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Review

Valorization of Peel-Based Agro-Waste Flour for Food Products: A Systematic Review on Proximate Composition and Functional Properties

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ABSTRACT: With the steadily growing world population, effective methods are needed to alleviate food shortages. One possible strategy could be to utilize agro-waste materials that accumulate in large quantities at every stage of the economic chain during harvesting, food production, and consumption. Peel-based agro-waste consists of promising materials that can be utilized to potentially substitute commonly used raw materials in products traditionally made from wheat, tapioca, and rice flours. In this systematic review, we aim at establishing prospective proximate components as basic nutrients and their valorization potential as substitutes in traditional flour products (bread, biscuits, etc.). Generally, the peel contains high levels of fiber and relatively low digestible carbohydrates, providing a healthier food ingredient. In terms of protein, it should be pointed out that seeds such as wheat utilize insoluble gluten as their major storage protein, while proteins in peel were found in quite high percentage although they were not yet well characterized. However, the general effect of using peel to substitute wheat in food products are the reduction of dough elasticity, increased hardness of the end-products, faster water absorption rate of the products, and in some cases, bitter taste and darker colors. The latter two could have been contributed by the secondary metabolites such as phenolic compounds. On the other hand, substitution of peel into food products can have valuable health benefits, e.g., retention of antioxidant activity due to the phenolic compounds or simply adding fiber. In this review, literature on the composition of promising agro-waste raw materials is being discussed in the relationship with physical properties and appearance of potential end-products. Antinutritional compounds and pretreatment processes are also being considered. It is hoped that a critical discussion will lead to a better understanding and higher acceptance of the incorporation of peel into food products.

KEYWORDS: *acceptability, agro-waste, peel byproducts, proximate components*

■ INTRODUCTION

Agricultural and food industries produce a huge amount of residue every year. Byproducts of industrial-based processing such as bagasse, fruit-based fiber-rich materials (peels, leaves, stalks), and seeds are abundant and very little utilized.[1] Left to the environment without proper disposal, these residues may cause environmental pollution and have a harmful effect on the health of humans and animals.[2] Some of this agro-waste has been explored as an alternate raw material for different products, such as biogas,[3,4] biofuels,[5,6] enzymes,[7] vitamins,[8] antioxidants,[9] animal feed,[10,11] antibiotics/drugs,[12,13] and other valuable commodities needed in daily life, research, and industry.[14,15] On the other hand, diversification of food staples or food raw materials can be an effective strategy to alleviate the food global shortage and hunger. Agro-waste or agricultural residues are often still rich in nutritional and bioactive compounds. Transformation of agro-industrial waste into value-added food can help to lower the production cost and, simultaneously, reduce the overall pollution of the environment.

Flours from wheat, rice, and tapioca are currently incorporated in huge amounts into many goods. The quality of the end-product after flour processing is related to the physical characteristics of the flour which in turn is also associated with the nutritional content of the raw material. Indeed, various plant secondary metabolites can play a role in the functional aspects of the flour, with positive effects due to additional functional activities such as antioxidants or negative impacts such as antinutritional effects and toxicity.[16] It is important to know the proximate composition as the set of the most basic chemical parameters which are related to nutritional and physical characteristics of the flour to be converted into end-products.

Most reviews on agro-waste utilization studied only one specific agro-waste. Example of reports on comparison between different agro-waste peels were the ones from Fierascu et al. and Mirabella et al.[17,18] The first one focused more on the

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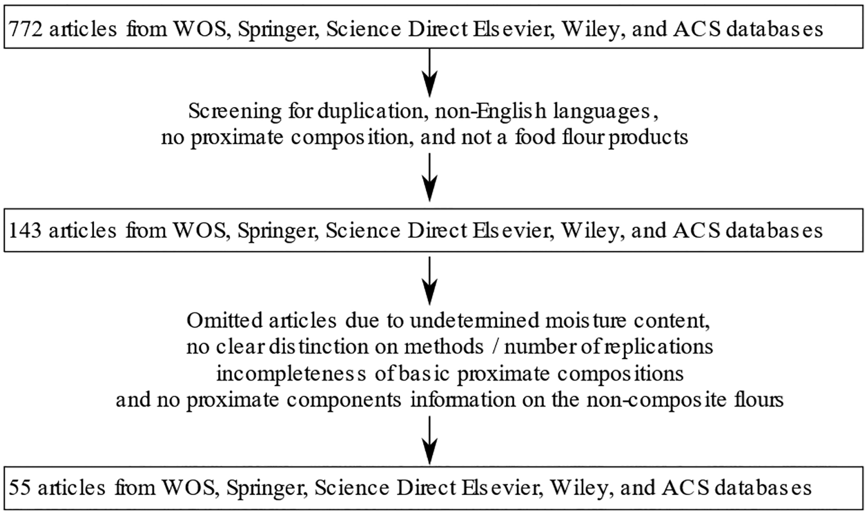

Figure 1. Flowchart of study selection.

active phytochemical compounds, while the later discussed more about the feasibility and constraints of the waste recycling process from the food processing industry. Yet, none of them provided any approximate composition of the agro-waste. The systematic review we report here has been performed to compile an approximate profile of agro-waste peel flours in the search for the potential to act as partial substitutes for commonly used flours. The approximate values considered relate to carbohydrate, protein, lipid, ash, and water contents. Straight grade wheat flour acts as the standard for comparison. It explores the possibility to obtain end-products of good quality that are accepted by the consumer. Functional properties of each plant flour and pretreatment strategies to alleviate the undesirable effects from antinutrients are discussed. The findings of this study may stimulate fresh ideas to develop a pretreatment which will yield a composite flour that meets the requirements of standard food flours.

METHODOLOGY

A literature search of articles written in English between 1950 and 2020 was conducted in the Web of Science database supplemented by further searching on Elsevier, Springer, Wiley, and ACS-based journals, which yielded approximately 800 relevant articles (see Figure 1). Keywords were employed and searched the in Title, Keywords, and Abstract section of articles, i.e., [agro-waste] or [agro waste] or [agromass] and [peel] or [fruit peel] or [peel flour].

Selection criteria were to include only experimental studies that presented nutritional data of the pure/individual flour from agro-waste peel, i.e., protein, fat, ash, and carbohydrate content. Research on both raw and processed food flour was included with notation. Other data such as sensory and functional compound information were included to support the discussion. Additionally, further information is given regarding antioxidant activity, sensorics, and acceptance tests as well as antinutrient compounds. Based on screening of the literature data, 21 types of agro-waste peel flours could clearly be identified from a total of 56 studies. There has been increasing interest over the last decades, especially the last 5 years, in the utilization of agro-waste for substitution of commonly used flours. Table 1 displays all values which were included in this study. The increased research activity highlights the importance of diversification of food raw materials. The incorporation of agricultural byproducts into conventional food staples could possibly alleviate global food shortages.

RESULTS AND DISCUSSION

The basic approximate profile plays an important role in the physical characteristics of flour. For comparison purposes, we related various approximate values from the peel- and skin-based agro-waste in this study to the commonly used flours for various end-products, such as wheat straight grade flour, rice flour, and cassava flour. Materials include fruit skins/peels/rinds/shells, tuber peels, and corn cobs. The most commonly used prerequisite can rather be found for wheat flour (based on dry weight and taken from the Food and Agriculture Organization of the United Nations (FAO) Codex Alimentarius International Food Standards for Wheat Flour (CXS 152-1985)).

Protein Content. Taken from CXS 152-1985, the acceptable nutritional approximate composition for sufficient protein is more than 7% for a wheat flour. As can be seen in Figure 2, some agro-waste materials readily exceed the protein content threshold and are comparable to that of straight grade wheat flour. For example, mature papaya Havai and Calimosa, potato, red grape peel, orange passion fruit, and corn cob peels contain a relatively high protein content. Notably, that of the red grape peel is higher than that of its white counterpart, similarly, orange passion fruit in comparison to yellow passion fruit. The largest discrepancy in protein contents between varieties is observed in the case of papaya.[19,20] Both studies employed the same milling technique to produce fine flour. The only difference beside the papaya source was that Santos et al. (2014) oven-dried the materials at 45 °C,[19] while Mumbai Papaya was dried at 70 °C. Indeed, increasing the drying temperature and time is often related to several transformations and decompositions in which the nutritional content is reduced.[21] However, the difference is nearly 3-fold and might rather be attributed to the variation in growing conditions.

