Critical Reviews in Food Science and Nutrition

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/bfsn20

Contribution of starch to the flavor of rice-based instant foods

Rongrong Ma, Zhengyu Jin, Fan Wang & Yaoqi Tian

To cite this article: Rongrong Ma, Zhengyu Jin, Fan Wang & Yaoqi Tian (2021): Contribution of starch to the flavor of rice-based instant foods, Critical Reviews in Food Science and Nutrition, DOI: 10.1080/10408398.2021.1931021

To link to this article: https://doi.org/10.1080/10408398.2021.1931021

Published online: 28 May 2021.

CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
https://doi.org/10.1080/10408398.2021.1931021

Taylor & Francis
Taylor & Francis Group

REVIEW

Contribution of starch to the flavor of rice-based instant foods

Rongrong Ma[a,b], Zhengyu Jin[a,b], Fan Wang[a,b], and Yaoqi Tian[a,b]

[a]State Key Laboratory of Food Science and Technology, Jiangnan University, Wuxi, China; [b]School of Food Science and Technology, Jiangnan University, Wuxi, China

ABSTRACT
Increased consumption of instant foods has led to research attention, especially rice-based instant foods. Starch, one of the most important components of rice, significantly affects food quality. However, the mechanisms by which starch contributes to rice-based instant foods flavor are poorly understood in many cases. The review aims to describe the common mechanisms by which starch contributes to food flavor, including participating in flavor formation, and affecting flavor release throughout starch multiscale structure: particle morphology, crystal structure, molecular structure. Five specific examples of rice-based instant foods were further analyzed to summarize the specific contribution of starch to flavor, including instant rice, fermented rice cake, rice noodles, fried rice, and rice dumplings. During foods processing, reducing sugars produced by heating or enzymatic hydrolysis of starch participate in Maillard reaction, caramelization and thermal degradation, which directly or indirectly affect the formation of flavor compounds. In addition, adsorption by granules, encapsulation by retrograded V-type crystal, and controlled release by starch gel all contribute to rice-based instant food flavor qualities. These mechanisms jointly contribute to flavor compounds formation and release. Proper theoretical application and improved processing methods are needed to promote the high-quality, mechanization, and automation of rice-based instant foods production.

KEYWORDS
starch; flavor; rice-based instant food; common mechanism; formation; release

Introduction

Rice is the staple food for over 50% of the worlds' population. Rice is rich in nutrients, including proteins and lipids that are essential for the human diet, and small quantities of micro-elements (Verma and Srivastav 2020). With the development of the economy and the speed up of people's life pace, instant foods have become preferred by consumers because they are simple and quick to prepare, affordable, hygienic, and consistent. Nowadays, a variety of convenience foods have occupied the market, such as instant noodles, instant rice, convenient hotpot, and others. Of these, rice-based instant foods satisfy the eating habits of consumers who consume rice as the staple food, and they occupy an important market share. Among these rice-based instant foods, instant rice, rice noodles, fried rice, fermented rice cake, and rice dumplings are the most popular among consumers.

Flavor is the key driver and main measure of food quality. For instant foods, flavor have a considerable impact on consumers selection compared with texture. Flavor compounds are usually volatile and easily to oxidized, resulting in loss or deterioration during storage. This phenomenon occurs in the rice-based instant food industry. Whilst a major source of flavor is the rice itself, the degradation of rice constituents during processing can also have a significant impact on the final flavor profile. Treatments such as high temperature, high pressure, shearing, and frying during food processing always exist and significantly affect the color, texture, and flavor of foods.

Starch is the most important carbohydrate in the human diet and provides a source of energy. In the food industry, starch has also been used as an ingredient in cereals, sauces, soups, as well as dairy, confectionary, coating, and meat products (Amagliani et al. 2016). Starch accounts for more than 70% of rice, and it can be considered as a rice skeleton. Starch has a multi-scale structure, which can be divided into molecular structure (amylopectin and amylose) (0.1–1 nm), amorphous and crystalline lamellae ($\sim$ 9 nm), blocklets (20–50 nm), growth rings (120–500 nm), and granule (2–100 μm) (Han, Shi, and Sun 2020). Granules have been reported by many researchers as adsorption materials (Fang et al. 2020; Li et al. 2021). The crystal of native rice starch is of the A-type, which is composed of compact double helixes (Bonto et al. 2021). Treatments such as heat, pressure and vibration in food processing cause starch gelatinization and/or degradation, along with the destruction of A-type crystal and transformation to amorphous (BeMiller and Whistler 2009). The process can change the viscosity and water activity of the food system, and further affect biochemical reactions rate. During cooling or storage, retrogradation promotes the transformation of amorphous to V- or B-type crystals, depending on whether there are ligands or not (Fu

