been fed with total mixed rations that contained corn silage, grass silage, chopped alfalfa hay and compound feed with the inclusion of dry ground corn, beet pulp, and wheat middlings (Dann et al., 2014). In the same fashion, equine diets are commonly based in hay, cracked corn, oats and wheat middlings (Harlow et al., 2016). Finally, starch-rich plant based ingredients such as soybean, linseed, canola, cottonseed, and sunflower meals, as well as wheat middlings, corn gluten, rice bran, barley, and rye have been all reported in various countries as a possible substitute for dietary fishmeal and oil in tilapia feeds (Maas et al., 2020). However, alfalfa, barley, beet pulp, canola, cottonseed, oats and rye are not ingredients of widespread use in Costa Rica as feedstuff.

Though Costa Rica is a producer of potato, very rarely are any rations or compound feed formulated using potato starch. It has been used both in Mexico and Brazil as a feed ingredient for fish feed (Frías-Quintana et al., 2017) and pet food (Domingues et al., 2019). Finally, locally Musaceae can be used as a feed ingredient, as well as produce of human consumption (see discussion below). However, most feed diets or rations will not include said plant as an ingredient; a fact more true for countries further from the tropics.

### 4.2. Starch in food commodities

As stated, harvesting, processing conditions and raw ingredient quality will affect RS values considerably (Muir and O'Dea, 1992). Such result is perceived in Green plantain flour for animal vs. human consumption or in the variable range of the RS of Malanga flours. Also, the amount of peels, leaves, and other plant structures incorporated into the meal will also be decisive for the amount of RS present (Muir and O'Dea, 1992).

Before peeling and pureeing and during banana processing, a thermic treatment of whole fruit (to inactivate polyphenol oxidase enzymes, aseptic processing, or blanching at 30 s and ca. 90 °C with rapid cooling) will undoubtedly affect the amount of RS content (Muir and O'Dea, 1992; Xiao et al., 2017). Novel approaches such as microwave-assisted blanching could assist in beneficially modifying the nutritional properties of fruits such as banana (Kumarasiri et al., 2018).

In the baking industry, the evaluation of the starch content in flours is essential for the gelatinization process to be ideal and thus obtain adequate hardness and texture characteristics in products such as bread (Oyango, 2016). Currently, due to the presence of celiac diseases, it has been necessary to search for new alternatives to wheat flour for the preparation of bakery products (Hosseini et al., 2018). Taro, banana, and green plantain flours have total starch values very similar to that of wheat flour, which has an average of 68 g/100 g (Hucl and Chibbar, 1996). So, it would be expected that the behavior of these nontraditional flours, in gelatinization, would be similar. Values for turmeric and ginger flours have also been reported previously (Alcázar-Alay Meirles, 2015). On the other hand, cassava, peach palm, and green square banana flours exhibited higher TS values compared to wheat flour. Hence, it would be expected their rheological characteristics to be slightly different. The high resistant starch content in ingredients such as green square banana flour, would impart an improved nutritional value related to its digestibility (Perera et al., 2010).

Considering the diversity starch sources were analyzed herein, it has to be acknowledged that several of these crops posess sufficient starch levels to cement themselves as widely available in gluten-free alternatives. This is especially relevant since nowadays there is a increasing interest in finding alternative starch sources for gluten-free diets (Horstmann et al., 2017).

The relevance of the study of banana and plantain starch lies in its commercial and nutritional value, especially for tropical countries (Joshi and Sarangi, 2014; Patterson et al., 2020). Notwitstanding, banana is a product that is usually absent in similar studies from other regions (Elmståhl, 2002). Differences in starch fractions between banana and plantain have already been described elsewhere (Soares et al., 2011). Additionally, plantain and banana flour have both found technological applications (Amini et al., 2019). Interestingly, the banana plant and fruit have also found a niche in animal feeding (DuPonte et al., 2016; Ranaudeau et al., 2014; Rusdy, 2017).

Another staple food, especially in America, are corn-based products, whose starch input is considerably high. For example, two cups of nixtamalized corn generates ca. 16 tortillas. In Costa Rica, tortilla consumption per person is about 25.6 kg per year (Guevara-Villalobos et al.,