It is of great importance that besides the nutritional impact, protein plays a huge role for the physical and rheology characteristics of food materials. Depending on the amino acid

Table 1. Approximate Compositions of Selected Agro-Waste Flours[a]

agro-waste flour	protein	lipids	ash	digestable carbohydrates	dietary fiber	crude fiber	total carbohydrates	refs
jabuticaba (*Plinia cauliflora*) peel	6.09	0.49	5.76	54.69	32.96	n.d.	87.65	22
orange (*Citrus reticulata*) peel	3.75 ± 0.48	2.55 ± 0.81	n.d.	80.45 ± 1.7	n.d.	13.25 ± 1.73	93.70 ± 0.39	23
corn (*Zea mays*) cob	8.99	4.90	6.63	39.76	39.72	n.d.	79.48	24
kiwi (*Actinidia deliciosa*) skin	4.63	1.61	4.78	57.52	31.47	n.d.	88.99	25
buriti (*Mauritia flexuosa*) peel blanched	2.69	0.54	1.06	3.74	91.97	n.d.	95.71	26
buriti peel unblanched	3.31	0.57	1.96	1.34	92.82	n.d.	94.16	26
cassava (*Manihot esculenta*) peel	4	0.4	1.24	94.36	n.d.	n.d.	94.36	27
cactus pear (*Opuntus ficus-indica*) peel from Egypt	3.94	1.37	11.15	n.d.	n.d.	n.d.	83.54	28
cactus pear peel from Tunisia	3.63	2.97	16.03	54.59	n.d.	22.77	77.36	29
cactus pear peel from Mexico	0.09	0.12	4.29	24.52	70.98	n.d.	95.50	30
red grape (*Vitis labrusca*) peel	12.88 ± 0.84	6.12 ± 0.40	4.90 ± 1.56	24.33 ± 2.38	51.78 ± 4.39	n.d.	76.11 ± 2.01	31−34
white grape (*Vitis vinifera*) peel	7.9	3.38	3.93	54.54	30.25	n.d.	84.79	33, 35, 36
cupuasu (*Theobroma grandiflorum*) peel	2.88	1.94	2.49	11.71	80.98	n.d.	92.69	37
pequi (*Caryocar brasiliense*) from Montes Claros, Brazil	5.77	n.d.	3.20	52.89	45.84	n.d.	98.73	38
Goias State, Brazilian pequi soaked for 0 h	2.65	1.32	2.09	34.27	59.67	n.d.	93.94	39
Goias State, Brazilian pequi soaked for 24 h	3.4	3.97	1.21	13.25	78.17	n.d.	91.42	39
Goias State, Brazilian pequi soaked for 48 h	3.39	3.76	1.16	0.69	91	n.d.	91.69	39
Goias State, Brazilian pequi soaked for 72 h	3.48	3.93	1.11	0.01	91.47	n.d.	91.48	39
pequi from Goiania, Brazil	5.77	0.88	2.95	51.18	39.23	n.d.	90.41	40
potato (*Solanum tuberosum*) (cv. Agata) from Mexico	4.21	1.05	8.42	55.79	30.53	n.d.	86.32	41
red potato	16.74	0.85	7	58.7	16.72	n.d.	75.42	42
gold potato	15.02	1.24	9.67	51.05	23.02	n.d.	74.07	42
organic russet potato	12.44	1.16	7.6	56.59	22.22	n.d.	78.81	42
nonorganic russet potato	17.87	1.14	7.63	50.09	23.27	n.d.	73.36	42
potato (abrasion)	16.72	0.56	7.73	48.39	26.6	n.d.	74.99	43
potato (steam)	18.55	1.07	6.01	17.87	56.5	n.d.	74.37	43
Bruguiera gymnorrhiza peel	6.52 ± 0.50	6.66 ± 0.83	4.34 ± 0.5	n.d	n.d	n.d	82.48 ± 1.2	44
banana (*Musa sp.*) peel	7.74 ± 1.96	5.63 ± 3.51	12.88 ± 5.23	24.04 ± 8.28	53.34 ± 10.45	10.16 ± 1.09	73.86 ± 7.22	45−51
banana peel var. Nanicao	6.01 ± 0.13	4.41 ± 0.31	9.55 ± 0.64	n.d	n.d	n.d	n.d	52
banana peel from Zengcheng, China	7.2	3.79	n.d.	n.d	23.49	n.d	83.59	53
yellow passion fruit (*Passiflora edulis*)	4.39 ± 0.97	0.7 ± 0.3	7.18 ± 0.88	31.55 ± 17.10	55.91 ± 18.08	26.63	87.73 ± 1.2	54−58
orange passion fruit	10.52 ± 0.61	4.43 ± 1.73	9.83 ± 1.62	21.4 ± 2.05	53.54 ± 1.96	n.d	75.23 ± 3.93	59, 60
papaya Havai and Calimosa	19.19 ± 1.77	2.61 ± 0.21	13.39 ± 0.28	25.65 ± 1.20	39.17 ± 1.06	n.d	64.82 ± 2.26	19
papaya (*Carica papaya*) (Mumbai)	6.63	2.33	9.3	5.93	75.81	n.d	81.74	20
peach (*Prunus persica*) peel	8.18	n.d	4.68	n.d	62.6	n.d	n.d	61
pineapple (*Ananas comosus*) peel (Colombia market)	4.4	0.3	3.55	n.d	n.d	n.d	91.75	62
pineapple peel (Mexico market)	0.36	0.19	3.18	25.55	70.72	n.d	96.27	30
lime (*Citrus latifolia*) shell	1.57	0.29	3.48	1.8	92.86	n.d	94.66	63
mango (*Mangifera indica*) peel	3.95 ± 1.99	3.28 ± 1.31	2.87 ± 0.54	29.96 ± 6.14	59.93 ± 6.69	n.d.	89.95 ± 2.68	64−70

Table 1. continued

agro-waste flour	protein	lipids	ash	digestable carbohydrates	dietary fiber	crude fiber	total carbohydrates	refs
mango peel from Serdang, Malaysia	4.08	1.62	n.d	n.d.	n.d.	n.d.	90.42	71
mango peel Tainong No. 1	7.32	0.97	n.d	n.d	47.79	n.d	n.d	72
mango peel cv. Daisheri	7.12	1.99	3.34	n.d.	n.d.	n.d.	n.d.	73
local pumpkin (*Cucurbita moschata*), Nigeria	5.1	0.43	2.5	90.14	n.d.	1.83	91.97	74
local pumpkin, New Zealand	2.19	0.3	7.25	90.26	n.d.	n.d.	90.26	75
almond (*Prunus delcis*) skin	11.8	23.7	n.d.	6.0	58.51	n.d.	64.51	76
straight grade flour, Pakistan	15.25	1.9	0.55	81.89	0.4	n.d.	82.29	77
Phitsanulok rice flour	6.89	1.2	0.5	90.53	n.d.	0.86	91.39	78
five genotypes of Thai cassava flour	1.67	0.22	2	93.42	n.d.	2.79	96. 21	79

[a]Data on water content or humidity were used to normalize the approximate data for comparison.

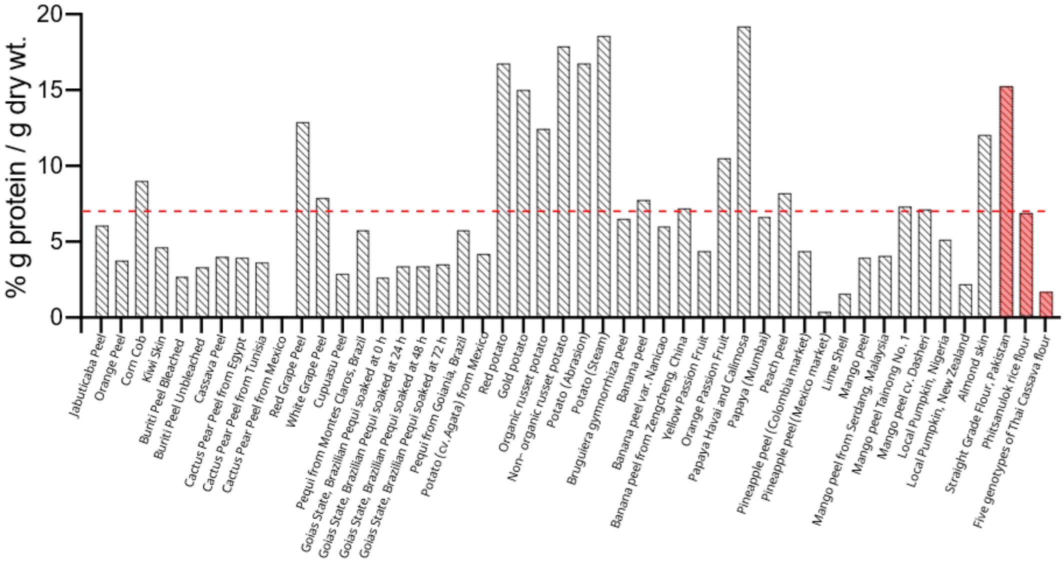

Figure 2. Protein content on a dry weight basis of flours extracted from various peels. The red line indicates the protein content threshold at 7%. Common commercial flours such as wheat, rice, and tapioca flours are used as the standard and marked in red.

composition and solubility, major wheat flour proteins are categorized into glutelin and prolamin, which is less water soluble. It is well-known that gluten (gliadin and glutenin) impacts the elasticity of the dough due to its water retention capability. A water-mediated interaction between protein molecules is promoted which increases the dough's stretching strength.[80] However, several doughs can also be formed from a variant of soft wheat flour with lower gluten content which is more suitable for pastry, larger diameter, and crispy products.[81] This might be a good option to make use of composite flours based on agro-waste materials. Cassava/tapioca flour contains a lower amount of protein in comparison to wheat flour; hence, it is mostly used to produce crispy end-products. Therefore, agro-waste materials with low protein content could also be recommended to substitute tapioca flour.