CONTACT Yaoqi Tian yqtian@jiangnan.edu.cn State Key Laboratory of Food Science and Technology, Jiangnan University, 1800 Lihu Road, Wuxi 214122, China

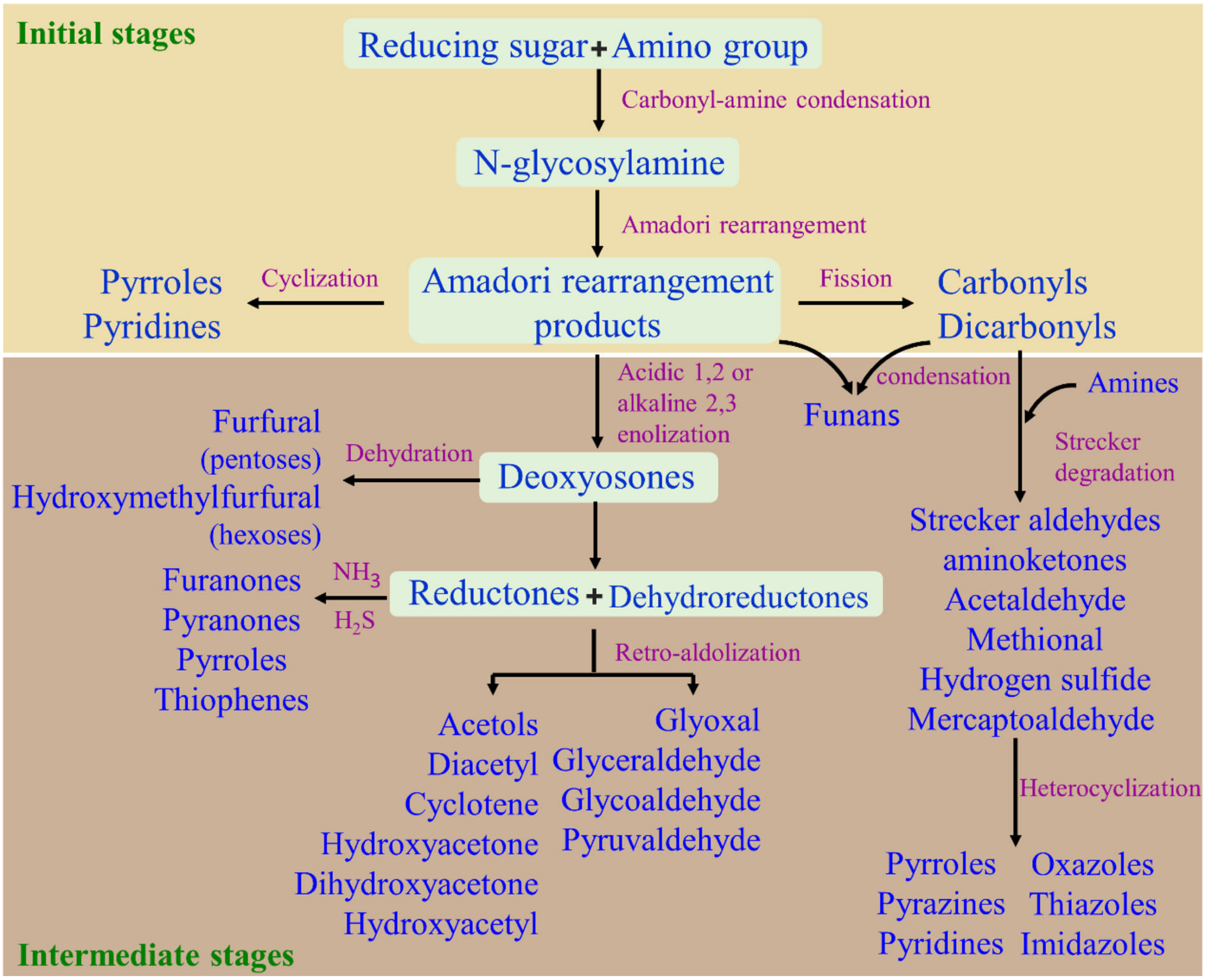

Figure 1. Possible mechanism of flavors formation in Maillard reaction with starch participation.

et al. 2015). Flavor compounds are effective ligands for inducing starch to form V-type complexes. In addition, changing the molecule structure can impact gelatinization and retrogradation (Wang and Shi 2020). Therefore, starch can be considered as a regulator and participant of the flavor formation and release.