**Table 6**
Theoretical Feed Formulations for Dairy Cattle and Pigs in Production.

| Nutrient | Requirements | Formulation | Raw Materials [g/100 g] | TS [g/100 g] | RS [g/100 g] |
|---|---|---|---|---|---|
| **Dairy Cattle Feed** | | | | | |
| Lactating Cows Feed | | | | | |
| CP (g/100 g min) | 16 | 16.27 | Corn [45] | 29.74 | 1.32 |
| CF (g/100 g max) | 10 | 8.79 | Soybean Meal [18] | NI | NI |
| EE (g/100 g) | 3 | 5.68 | Soybean Hulls [10] | NI | NI |
| Ca (g/100 g) | 0.5 | 0.53 | Wheat Middlings [10] | 2.52 | 0.21 |
| P (g/100 g) | 0.3 | 0.44 | Palm Nutsedge Meal [10] | NI | NI |
| Energy NL (Mcal/kg min) | 1.75 | 1.78 | Citrus Pulp Dried [3] | NI | NI |
| | | | Vegetable Oil [2] | NA | NA |
| | | | Dicalcium Phosphate [0.2] | NA | NA |
| | | | Calcium Carbonate [0.6] | NA | NA |
| | | | Salt [0.3] | NA | NA |
| | | | Premix [0.25] | NA | NA |
| | | | TOTAL [100] | | |
| Dry Cows Feed | | | | | |
| CP (g/100 g min) | 14 | 14.13 | Corn [27] | 17.84 | 0.79 |
| CF (g/100 g max) | 11 | 11.66 | Distillers' Grains [16] | NI | NI |
| EE (g/100 g) | 5 | 6.61 | Soybean Hulls [14] | NI | NI |
| Ca (g/100 g) | 0.3 | 0.33 | Wheat Middlings [12.5] | 3.15 | 0.27 |
| P (g/100 g) | 0.45 | 0.52 | Wheat Shorts [12.5] | 3.72 | 0.20 |
| Energy NL (Mcal/kg min) | 1.65 | 1.70 | Palm Nutsedge Meal [12.15] | NI | NI |
| | | | Citrus Pulp Dried [3] | NI | NI |
| | | | Vegetable Oil [2] | NA | NA |
| | | | Calcium Carbonate [0.3] | NA | NA |
| | | | Salt [0.3] | NA | NA |
| | | | Premix [0.25] | NA | NA |
| | | | TOTAL [100] | | |
| *Swine Feed* | | | | | |
| Growing Pig | | | | | |
| CP (g/100 g min) | 14 | 15.19 | Corn [37] | 24.45 | 1.09 |
| CF (g/100 g max) | 6 | 7.28 | DDGG [24] | NI | NI |
| EE (g/100 g) | 3 | 6.58 | Wheat Middlings [12] | 3.02 | 0.26 |
| Ca (g/100 g) | 0.5 | 0.51 | Wheat Shorts [12.25] | 3.65 | 0.20 |
| P (g/100 g) | 0.4 | 0.58 | Palm Nutsedge Meal [12] | NI | NI |
| Energy M (Kcal/kg min) | 2900 | 2890.10 | Vegetable Oil [1.5] | NA | NA |
| | | | Calcium Carbonate [1] | NA | NA |
| | | | Premix [0.25] | NA | NA |
| | | | Total [100] | | |
| Growing Pig (with banana) | | | | | |
| CP (g/100 g min) | 14 | 13.50 | Corn [37] | 24.45 | 1.09 |
| CF (g/100 g max) | 6 | 6.46 | DDGG [20] | NI | NI |
| EE (g/100 g) | 3 | 6.13 | Wheat Middlings [5] | 1.26 | 0.12 |
| Ca (g/100 g) | 0.5 | 0.50 | Wheat Shorts [13] | 3.87 | 0.21 |
| P (g/100 g) | 0.4 | 0.48 | Palm Nutsedge Meal [12.25] | NI | NI |
| Energy M (Kcal/kg min) | 2900 | 2983.81 | Banana [10] | 6.89 | 3.71 |
| | | | Vegetable Oil [1.5] | NA | NA |
| | | | Calcium Carbonate [1] | NA | NA |
| | | | Premix [0.25] | NA | NA |
| | | | Total [100] | | |

Dairy Cattle and Swine Requirements (NRC 2001; Rostagno et al., 2017). Nutritional information about raw materials (de Blass et al., 2019; García et al., 2013, Montoya-López et al., 2014). TS and RS data come from Table 3.

2019). Based on the mean values of TS and RS for cornmeal, this staple food will input 129.46 and 5.96 g, respectively. Nixtamalization does not seem to affect RS content, interestingly, though, RS will increase during tortilla storage (Garcia-Rosas et al., 2009; Santiago-Ramos et al., 2015).

Though some root vegetables can exhibit a considerable amount of RS, especially on dry weight basis, it is crucial to consider the presentation in which the crop is consumed (and the prior processing it was given). For example, an uncooked potato, in dry weight basis possesses (63–83 g/100 g moisture), it can input 67.9 and 29.9 g/100 g of TS and RS, respectively (Zhao et al., 2018). However, when the potato is used in preparations such as salad, mashed potatoes, or it is boiled (where potato starch will be cooked and cooled; RS type 2/3), the RS values can reach of 5.9, 2.4, or 2.0 g/100 g, respectively (Elmståhl, 2002). Malanga, that is another vegetable root, is popular in tropical countries (Graff et al., 2018). It has been reported that Malanga carbohydrates occur in higher abundance. These carbohydrates were characterized by a higher amylopectin content, and were more bioaccessible and bioavailable than those of potato (Graff et al., 2018). Besides, its consumption positively affects gut microbiota diversity (Graff et al., 2018).

Several bioactive substances have been described for corn including Type 2 RS (digestibility related to native granule structures) (Sheng et al., 2018). The benefits of corn-derived RS studied in animal models are primarily associated with diabetes (Kim et al., 2003; Sheng et al., 2018).

## 5. Conclusions

Starch should be included as part of regular quality analysis/surveillance programs of feeds, as feed sits at the start of the food chain. Once milled, with the exception of ingredients such as distillers' grains and pelletized feed (e.g., pet foods and fish and shrimp feeds), most feed ingredients and compound feeds will retain their RS fraction as are usually exempt from additional operation units (such as cooking). In animal nutrition, being the most specific current the formulation concerning the consumption, digestion, and absorption of nutrients, special consideration should be given to it. Including this type of analysis, provides more information that allows the best food to be prepared by growth stage and type of animal In food commodities, it is vital to know the TS and RS content to evaluate rheological properties in its products as well as its effect on health in improving the functioning of the digestive tract can be an alternative to traditional products that can provoke an allergic reaction. Also, it is relevant in know-how aspects of harvesting, maturation, and unit operations such as enzymatic maceration, blanching, frying, or others that can affect the content of these nutrients to improve the operations or research alternatives.

## CRediT authorship contribution statement

**Graciela Artavia**: Writing - original draft, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - review & editing, Visualization, Project administration. **Carolina Cortés-Herrera**: Formal analysis, Investigation, Writing - review & editing, Funding acquisition. **Fabio Granados-Chinchilla**: Methodology, Formal analysis, Writing - review & editing, Validation, Conceptualization, Data curation, Visualization, Supervision.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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