Lipid Content. In general, the lipid content of wheat flour is about 1% (g/g dry weight). In contrast to gluten, high lipid content interferes with gluten cross-linking (nonpolar phase) and rather interacts by hydrophobic interaction with the amino acids (or H-bond if it is a glycolipid), thus reducing flour elasticity and tensile strength.[82−84] In that regard, several agro-waste materials are not recommended to completely substitute or to be used in large proportion in composite flours (Figure 3). In comparison, agro-waste from jabuticaba, buriti, cassava, two cactus pear varieties, Cupuasu, untreated pequi, potato, yellow passion fruit, pineapple, lime, several mango varieties, and pumpkin peels could possibly be utilized to substitute the three common flours (wheat, rice, and tapioca). It is particularly worth mentioning that maceration apparently increased the fat level in pequi flour,[39] while different skin colors of passion fruits (*Passiflora edulis* cv. Flavicarpa) played a role for the nutritional content, probably due to the ripening stage.[56,59] Interestingly, one outlier data from the peel-based material is given from the almond skin. Although seeds are commonly known to contain a high level of fat, the same can also be said particularly for the skin of almonds.[76]

Ash and Mineral Content. Ash and mineral contents depend on the ability of plants to absorb macro- and micronutrients from the soil and to realize mineral transport and storage in each plant organ and is strongly impacted by the respective cultivating conditions. Comparing ash content of plants grown under different conditions is, however, practically

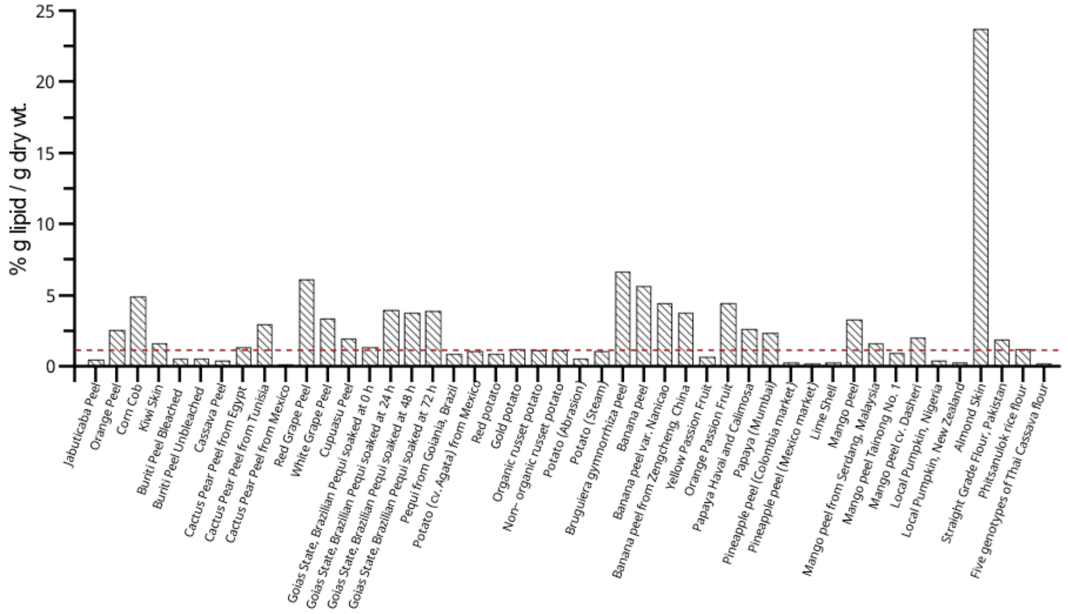

Figure 3. Lipid content on a dry weight basis of flours made from various peels. The red line indicates the total fat content of wheat all purpose flour (USDA FDC 169761) at 1.11% g/g dry weight.

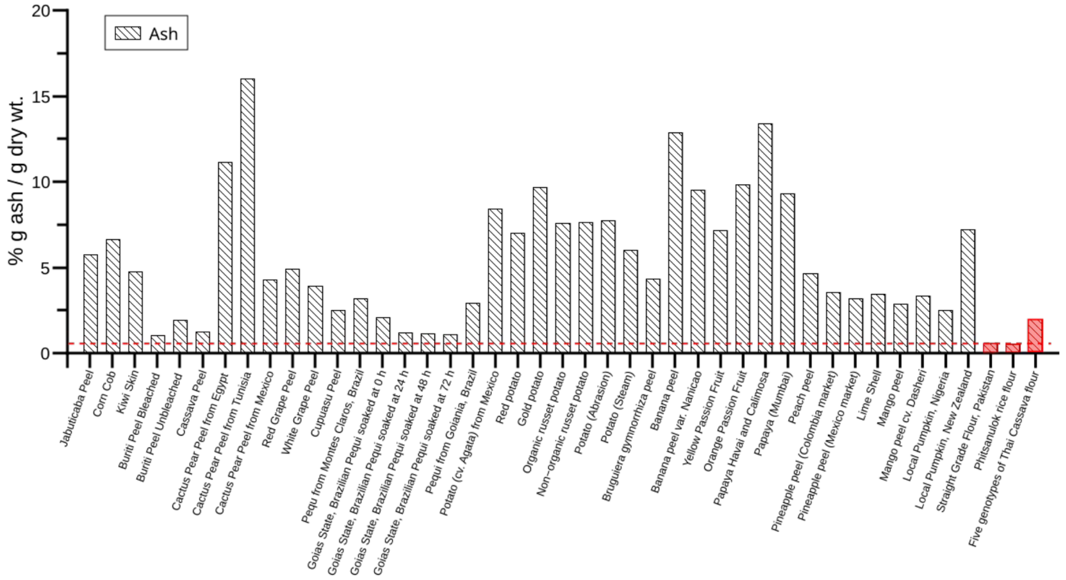

Figure 4. Ash content on a dry weight basis of flours based on various peels. The red line indicates the ash content of wheat flour, all purpose flour (USDA FDC 169761) at 0.53% g/g dry weight. The common commercial flours such as wheat, rice, and tapioca flours are marked in red.

impossible. The ash content of wheat flour has been set to about 0.5% g/g dry weight, although it is mentioned in CXS 152-1985 that the ash content can be modified according to certain purposes. Indeed, minerals by themselves do not really have a major impact on the macroscopic physical characteristics of flour and dough. Rather, the mineral content is related to its functional and antinutritional properties. Silica and precipitated calcium salt with oxalate or carbonate can readily be deposited in plant cell walls. These salts might cause renal problems.[16,85,86] Particularly, calcium oxalate crystals are concentrated in the fruit skin and seeds, possibly to deter herbivores.[87,88] Pretreatments of raw materials, such as blanching and chemical treatments, are often employed to reduce the ash content,[39] which will be discussed further below. Without any pretreatment, it is better to avoid using some of the agro-waste materials except buriti, cassava, and pequi peels in large amounts in a composite flour (Figure 4).

Total and Digestible Carbohydrate Content. Digestible carbohydrate was obtained by subtraction of other proximate content including fiber if the data were provided. Total carbohydrates was calculated either directly by difference to other proximate composition or by the summation of the digestible carbohydrate to either crude fiber or dietary fiber. Orange peels total and digestible carbohydrates include ash in its calculation (Figure 5; marked by a red asterisk).

The total carbohydrates of the agro-waste materials seem to be comparable to common flour materials (Figure 5) with the exceptions of cactus pear varieties, red grape peel, potatoes,