Whether during the food processing stage or the storage phase, starch is considered to contribute to the formation and release of food flavor. From this point of view, understanding the contribution of starch to flavor formation also contributes to the development of high-quality products. However, to the best of our knowledge, no review has focused on the contributions of starch to rice-based instant foods flavor qualities. Therefore, this review summarizes the common mechanisms by which starch contributes to flavor properties of food in general, and in particular for five specific products: instant rice, fermented rice cake, rice noodles, fried rice, and rice dumplings.

Common mechanisms for the effect of starch to the flavor of rice-based instant foods

As the main component of rice-based instant foods, starch contributes to its flavor, which is mainly reflected in two aspects. On the one hand, starch molecules could participate in the formation of flavors during food processing. On the other hand, the complex multi-scale structure of starch could regulate the adsorption, embedding and controlled release of molecules responsible for food flavors.

Starch and flavor formation

Maillard reaction

The Maillard reaction is a non-enzymatic and thermally induced reaction, which is of particular importance to the flavor of rice-based products. It involves the reaction between reducing sugars and amino groups (Gao, Xia, et al. 2020).

Native rice starch has very large molecular weight (Mw) and degree of polymerization (DP). The Mw of amylose is in the range of $10^5 \sim 10^6$ g/mol, and the average DP is $10^2 \sim 10^4$, while for amylopectin the Mw ranges from $10^7 \sim 10^9$ g/mol and the average DP is about $10^3 \sim 10^5$ (Wani et al. 2012). Each amylose or amylopectin chain carries the sole reducing end group. Thus, it is generally considered that native starch cannot participate in Maillard reactions directly because of its raised steric hindrance and inert property. However, whether it is in a domestic kitchen or in food industry processing, treatments such as boiling, pressure cooking (retorting), roasting/baking, frying,

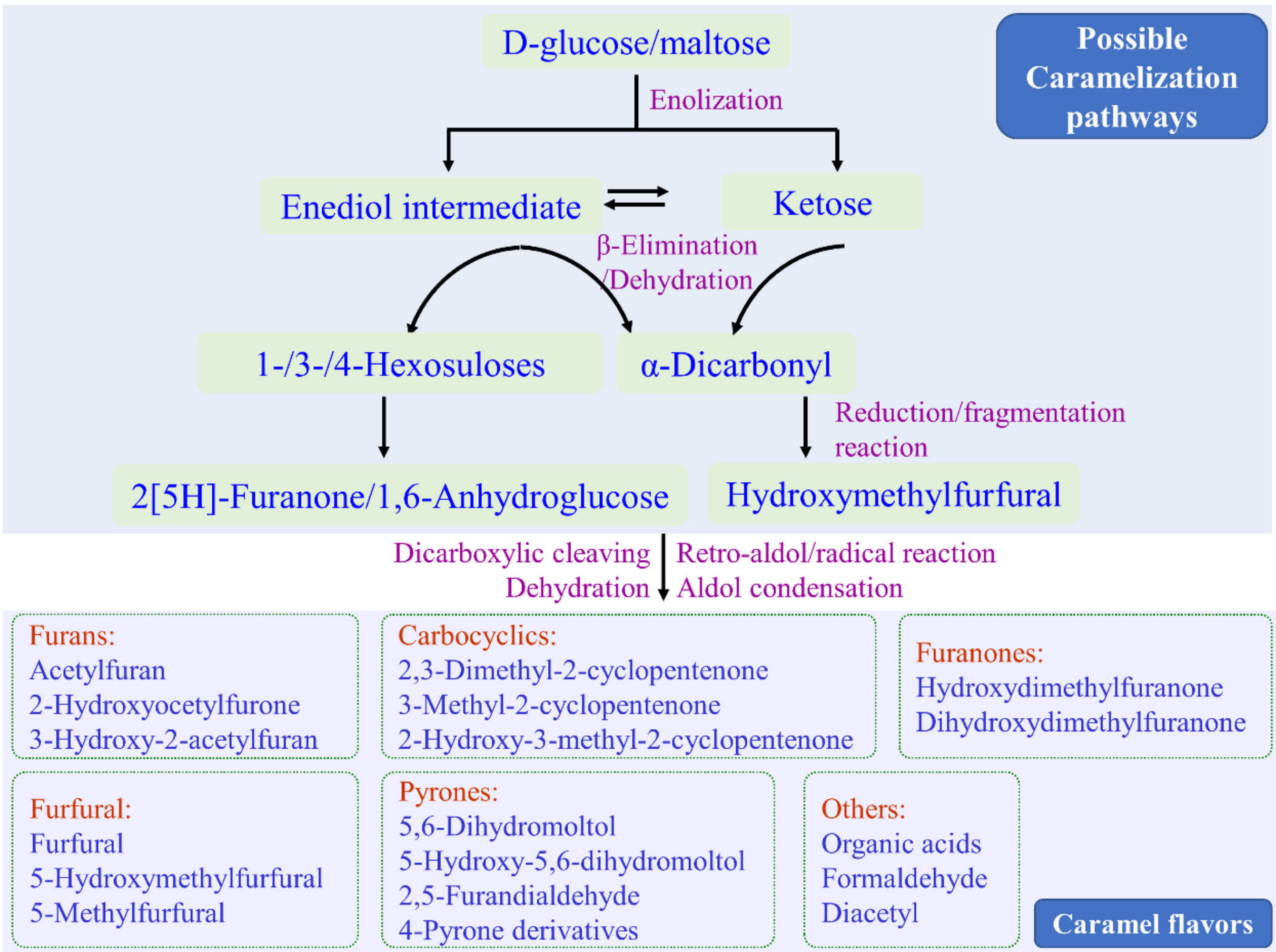

Figure 2. Proposed pathways of flavors formation by caramelization with starch participation.

pasteurization, microwaving and ultra-high temperature processing can change the structure of starch in food matrixes (Hellwig and Henle 2014; Parker 2015). In addition, rice contains endogenous amylolytic enzymes such as α-amylase (Huang and Lai 2014a; Sun et al. 2015a), which can degrade starch and produce reducing sugars such as maltose and glucose. The mechanisms by which starch influences or participates in Maillard reactions are summarized in the following two ways.

First, starch affects the Maillard reaction by changing the distribution of water molecules of the whole food matrix in the process of gelatinization. Water plays an important role in Maillard reaction because it acts both as reactant and a solvent. Water molecules location, mobility and interaction with other components of food matrixes could affect the properties of starch-based foods (Zheng et al. 2020). Water activity is often used to study the effect of moisture on the Maillard reaction. Water activity varies widely within rice-based products, ranging from high values such as in cooked rice (about 0.82) (Azanza 2014), to low values such as in fried rice (less than 0.4 of raw rice) (Ozbekova and Kulmyrzaev 2019). The Maillard reaction rate would decrease in presence of a high water activity due to reactant dilution, while the reaction would increase with a decrease of water activity due to the higher concentration of reactants. However, low water activity will also cause the loss of substrate mobility, resulting in a lower rate of reaction (Newton et al. 2012). Gelatinization is accompanied by the disintegration of blocklets and melting of amylopectin nanocrystals, with release of amylose chains into the matrix (Huang et al. 2014b). Therefore, food matrix morphology, viscosity, and water location in gelatinization process changes accordingly. It could affect water-holding attributes of foods and the probability of interaction of the substrates involved in Maillard reaction (Nooshkam, Varidi, and Verma 2020).

Second, starch molecules could be degraded by the rice endogenous amylolytic enzymes, or by treatment during food processing, and the reducing sugars produced by degradation could provide substrates for the Maillard reaction. Lu et al. (2020) studied the effect of high-temperature baking on the fine structure of waxy rice powder and found that waxy starch could be severely degraded with disruption of hydrogen bonds, and even of glycosidic bonds. Cai et al. (2019) reported that one-step reactive extrusion treatment caused heterogeneous degradation of both rice amylopectin and amylose. In addition, treatments such as enzymatic hydrolysis, acid hydrolysis, ultrasound and high pressure have also been reported to cause the degradation of starch (Almeida et al. 2019; Lacerda, Leite, and da Silveira 2019; Li