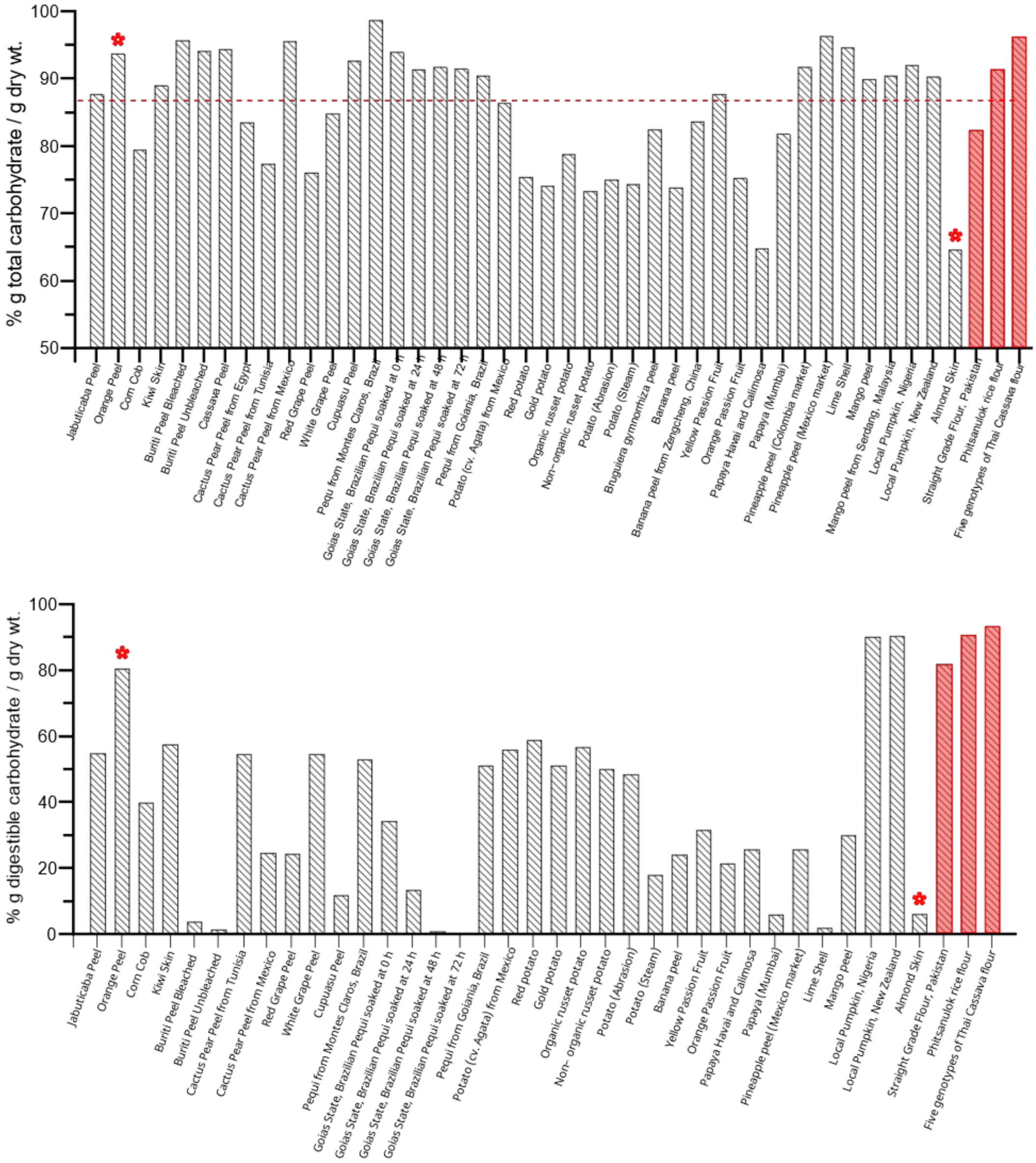

Figure 5. Total (top) and digestible carbohydrate content (bottom) on a dry weight basis of flours obtained from various peels. The red line indicates the total carbohydrate content of wheat, all purpose flour (USDA FDC 169761) at 86.64% g/g dry weight. The carbohydrate contents of common commercial flours from wheat, rice, and tapioca are shown in red. The orange peel and almond skin include ash (marked by asterisks).

and papaya. It is to be noted that total carbohydrate includes digestible carbohydrate (starches, sugars) and fiber. Unfortunately, the calculation of the digestible carbohydrates varies between studies. Two different fiber classifications based on the assays were used to determine the fiber content in which determination of the digestible fiber with an enzymatic technique measured the fiber more comprehensively than the crude fiber determination with, e.g., acid hydrolysis. The digestible carbohydrate content counted from crude fiber presented in Figure 5 and therefore appears higher (see Tunisian cactus pear peels in comparison to the other two varieties).[29] Most of the studies are listed and used AOAC techniques without mentioning the protocol series. Listed protocols that can be found in the methods section are rather traditional techniques for the measurement of dietary fiber, i.e., AOAC 985.29 (for example, ref 25) and AOAC 991.43 (for example, refs 42 and 76), with the exception of one working group that uses a near-infrared technique to determine dietary fiber.[32−36] The two traditional methods do not account for resistant starch and nondigestible oligosaccharides that may also underestimate the values of dietary fiber itself in comparison to the integrated method of AOAC 2009.01 and 2011.25.[89,90] Moreover, incomplete characterization of the approximate composition poses a challenge to convey the carbohydrate content.[23] Although possibly no absolute values can be extracted for the fiber level in this study, the level and the trend can be compared to each other.

Both the linear and branched starch polymers play a big role on the gelatinization of flour during subsequent heating processes due to rearrangement in its molecular structure and water retention activity. It is to be reminded that fiber is a mixture of various carbohydrate polymers with different sugar components, degree of branching, size, morphology, and other physical properties and may play a role in to the final food

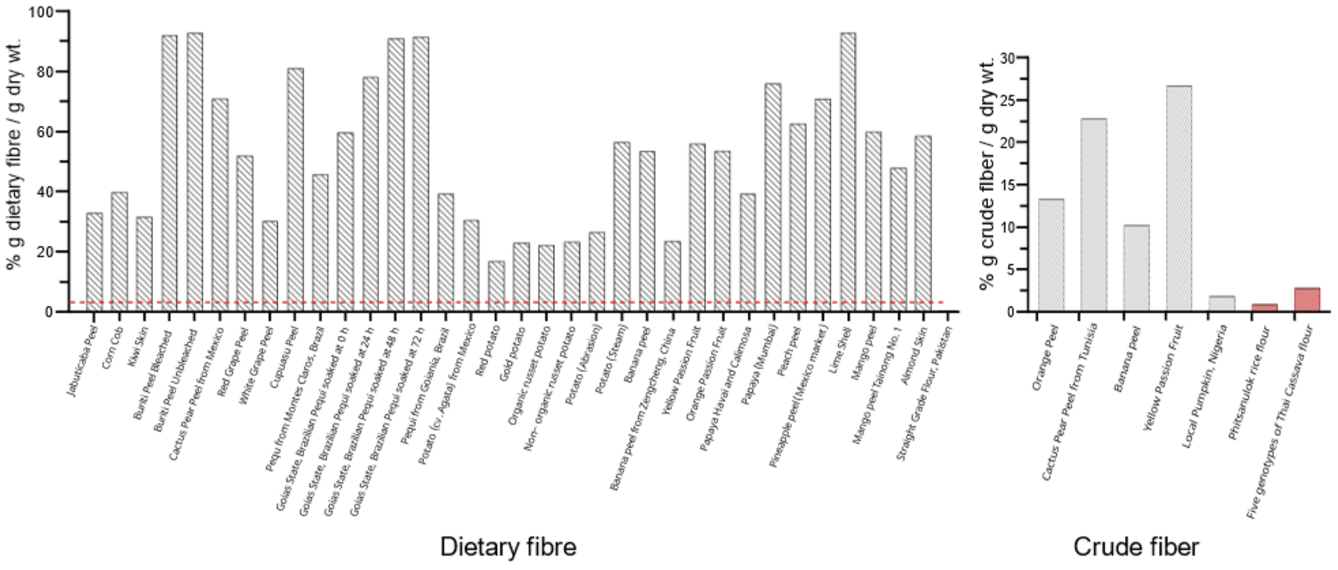

Figure 6. Dietary (left) and crude fiber content (right) on the dry weight basis of flours of various peels. The red line indicates the dietary fiber content of wheat, all purpose flour (USDA FDC 169761) at 3.07% g/g dry weight. Common commercial flours from rice and cassava are shown in red.

Table 2. Effect of Various Pretreatment Techniques to the Approximate Composition of Selected Agro-Waste Flours[a]

		changes in percentage							
agro-waste flour	techniques	protein	lipid	ash	digestible carbohydrate	dietary fiber	crude fiber	total carbohydrate	refs
buriti peel	blanched for 3 min	−18.7%	−5.3%	−45.9%	+179.1%	−0.9%	n.d.	n.d.	26
pequi peel	blanched for 6 min + soaked in water (4 °C; 24 h)	+28.3%	+200.8%	−42.1%	−61.3%	+31.0%	n.d	n.d.	39
	blanched for 6 min + soaked in water (4 °C; 48 h)	+27.9%	+184.5%	−44.5%	−98.0%	+52.5%	n.d	n.d.	
	blanched for 6 min + soaked in water (4 °C; 72 h)	+31.3%	+197.7%	−46.7%	−99.97%	+53.3%	n.d	n.d.	
pumpkin peel	cooked for 20 min without flour-making process	−54.7%	+48.1%	−44.6%	+5%	n.d.	−44.0%	n.d.	74
potato peel	peeling techniques (abrasion vs steam)	+10.9%	+91.1%	−22.3%	−63.1%	+112.4%	n.d.	n.d.	43
Bruguiera gymnorrhiza peel	fermentation by 0.2% tempeh mold	+3.8%	−27.8%	−31.2%	n.d	n.d	n.d	+4.4%	44
	fermentation by 0.4% tempeh mold	+ 5.5%	−31.5%	−31.7%	n.d	n.d	n.d	+4.7%	
	fermentation by 0.6% tempeh mold	+21.7%	−28.6%	−21.3%	n.d	n.d	n.d	+2.5%	
pineapple peel	fermentation by *Lactobacillus* and *Bifidobacterium*	+23.9%	−43.1%	n.d	n.d	n.d	−5.1%		23
citrus peel	fermentation by *Trichoderma viridae* for 24 h	+73.3%	+82.5%	−1.8%	−6.7%	n.d.	+9.0%	n.d	95
	fermentation by *Trichoderma viridae* for 48 h	+122.1%	+88.9%	−0.7%	−11.6%	n.d	+18.1%	n.d	
	fermentation by *Trichoderma viridae* for 72 h	+199.3%	+95.2%	+0.4%	−19.0%	n.d	+31.7%	n.d	
	fermentation by *Trichoderma viridae* for 96 h	+147.5%	+92.1%	−0.3%	−15.6%	n.d	+30.9%	n.d	