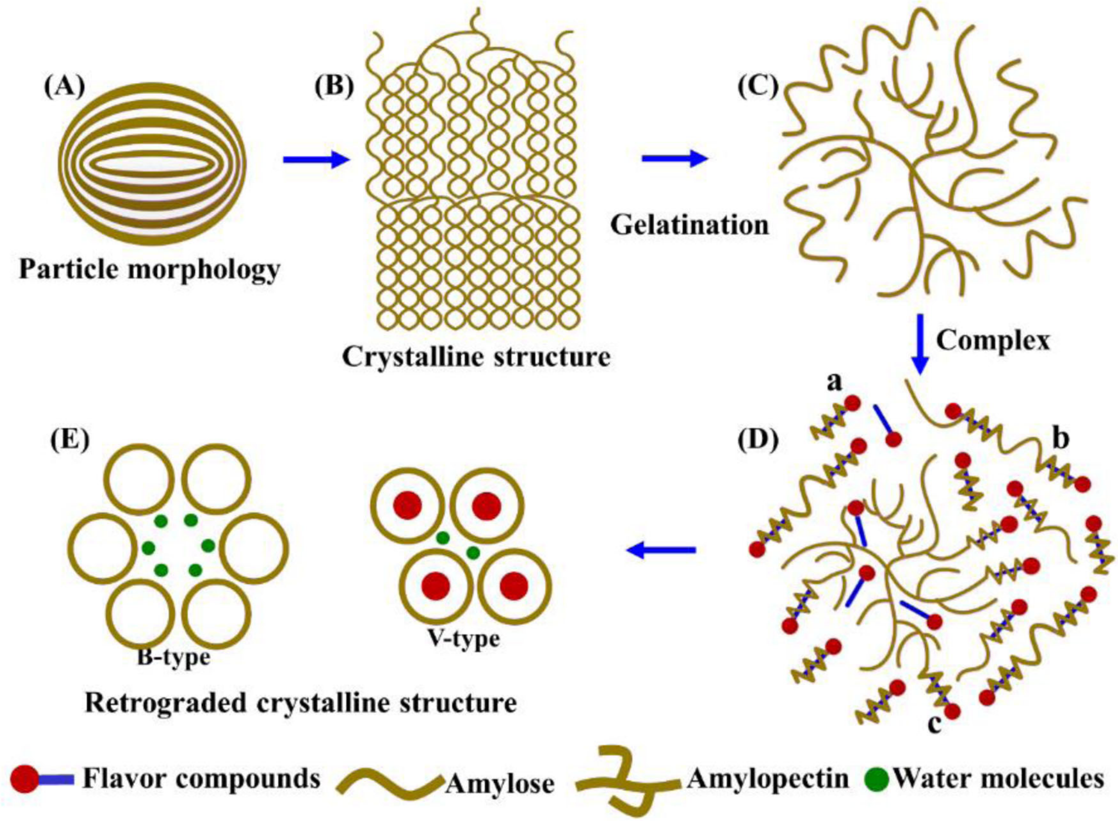

Figure 3. Diagram for starch particle structure, crystal structure and flavor encapsulation.

et al. 2017; Ulbrich, Daler, and Floter 2019; Wang et al. 2017). Maillard reaction progression is usually divided into three stages: the initial, the immediate, and the final stage, and the former two stages are considered to be the most important for flavor formation. Possible chemical pathways involved in formation of flavors during the initial and immediate stages with starch were summarized in Figure 1 (Ho and Romero 2007; Pastoriza et al. 2016). Amadori products formed in the initial stages may further be degraded into furfurals, reductones, and fragmentation derivatives, or transformed into Strecker aldehydes and aminoketones via Strecker degradation process after fission, which may later condense into pyrazine derivatives causing formation of flavor compounds in foods (Gupta et al. 2016). Especially, the popcorn-like flavor, 2-acetyl-1-pyrroline (2-AP), is the major contributor to 'aroma and roasted aroma' described in many rice-based foods such as cooked rice (Ma et al. 2020) and fried rice (Montero et al. 2020). Some researchers reported that 2-AP is formed during the process of plant growth, mainly depending on cultivated varieties (Funsueb et al. 2016; Malekzadeh and Fatemi 2015; Mo et al. 2017). But, 2-AP was also observed to be a product of Maillard reaction (Handoko et al. 2014). It can be formed by the reaction of proline and methylglyoxal through the Strecker reaction (Ruckriemen et al. 2015).

Caramelization

Caramelization usually occurs when carbohydrates, especially monosaccharides, are present alone without amino acids. It is an important no-enzymatic browning reaction with complex enolization, water elimination, redox reactions and polymerization reactions, which produce various compounds that are responsible for food flavors (Kocadagli and Gokmen 2016).

As mentioned above, reducing sugars produced by starch degradation during food processing could provide reaction substrate for caramelization. The proposed pathways of flavors formation by caramelization with starch participation were summarized in Fig. 2 (Aguiar et al. 2015; Quintas, Fundo, and Silva 2010; Sengar and Sharma 2014). The generation of flavors in caramelization requires that sugars, normally glucose and maltose produced by starch degradation, first undergo intramolecular rearrangements. After enolization reaction, β-elimination mechanism is responsible for the formation of hydroxymethylfurfural (HMF) or furanone via an enediol intermediate. With the further development of the caramelization, accompanied with complex mechanisms including dehydration, dicarboxylic cleaving et al, HMF and furanone can be degraded to various flavors, such as furfural, 5-methylfurfural, diacetyl. Most of these flavor compounds have a caramel-like aroma, which are very common in rice-based instant foods, especially fried rice.