[a]Data on water content or humidity were used to normalize the approximate data for comparison.

product's physical features. For example, the soluble fiber may interact with water and forms a viscous solution and even gel and thus are often implemented in liquid-colloidlike products such as ice cream or yogurt with less negative effects on the rheology than solid flour/dough.[61,91,92] The water retaining capability of fiber increases the dough stickiness but also interferes with the extensibility of gluten and leads to an easier breakdown of the dough.[20,93] Generally fiber and especially the insoluble fiber increases the hardness of the end-products possibly due to the higher amount of total solid and impairs dough properties and flour gelatinization due to a lower level of starch.[94] Other changes of the properties of dough can also be given from attraction or repulsion intermolecular interactions between the fiber and other biomolecules. A comprehensive review about dietary fiber, its functional physical properties on food, determination, and detail characterization on type of dietary fiber on various foods is written by Tejada-Ortigoza and colleagues.[91] As expected, the fiber content in peel is significantly higher than that of common commercial flours (Figure 6). Exceptions are jabuticaba, corn cob, kiwi, white grape peel, potato, and certain types of banana peels. Taking a look at crude fiber levels, pumpkin peel shows comparable values to rice and cassava flour and seems to be promising to be used as a substitute for raw materials.

Considering approximate composition data from the published studies, it seems quite difficult to completely substitute commonly used flour (wheat, rice, etc.) by flour obtained from peel-based agro-waste. For example, the data sets for corn cob and red grape peel data show promising levels of protein but apparently contain high amounts of fat.[24,31−33] Other data sets indicate high fiber, hence, low digestible carbohydrate content, but appear to be difficult to substitute wheat flour in a larger ratio, for instance, above 30%. Examples include buriti, cupuasu, lime shell, papaya, and pineapple peels (Figures 5 and 6).

Several studies suggested various pretreatment techniques to improve the nutritional value of the materials in addition to reducing the amount of antinutrition compounds (discussed below). While Table 2 shows the changes in ratio, the absolute value of proximate contents can be found in Table 1. The large percentage cannot be due to the significant change but rather from the already small denominator of the flour approximate levels. For example, blanching in boiling water followed by soaking in cold water for days has been proposed. It was, however, also found that blanching did not significantly change the concentration of the approximate components with the exception of a reduction in ash content, possibly due to better water solubility of minerals in comparison to biomolecules.[26,39] In an extreme case, the digestible carbohydrate content was reduced to nearly 100%, followed by a large increase of dietary fiber content in the soaking treatment of pequi peel which hints at a complete wash of soluble carbohydrates upon soaking.[39] Pumpkin peel also shows an acceptable level of approximate values except for its low protein after cooking treatment without a further flour making process.[74]

Another strategy to manipulate the contents is by fermentation in which the reaction depends on the enzymatic processes. It is to be noted that fermentation processes can simply be a biotransformation and differ when using different inoculum. Reports on the effectiveness of fermentation treatments varied. For example, no significant changes were obtained in the case of *Bruguiera* fungal fermentation as can be followed from the relative standard deviation from Table 1;[44] a large increase in protein was observed followed by reduction of carbohydrates, but no other proximate components changed when using *Trichoderma viride* enriched pineapple peel;[95] and a reduction in fat content and an increase in protein level was discerned in fermented citrus peel powders.[23] It is also possible that the change in the proximate components level is due to the added inoculums in the peel materials.

Peeling techniques can also affect the quality of the raw materials. Abrasion peeling retains higher starch content with less dietary fiber and lipid in comparison to steam peeling (e.g., potatoes).[43] Aside from high ash content, various potato peels displayed acceptable levels of protein and fat, along with lower dietary fiber content simply with manual peeling.[42] Therefore, composite flour made from combinations of raw materials, a suitable peeling technique, and possibly pretreatment could serve to diversify the usage of raw materials, hence alleviating food shortages.

OVERVIEW OF FUNCTIONAL PROPERTIES AND PRODUCT APPLICATIONS

Many different types of fruit peel flour have been reported to show functional properties important for food production (see Tables 3 and 4). Among all papers reviewed in this study, two dominant purposes emerge when applying fruit peel flour as one of the ingredients in food products, i.e. texture improvement and health benefits, such as lowering the GI (Glycemic Index) and fighting obesity. Several studies have explored antioxidant capacity, phenolic content or other phytochemical profiles of flour from agro-waste. Also pectin or gluten related characteristics and physical properties like Water Holding capacity (WHC), Oil Holding Capacity (OHC), Swelling Capacity (SC), pH, rheological behavior among others have been considered.[20,39,42,65]

Utilization of peel-based composite flour has been reported, and some potential end-products are compiled in Table 5. However, the optimum substitution rate has to be established. An example for a substitute of regular flour is mango peel flour (MPF). When substituting wheat flour in biscuits by increasing levels of MPF in the range of 5−20%, the dough stability and expandability decreased due to less gluten and a higher level of dietary fiber.[69] The biscuits were harder, darker in color, and tasted bitter with increasing proportions of MPF. The change in color might be due to browning based on the oxidation of phenolic compounds. On the other hand, higher dietary fiber content increased the rate of water absorption. It was reported that substitution by 10% MPF was best in terms of end-product quality. Such MPF-enriched biscuits might have the gained benefit of the antioxidant compounds such as phenolics and carotenoids.[69] Similar trends by adding mango peel flour have also been reported in other studies.[65,68,72,73]

Additionally, it was found that in a study increasing MPF levels are related to a slower rate of digestion.[67] The insoluble dietary fiber layer seems to cover food matrixes while soluble fibers trap other soluble molecules by gel formation. Although generally an antinutritive effect, it could advantageously be used to support a low-glucose diet. A sponge cake containing 30% MPF, for instance, had the lowest predicted glycemic index due to the slow rate of digestion and absorption of starch. The high content of fiber in MPF also increased the density of sponge cake.[67]

Another example for the application of agro-waste as a substitute is jabuticaba peel flour (JPF).[96,97] Ferreira et al. (2020)[97] employed 5−15% of JPF to substitute wheat flour in whole-grain pan bread. The JPF addition caused an increase in the water absorption ability of the end-product, rendering it faster to become soggy due to the fiber content as well as darker in color.[97] However, if stored for a shorter time, such end-products are crispier and therefore could be marketed in the form of dry goods. Toasted bread was found to have a better texture and surface feeling after the addition of orange peel flour or cupuasu peel flour.[23,37] However, it depends on the type of end-product; bread enriched with orange passion fruit peel flour had better overall consumer acceptance than cake enriched with the same agro-waste.[59]

One particularly interesting example of a quite different value-added end-product is ice cream. Apparently, adding more fiber from peach flour increased the viscosity of the ice cream, improved its texture, and enhanced its melting rate compared to that of the control,[61] which indicates that ice cream can be a promising candidate for incorporating higher

Table 3. Phenolic Compounds in Agro-Waste Flours[a]