Caramelization and the Maillard reaction could occur simultaneously consisting of parallel and consecutive reactions. Therefore, changes in water activity and viscosity of the food matrix caused by starch gelatinization are also conducive to caramelization. Except when accelerated by high temperature treatments, caramelization is a slow process (Hamzalıoğlu and Gökmen 2020a). It has been reported that caramelization could occur and be responsible for the

Table 1. Crystal forms of starch and flavor compound complexes in rice-based products.

Crystal type	Flavor in rice-based foods		Characteristic of complex
V_6	1-Butanol (Verma and Srivastav 2018)	Hexanal (Yang 2007)	Sixfold left-handed amylose helices in which the flavor is included in the cavity (V_{6I}) or entrapped between helices (V_{6II} and V_{6III}).
	1-Decanol (Zeng et al. 2009)	Hexenal (Hu et al. 2020)	
	1-Decanal (Yang 2007)	Hexanol (Concepcion et al. 2018)	
	1-Octen-3-ol (Ma et al. 2019a, 2020)	Hexanoic acid (Champagne 2008)	
	2-Acetyl-1-pyrroline (Ma et al. 2019b)	Linalool (Hu et al. 2020)	
	2-Hexanone (Verma and Srivastav 2018)	N-heptanol (Concepcion et al. 2018)	
	3-Hexen-1-ol (Verma and Srivastav 2018)	N-nonanol (Hu et al. 2020)	
	Decanoic acid (Wu, Yang, et al. 2011)	N-octanol (Ma et al. 2020)	
	(E)-2-nonenal (Ma et al. 2020)	γ-Decalactone (Ma et al. 2019ab)	
	Ethyl hexanoate (Verma and Srivastav 2018)	δ-Dodecalactone (Verma and Srivastav 2018)	
V_7	Guaiacol (Ma et al. 2019a)	Menthol (Verma and Srivastav 2018)	More space was available between helices in V_7-type crystal than V_6, and the flavor could be both partially contained within the cavity or entrapped between helices.
	Menthone (Verma and Srivastav 2018)		
B-type	2-Hexanone (Verma and Srivastav 2018)	Furaneol (Verma and Srivastav 2018)	Sixfold left-handed double helices with 36 water molecules.
	2,3-Butandione (Ma et al. 2019b, 2020)	Ethyl acetate (Verma and Srivastav 2018)	
	Benzaldehyde (Zeng et al. 2009)	Citral (Verma and Srivastav 2018)	
	3-Hydroxy-2-methyl-4H-pyran-4-on (Verma and Srivastav 2018)		
	3-Methoxy-4-hydroxybenzaldehyde (Jezussek, Juliano, and Schieberle 2002)		

change in flavor of starch-based foods during storage (Zhang, Chen, and Wang 2013). In addition, acids, bases or salts that usually exist in complex food systems are considered as the catalysts for caramelization (Quintas, Fundo, and Silva 2010). The change of viscosity and water activity could affect the substrate migration and molecular interaction between substrates and catalysts. Thus, the effect of starch on caramelization is long-term and sustained.

Starch-lipids complex separation or re-complex

In rice, the main form of lipids existence in endosperms is amylose-lipids complex. Food processing can free amylose from granules and cause complex separation. The degradation of lipids by biochemical reactions or heat gives rise to a wide range of flavor compounds (Shahidi and Abad 2019). Besides the Maillard reaction and caramelization, it is another important way to produce flavor compounds. However, flavor deterioration may occur during storage, characterized by the loss of pleasant flavors or by the formation of off-flavors. The majority of flavor compounds are produced from lipids by three processes: lipoxygenase pathway, β-oxidation, and α-oxidation, with production of various molecules, including aldehydes, ketones, lactones, esters, acids, and others (Wang et al. 2020a). These flavor compounds are prone to directly or indirectly undergo a process of deterioration. In addition, these oxidation products have shown possible harmful effects on health (Hamzalıoğlu and Gökmen 2020b). Many researchers have reported that starch can form V-type crystal with lipids (Cervantes-Ramirez et al. 2020; Lopez, de Vries, & Marrink, 2012). Therefore, the formation of starch-lipid complexes during storage can reduce lipid peroxidation, which is conducive to improving the flavor of rice-based instant foods.