study	agrowaste flour	phenolic compounds		total tannins	total flavonoids			anthocyanin
96	jabuticaba peel	2.45 mg GAE/g flour		6.47 g/100 g	110.97 mg CE/100 g flour			41.93 mg of cyanidin-3-glucoside/100 g flour
23	citrus/orange peel				hesperidin (%)	nobiletin (%)	tangeretin (%)	
	unfermented-100 °C	79.3 mg GAE/g flour			5.3	2.7	3.6	
	unfermented-150 °C	132.3 mg GAE/g flour			6.1	3.5	4.9	
	fermented-100 °C	47.1 mg GAE/g flour			7.8	n.d.	n.d.	
	fermented-150 °C	63.3 mg GAE/g flour			6.1	n.d.	n.d.	
25	kiwi Peel							
	Var. Bruno	12.5 mg GAE/g flour			280 mg QE/100 g flour			
	Var. Monty	8.5 mg GAE/g flour			490 mg QE/100 g flour			
26	buriti peel							
	blanched	934.6 mg GAE/100 g flour						4085.3 mg proanthocyanidins/100 g flour
	unblanched	785.1 mg GAE/100 g flour						5008.1 mg proanthocyanidins/100 g flour
28	cactus pear peel	2243.84 ppm						
29	cactus pear peel	2776.0 mg GAE/100 g flour						
31	red grape peel	1063.58 mg GAE/g flour						
38	pumpkin peel	496.97 mg GAE/100 g flour						
	pequi peel	20893.73 mg GAE/100 g flour						
39	pequi peel	total phenolic compound = 85.60 mg/g flour		14.51 ± 0.12 mg/g flour				
42	potato peel	caffeic acid (μg/g flour):	chlorogenic acid (μg/g flour):		α-solanine (μg/g flour):	α-chaconine (μg/g flour):	solanine + chaconine (μg/g flour):	
	red potato (RP)	244	1478		572	1604	2180	
	gold potato (GP)	138	1148		636	1301	1940	
	organic Russet (OR)	133	2293		268	593	861	
	nonorganic Russet (NOR)	215	6422		347	781	1128	
45	banana peel							
	extractable polyphenols	7.71 mg GAE/g flour						
	condensed tannins	30.98 mg GAE/g flour						
	hydrolyzable tannins	20.06 mg GAE/g flour						
19	papaya peel							
	Hawai	5.75 mg TA/g flour						
	Calimosa	5.53 mg TA/g flour						
68	mango peel	96.2 mg GAE/g flour						
64	mango peel							
	wheat flour (control)	n.d.			n.d.			8.35 mg anthocyanin/g flour
	green peel flour	102.41 mg/g flour			33.00 mg/g flour			215.74 mg anthocyanin/g flour
	ripe peel flour	70.20 mg/g flour			29.24 mg/g flour			425.02 mg anthocyanin/g flour
72	mango peel	3.4%						
66	mango peel	84.55 mg GAE/g flour						
65	mango peel	98.96 mg GAE/g flour						

[a] GAE, gallic acid equivalent; CE, catechin equivalent; QE, quercetin equivalent; TA, tannic acid equivalent.

Table 4. Antioxidant Property, Vitamin C, Carotenoids, and Chlorophyl Contents of Agro-Waste Flours

		antioxidant capacity							
			DPPH[a]						
study	agro-waste flour	ABTS (μM TE per g)[a]	(μM TE per g)[a]	IC50	(mg AAE/g)[a]	(mg Vit.E equiv./g)	FRAP (μM Fe_2SO_4/g)[a]	vitamin C (mg/100g flour)	carotenoids/chlorophyl (μg/g flour)
96	jabuticaba peel		468.54				169.17		
23	citrus/orange peel								
	unfermented-100 °C				42.5	156.5			
	unfermented-150 °C				75.9	336.9			
	fermented-100 °C				11.7	125.9			
	fermented-150 °C				19.1	192.3			
25	kiwi peel								
	Var. Bruno			8 mg/mL extract			360 (μmol TE/100 g flour)	100	carotenoids = 2400; chlorophyl = 120
	Var. Monty			8 mg/mL extract			410 (μmol TE/100 g flour)	175	carotenoids = 2500; chlorophyl= 100
26	buriti peel								
	blanched			413.1 g sample/g DPPH			155.5 (μmol Fe_2SO_4/g flour)		10.40
	unblanched			1036.7 g sample/g DPPH			88.9 (μmol Fe_2SO_4/g flour)		11.87
29	cactus pear peel		274.7						10.90
30	cactus pear peel	2.6							
	pineapple peel	1.5							
31	red grape peel	270	460				165		
38	pumpkin peel	78.21					69.37		249.04
	pequi peel	2105.18					6292.11		33.80
45	banana peel								
	extractable polyphenols	84.73							
	condensed tannins	67.64							
	hydrolyzable tannins	49.65							
19	papaya peel								
	Hawai							337	
	Calimosa							296	
68	mango peel			79.6 (μg)					3092
	mango peel								
64	wheat flour (control)		n.d.				n.d.	157	0.15
	green peel flour		54.23 (mg/g)				70.53 (mg/g)	10971	96.91
	ripe peel flour		43.30 (mg/g)				65.92 (mg/g)	5251	160.64
66	mango peel			0.05 (mg)					
65	mango peel	EC50 = 0.09 μg AAE/g							

[a] ABTS, 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid; DPPH, 2,2-diphenyl-1-picrylhydrazyl; TE, Trolox equivalent; AAE, ascorbic acid equivalent; FRAP, ferric reducing antioxidant power.

Table 5. Effect of Agro-Waste Flour Addition to Food/Feed Products

			effect of flour addition to product functional properties					
study	agro-waste flour	developed product	antioxidant source	fiber source	antiobesity	lower GI	low calorie	additional issue related to functional compound in product
97	jabuticaba peel	pan bread	+	+				
96	jabuticaba peel	cookies	+	+				
22	jabuticaba peel	extruded breakfast cereals	+					
23	citrus/orange peel	doughs for bread making						The unfermented-150 °C extract showed better antioxidant activity, higher polyphenols, and functional flavonoid components
	unfermented-100 °C		+	+				
	unfermented-150 °C		+	+				
	fermented-100 °C		+	+				
	fermented-150 °C		+	+				
28	cactus pear peel	biscuits	+					
29	cactus pear peel	biscuits	+	+				Cactus pear peel flour contained higher phenolic compounds, careotenoids, and fiber in biscuits.
31	red grape peel	cookies	+				+	The flour itself was low in calories and dietary fiber content and had high antioxidant capacity.
42	potato peel	experimental mice feed	+		+			Supplementation of high-fat diets with 10 or 20% potato peel powders reduced 73% of body weight.
69	mango peel	soft dough biscuits	+	+				The total dietary fiber, polyphenols, and carotenoid increased with incorporation of 20% mango peel flour.
68	mango peel	macaroni	+	+				
72	mango peel	bread	+					Adding 5% of mango peel powder significantly reduced the starch digestion rate and maintained good sensory and texture quality of the bread.
66	mango peel	extruded snacks	+	+				The final product was high in fiber and phenolic compounds.
65	mango peel	tortilla chips	+	+		+		Tortilla chips enriched with mango peel flour exhibited a lower in vivo glycemic index (GI) and higher phenolics and fiber.

substitution ratios of agro-waste. It has to be mentioned though that ice cream is not considered a staple food.

Impact of Agro-Waste Flour Incorporation on Sensory Properties and Consumer Acceptance. The incorporation of peel-based raw materials into food products had a clear effect on their sensory characteristics and the overall customer acceptance (Table 6). It is quite obvious that in general an increased proportion of peel-based agro-waste as wheat flour substitute decreased dough extensibility, darkened the color, frequently added a bitter after-taste, and enhanced the rate of water absorption of the end-product. Therefore, there is a limitation on how much agro-waste raw materials can be substituted for wheat flour. Of course, it also depends on the type of raw material used. The highest substitution ratio was reported for orange passion fruit peel flour−wheat flour with a ratio of 50:50.[59] However, the acceptance score turned out to be significantly lower. In general, for most agro-waste substitutes, such as mango, banana, passion fruit, and lime peels, the maximum ratio of substitution was approximately 10%.[48,49,57,63,65,67,69,98]

Antinutritional Content of Agro-Waste Based Food Products and Potential Pretreatment Techniques. Potential problems when using agro-waste-based raw materials for food consumption are antinutritional factors. Compounds that have an antinutritional impact are those that reduce effective utilization of nutrients and/or the digestion of food from plant materials. In nature, these compounds serve the plant to defend itself against herbivores. For example, grain producing plants are especially rich in carbohydrates, lipids, and proteins, and to protect themselves, they might generate chemical compounds that have a negative impact on human consumption. These compounds include lectins, oxalates, nonprotein amino acids, alkaloids, glycosides, saponins, tannins, isoflavones, phytates, and others. At low concentrations, these compounds may initially function as antioxidants. However, upon accumulation in the body, they can reach toxic levels. These antinutritional compounds are present in various types of plants and in different amounts.[99,100]

Tannins, for example, are phenolic compounds that are bitter in taste and that can bind or precipitate protein and various other organic compounds, such as amino acids and alkaloids. Thus, tannins are said to reduce protein digestibility in animals and humans. Tannins chelate minerals and form complexes with various proteins of the digestive system.[101−104] However, in general, the amount of phenolic compounds varies depending on the drying method.[97] Tannins have been found in in jabuticaba peel flour in fairly high concentration. The amount of condensed tannins in Jabuticaba skin showed a moderate level compared to other fruits, such as guava and Brazilian cherry.[96]

Orange peel and kiwi peel flour have also been analyzed for phenolic compound content.[23,25] In kiwi, the concentration of these phenolic compounds seemed to decrease as the fruit ripened. Influencing factors included the growth conditions of the plant itself, soil composition, preparation for plant extraction, the extraction process, the methodology used to

Table 6. Acceptance and Sensoric Evaluation of Studied Peel-Based Substituted End-Products

study	agro-waste flour	product	acceptance and sensoric evaluation of product
69	mango peel (MP)	biscuit	The greater the concentration of MP, the darker the biscuits. Biscuits with MP up to 10% were acceptable.
68	mango peel (MP)	macaroni	Increasing the MP proportion created darker color in macaroni. Macaroni with MP up to 5% were acceptable.
67	mango peel (MP)	sponge cake	The crust and crumb of sponge cakes were darker as the MP concentration increased. Sponge cakes with MP up to 10% were acceptable.
72	mango peel (MP)	bread	The crumbs of bread were darker as the concentration of MP increased. Bread with addition of MP greater than 10% had significant hardness. The chewiness of bread increased 2 times when 10% MP was added.
73	mango peel (MP)	pasta	Pasta with 5% MP was acceptable. Addition of 5% MP improved the color of pasta control significantly.
65	mango peel (MP)	tortilla chips	Tortilla chips with 5% and 10% MP were acceptable.
96	jaboticaba peel (JP)	cookies	Cookies with 2.5% JP and vanilla essence were the most favorite.
23	orange peel (OP)	toast bread	Toasted bread with F (fermentation)-100 °C 2% OP had the best color. Toasted bread with UF (without fermentation)-150 °C 4% OP had the best flavor. Toasted bread with UF-100 °C 6% OP had the best hardness and surface feeling. Toasted bread with UF-150 °C 4% OP and UF-100 °C 6% OP were the best in terms of overall acceptability. Toasted bread with unfermented OP was much acceptable in surface feeling, hardness, flavor, and overall acceptability but not in color
28	cactus pear peel (CPP) dried cactus pear peel (DCP)	biscuits	Biscuits with CPP AIS had the best color and overall acceptability. Biscuits with 10% of CPP AIS or 10% of DCP were not acceptable. Biscuits with CPP AIS or DCP up to 7.5% were acceptable.
29	prickly pear peel (PPP)	biscuits	Biscuits became darker as the level of PPP increased. Biscuits with 30% PPP were more difficult to chew and took the longest to be ingested. Smell and taste acceptance scores of biscuits increased as the concentration of PPP increased. 20% and 30% PPP reduced the crispness of biscuits.
37	cupuassu peel (CP)	whole bread	Breads with 0, 6, and 9% CP had darker crust. Breads with CP up to 6% were acceptable.
48	plantain peel (PP)	cookies	The thickness of the control was lower than cookies supplemented with PP. Cookies became darker and softer with increasing PP. Cookies supplemented with 10% PP had high scores for color, taste, texture, and overall acceptability.
98	green banana peel (GBP)	gluten free cakes	Color of gluten free cakes became darker as the concentration of GBP increased. Gluten free cakes supplemented with 15% and 20% GBP had poorer physical properties. Gluten free cakes with 5% and 10% GBP were acceptable.
49	banana peel (BP)	chapatti	The stickiness and strength of the chapatti dough increased as BP increased. The rating for the kneading and rolling of the chapatti dough increased as the percentage of BP increased. Chapatti dough became darker as the percentage of BP increased. Chapatti became softer as the percentage of BP increased. Chapatti with BP up to 10% had a good taste.
57	passion fruit peel (PFP)	cookies	Cookies with 5% and 10% of PFP were only significantly different in aroma. Cookies with 10% PFP were recommended.
59	orange passion fruit peel (OPFP)	bread and cake	Lightness, redness, and yellowness of the bread control and bread with 15% OPFP were not significantly different. Bread supplemented with OPFP had better acceptance than the cakes. All of the formulations tasted had acceptance of 70% for all sensory parameters.
20	papaya peel (PE) and watermelon rind (WR)	thepla	Tear force and extensibility values of thepla decreased as the concentration of PE and WR increased. Thepla got darker as the concentration of PE increased. However, WR counteracted this effect. No significant difference in sensory acceptance for all formulations, except for thepla with 6% and 9% WR
61	peach peel	ice cream	Addition of peach peel lowered the overrun rate of the ice creams. Ice cream with 1% peach peel had the shortest complete melting point Ice cream with 2% peach peel had the lowest color scores Ice cream with the addition of peach peel had high score in organoleptics test
63	lemon shell (LS)	cake	The cake control and cake with the addition of 10% of LS were similar. Cake with the addition of 30% of LS was bitter, green, and had an unpleasant color. The hardness of cakes increased as the percentage of LS increased.
76	almond skin (AS)	biscuits	The addition of AS increased caramel and leafy odors, darkened the color of biscuits, and increased the friability and graininess of biscuits. The addition of AS decreased the thickness and increased the diameter of biscuits. The weight loss of biscuits were reduced when AS was added.

identify the phenolic compound, and the choice of solvent. Kiwi peel flour also showed coliform contamination at 35 °C, which can be explained by the fact that the skin of any fruit is most exposed to environmental conditions and contamination. Results of coliform concentration in Soquetta et al.'s (2016) study, however, were within the prescribed legal limits at 45 °C.[25]

Studies of Buriti skin,[26] cactus pear peel,[28,29] and grape skin flour[31] showed that processing treatments, such as blanching, could reduce the phenolics concentration by inactivating specific enzymes, such as polyphenol oxidase. Twenty-four phenolic compounds were identified in cactus pear peel powder, with the major components being pyrogallol, catechol, and catechin.[28] It was observed that the phenolics concentration could be reduced when prickly pear skin flour was exposed to partial thermal degradation under conditions such as during baking.[29] Phenolic compounds were also detected in red grape skin flour with varying levels due to many factors such as climate and also the level of fruit maturity.[31]

The results of phytochemical analysis on Cupuassu peel flour showed the presence of tannins, phytic acid, and other phenolic compounds. The addition of cupuassu peel flour as a food ingredient is known to reduce protein digestion by *in vitro* protein digestibility experiment. However, this effect may also be due to the addition of dietary fiber which forms a complex with protein or the presence of antinutritional tannins and phytic acid.[37] Phytic acid causes a decrease in the bioavailability of several essential minerals and forms complexes with protein through direct interaction or mediated with metal ions.[100] Binding thermodynamic analyses between phytate and various divalent metal ions reveal dissociation constants in the micromolar range, especially for Fe^{2+} and Ca^{2+}. The binding constants were found to be dependent on pH.[105] Similarly pequi skin flour[38,39] was reported to also contains lectins, trypsin inhibitor, and tannins.

Potato skin is high in glycoalkaloid and proteinase inhibitors which are potentially toxic.[42,106] The major glycoalkaloid components found were alpha-kakonin and alpha-solanine. The levels of these glycoalkaloids vary and might change during storage and postharvest processing.

Bruguiera peel flour contains tannins and hydrogen cyanide (HCN) as antinutritional factors.[44] Cyanide develops from cyanogenic glycosides when consumed. So far, an ash suspension has been used to reduce HCN and tannin levels because the ash can absorb these compounds. Fermentation with mold apparently also resulted in reduced tannin and HCN content.[44]

Banana peel flour has a lower extractable polyphenol content than nonextractable polyphenols, although condensed tannins and hydrolyzable tannins are present at a higher concentration. The presence of polyphenol compounds in banana peels is related to the natural defense system of plant tissues against abiotic stress.[45,47,48] Another study showed that flavonol glycosides were found to be dominant in banana peels.[46] Phenolic compounds were also detected in passion fruit skin,[55,59] papaya peel,[19] peach skin,[61] and mango peel flours.[68,69] In mango peel flour, one of the factors that seemed decisive was the level of fruit maturity. The reduction in total phenolics in ripe mangoes might occur through oxidation of phenolic compounds by polyphenol oxidase.[64]

To manipulate antinutritional compound contents, several pretreatment processes have been suggested in a number of studies. Beside fermentation, soaking (or maceration) and blanching in hot water are frequent domestic treatments that are used to prepare food at home and have been reported to be generally beneficial for enhancing the nutritive value by removing soluble compounds. On a technological level, these techniques may be an alternative to decrease the content of antinutritional compounds present in, e.g., pequi peel flour.[39] Trypsin inhibitor content decreased considerably after soaking possibly due to its water-solubility or due to the extraction of ions essential for the inhibitor's activity. Also, there was a significant reduction in phytic acid content with increased maceration time. Soaking also improves starch digestibility, thus conferring improvement of nutritional characteristics to the pequi peel flour.[39]

It is argued, however, that various heat-related preprocessing treatments such as blanching and roasting tend to increase the degradation of vitamins.[107,108] However, heat treatments such as blanching, roasting, and frying managed to modulate approximate contents, mineral compositions, and antinutrients. In a study using corn, heat treatments managed to reduce various antinutrients such as phytate, saponin compounds, trypsin inhibitor, including heavy metals such as selenium, although not statistically significant.[108] Additionally, conventional cooking and microwave heating of vegetables led to a significant decrease of polyphenol content.[73,109,110] Surprisingly, roasting and extrusion apparently did not alter polyphenol content in one study using buckwheat flour.[111] Heat treatment in blanching may manage to deactivate several enzymatic processes. As such, blanching might also be beneficial to retain antioxidant activity and brightness by reducing the activity of the oxidizing enzyme such as polyphenol oxidase.[26] Furthermore, it was found that using more intense processing such as heat sterilization treatment gives better volatile chemical compound profiles that are related to better aromas than soaking in chickpeas.[112]