Starch particle morphology and flavor adsorption

Starch is usually spherical or ellipsoidal in shape (Fig. 3A), but with protrusions, depressions, and pores in the granules surface. Small pores, less than 100 nm diameter in size, have been observed on the surface of rice starch granules, which might be formed under genetic control during granule growth (BeMiller et al., 2009). Besides, porous structures could be prepared via physical, chemical, and enzymatic methods or aforementioned two or more synergic methods (Chen et al. 2020), which could greatly increase the specific surface area of starch granules. It has been reported that starch with a porous structure has the ability of adsorbing and encapsulating small molecules. In the food industry, porous starch has been used for the encapsulation and slow release of easily oxidized, volatile, and unstable components, such as bio-active substance, oil, and flavor compounds (Belingheri et al. 2012; Saifullah et al. 2019). Flavor compounds are physically adsorbed into pores without covalent bonding, so they can be completely released in a continuous manner (Wang, Yuan, et al. 2015). Belingheri et al. confirmed the potential application of porous starch as a carrier for flavors in industrial applications (Belingheri, Ferrillo, and Vittadini 2015). In addition, starch with porous structures can also be used to mask off-flavor compounds (Asghari Ghajari et al. 2017).

Starch crystal structure and flavor encapsulation

Cooking or thermal processing of rice-based instant foods causes irreversible swelling or even disruption of the starch granules, a process called gelatinization (Fig. 3C). During storage of gelatinized starch, both amylose and amylopectin molecules rearrange, in the process of retrogradation. During retrogradation process, starch can transition from

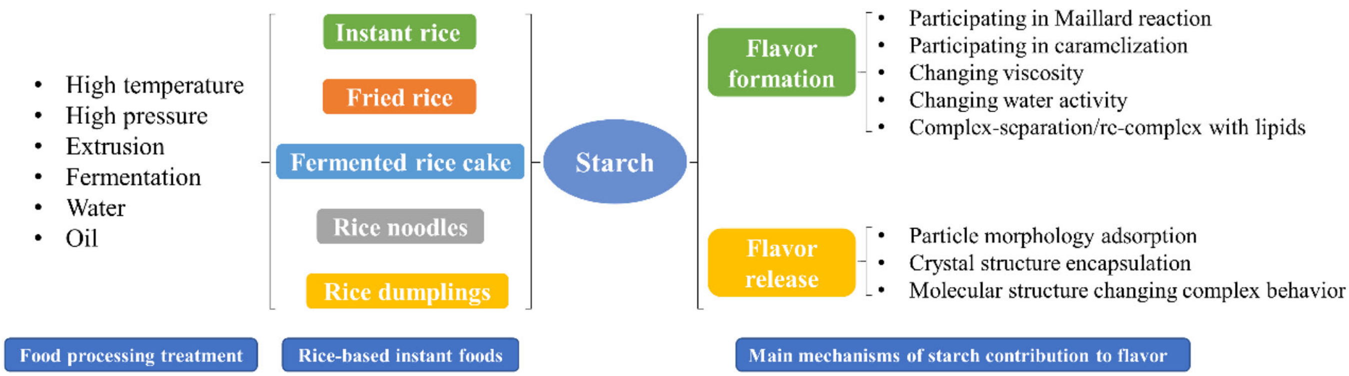

Figure 4. Main mechanisms of starch contribution to rice-based instant foods flavor.

random coil to single helix, with the exitance of suitable ligands such as iodine, lipids, zinc, emulsifying agents, as well as flavor compounds (Ma et al. 2019b); or it can transition to double helix, without ligands exitance (Fig. 3D). The two different structures appearing as macroscopic crystal forms were V-type or B-type crystals (Fig 3E).

Amylose rearranges quickly and dominates the short-term retrogradation process due to its small steric hindrance. In contrast the large molecule and multi-branched structure of amylopectin hinders the arrangement, and therefore, amylopectin is mainly involved in long-term retrogradation (Zhu et al. 2020). For this reason, it is generally considered that amylose contributes to complexation, especially in the early stages of storage. The single helix of amylose is hydrophilic on the outside and hydrophobic inside the cavity, and could complex through hydrophobic interactions with flavors such as aldehydes, ketones and phenols present in rice-based instant foods. In addition, chemical properties of flavor compounds, including solubility, chain length, structure, and polarity, have been shown to influence the complexation behavior (Feng et al. 2018; Tapanapunnitikul et al. 2008), which causes the formation of a single helical conformation with 6, 7 and 8 glucose units per turn. The crystal forms of starch and flavor compound complexes in rice-based products reported in previous studies are listed in Table 1. For V_6 types, the most common types, two trapping modes are suggested: intra helices inclusion V_{6I} and intra-inter helices inclusion V_{6II}, V_{6III}. V_7-complexes consist of sevenfold left-handed amylose helices in which flavors are included in the cavity or entrapped between helices. V_7-complexes could be transformed into V_6-complexes via drying treatment, thus, some researchers assumed that V_{6II} or V_{6III} are actually V_7-complexs (Gao, Zhang, et al. 2020). However, to date, the typical representative of the V_8-complex is the starch-1-naphthol complex, which has not been reported in rice-based foods. Competition phenomena can occur when several flavoring compounds are in contact with amylose. A co-complexation study by Pozo-Bayon et al. proved that several complexing flavor compounds could be present in the same crystalline aggregate (Fig. 3D-b) (Pozo-Bayon et al. 2008).