Bias Across Study. Our analyses suffer from various incompleteness and different methods/units employed by each research study. Indeed, the AOAC guideline is a compilation of standard methods that should be used when dealing with food analytics. However, there are studies in which the IR-based rapid test is used to determine the fiber content of a grape peel.[32−36] One study using orange peel did not include ash content in the approximate determination.[23] We also perform normalization toward dry weight as mentioned above so that comparison can be done in a fairer way. However, the most crucial difference in the proximate analysis is the determination of fiber and carbohydrate contents. As can be seen in Table 1, there are two approximate values for the fiber section which were determined from two different methods, i.e., traditional enzymatic-gravimetric treatment to analyze dietary fibers and chemical treatment to yield crude fiber. However, the fiber content determination using crude fiber will always underestimate the amount of total fiber since crude fiber is just a fraction of dietary fiber. As mentioned above, the reported dietary fiber itself might contain errors and might not reflect the total amount of fiber in the sample. The integrated methodology techniques (AOAC 2009.1 and 2011.25) are superior to the traditional techniques (AOAC 958.29 and 991.43), further separating fiber solubility after enzymatic treatment by ethanol which analyzes the fiber in a more comprehensive way to measure resistant starch and low molecular weight fiber. The traditional technique for dietary fiber determination was studied to also underestimate the dietary fiber value in comparison to the integrated method-

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ology.[89] The error is then carried over to the carbohydrate determination (nitrogen free extract) in which its calculation is just by difference. There is a trend in which the determined carbohydrate seems to be higher in which the value is apparently subtracted from crude fiber and then overestimated.

Furthermore, various antioxidant activity analyses[113,114] are rather semiquantitative measurements in which the resulting values are just relative/equivalent to various standard antioxidant compounds or the oxidizing agent used in the study. With the exception of HPLC, determination of total phenolic and total flavonoid contents suffer from various setbacks due to the nature of the methods and the standards themselves. For example, the total phenolic content is determined using Folin−Ciocalteu utilizing the oxidation−reduction reaction of phosphotungstate and phosphomolybdate. Depending on the concentration and the reduction potential,[115] other compounds which can exert reduction activity, such as vitamin C or carotenoid from the terpenoid class may interfere with the analytical determination. Furthermore, absorbance/emittance and other electronic transitions obtained from spectroscopic analysis are highly dependent on the environmental conditions which are disregarded in the measurement of crude extract to the standard compounds. These facts also apply to the determination of antioxidant activity using various free radical species (ABTS, DPPH) or ferric reducing power assay. In terms of units, different standard compounds (trolox, gallic acid, catechin, quercetin, etc.), units (g/g, ppm, IC50, molar and mol), and experimental conditions make the comparison between studies seem unfair.

On the other hand, uncertainties are reduced in various studies that try to measure vitamin C[64] and carotenoids content by standard titration or spectrophotometry preceded by proper purification techniques[25,29,38] under the assumption of a similar molar extinction coefficient in a particular solvent. It should be reminded that carotenoid is a class of various tetraterpenoid compounds in which different proportions display different absorbance quantities in a particular wavelength. Additionally, the method for the determination of chlorophylls and carotenoids just rely on a linear equation of the multiplication of some coefficients to several wavelengths, for example, the one that was developed by Lichtenthaler[116] is indeed a fast method. However, solely utilizing the equation without proper purification as described in the protocol confers large drawbacks for analytical purposes and can be rationalized from this method, for example, nonideal spectrophotometer conditions but mostly from different molar extinction coefficients of each mixture and wavelengths due to different environments in the solution.

The increase of the world population must be accompanied by the higher production of food. Utilizing unused byproducts such as agro-waste is one strategy to increase global food resilience. By analyzing the approximate components, nearly all materials cannot be readily to completely substituted as staple foods even with the addition of pretreatment techniques to manipulate approximate values. Substitution of commonly used plant foods can also be proposed. Additionally, some beneficial and functional effects can also be gained by further utilizing agro-waste, e.g., due to dietary fiber and secondary metabolites.

Beside reducing domestic waste, utilization of waste products is one strategy to improve the overall efficiency of the materials. The potentials of agro-waste are obviously not limited as a material for substituted flour. Several chemicals from agro-waste can also be extracted and, e.g., be used as food additives, thickening agents, and other functional materials. However, safety aspects due to various physiological effects of secondary metabolites should also be considered before fully implementing agro-waste into food products.

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Notes

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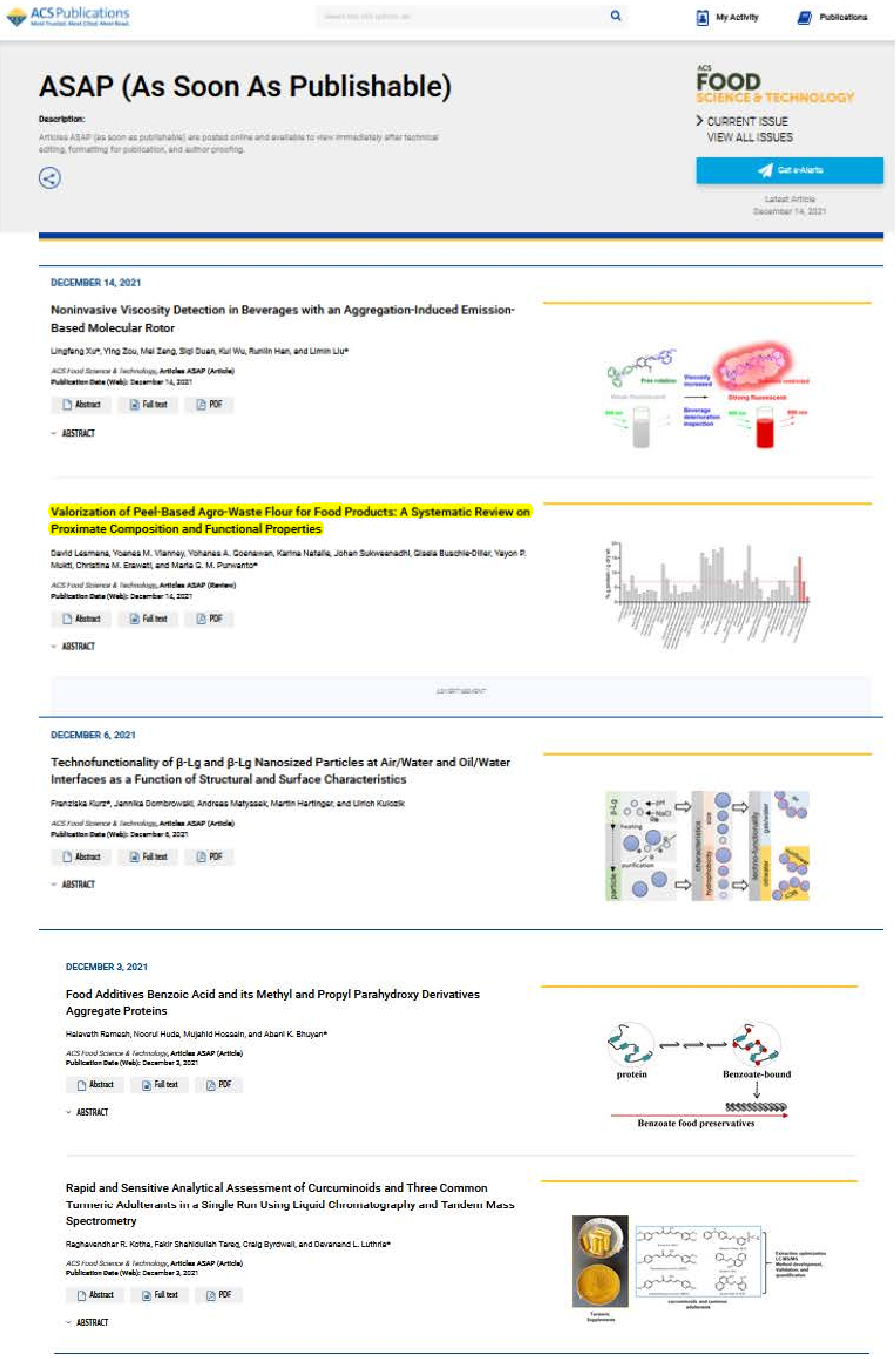

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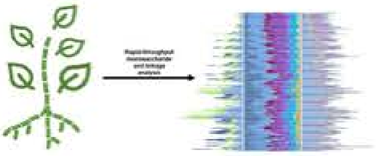

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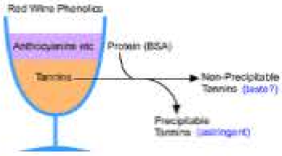

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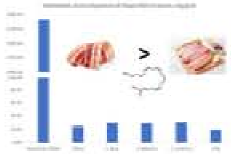

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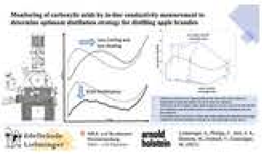

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