Retrogradation of amylopectin was considerably slower than that of amylose, and mainly formed B-type crystals (Fig.3E) according to the outer chain rearrangement. Although some researchers considered that B-type crystals could not form inclusion complexes, the formation and growth process of B-type crystals could also affect flavor retention. The importance of amylopectin in flavor retention has also been demonstrated in previous studies (Jouquand, Ducruet, and Lebail 2006). With the prolongation of storage time, starch chains rearrange tightly, and B-type crystals form and growth, accompanied by migration of water molecules, resulting in gradual collapse of starch gel network structure. Thus, flavor compounds immobilized on starch gel are slowly released. In addition, within a static equilibrium system, flavor compounds will partition into the headspace until they eventually reach dynamic balance (Henry's Law) (Fisk 2015). Therefore, flavor compounds can also escape from rice-based instant foods matrix gradually, but the interactions between starch and flavor delays the process.

Starch molecule structure and flavor retention

As reported by Błaszczak et al. and Keatkrai et al., starch from different sources affects the formation and retention of flavor compounds (Błaszczak et al. 2013; Keatkrai et al. 2017). The sources of starch lead to great differences in its molecular structure, including amylose content, chain length, and degree of polymerization. Therefore, relevant research was further carried out. The results of Kasemwong et al. showed that starch with high amylose content tends to complex a higher number of flavor molecules (Kasemwong and Itthisoponkul 2013). Wulff et al. demonstrated that the association constant of the same flavor compound with amylose was closely related to the chain length of amylose (Wulff, Avgenaki, and Guzmann 2005). Other scholars have summarized that an appropriate chain length is helpful for the stability of the complex and for improving the efficacy of flavor compounds retention. Too long amylose chains (DP $>$ 60) will lead to conformational disorders, resulting in faults in the crystal structure. In contrast, too short amylose chains (DP $<$ 20) could hinder the formation of crystals (Putseys, Lamberts, and Delcour 2010).

Specific examples of starch influence on the flavor of rice-based instant foods

The contribution of starch to each food flavor varies due to the different food processing treatment. Therefore, based on

Table 2. Major flavor compounds derived by thermal reactions.

Flavor compounds		Reactions	Rice-based products	References
Pyrrolines	2-Acetyl-1-pyrroline	[M]	Instant rice, rice cake, fried rice	a, b, c, d
	2-Methylpyrazine	[M]	Instant rice, rice cake, fried rice	a, c, e
Aldehydes	2-Butyl-2-octenal	[M]	Instant rice, rice noodle, fried rice	c, d, f, g, h
	2-Methylbutanal	[M]	Instant rice, rice cake, fried rice	a, c, d
	2-Methylpropanal	[M]	Instant rice, rice cake, fried rice	a, c, f, g
	2,4-Decadienal	[M]	Instant rice, rice cake, fried rice	a, c, f, g, h
	3-Methylbutanal	[M]	Instant rice, rice cake, fried rice	a, c, d
	5-Hydroxymethylfurfural	[C]	Fried rice	i
	5-Methyl-2-furancarboxaldehyde	[T]	Instant rice, fried rice	e, f, i
	5-Methylfurfural	[M]	Instant rice, rice cake	a, d
	Benzaldehyde	[M]	Instant rice, rice cake, rice noodle, fried rice	a, c, f, g
	Formaldehyde	[M]	Instant rice	c, f, g
	Furfural	[M]	Instant rice, rice cake	a, e, j
	Phenylacetaldehyde	[M]	Instant rice, rice cake, rice noodle	c, f, g, h, k, l
Alcohols	2-Phenylethanol	[M]	Instant rice	f
	Methanethiol	[M]	Instant rice, fried rice	c, d
Ketones	l-Hydroxy-2-propanone	[M]	Instant rice, rice cake	a, f, g
	2-Aminoacetophenone	[M]	Instant rice,	m
	3-Hydroxy-4,5-dimethyl-2(5H)-furanone	[M]/[T]	Instant rice, fried rice	c, f, m
	4-Hydroxy-2,5-dimethyl-3(2H)-furanone	[C]	Instant rice, rice cake, fried rice	a, c, i, f
	4,5-Dimethyl-3-hydroxy-2(5H)-furanone	[M]/[T]	Instant rice	f, m
	5-Methyl-2(3H)-furanone	[T]	Fried rice	e
	5-Ethyl-3-hydroxy-4-methyl-2(5H)-furanone	[M]	Instant rice	f
	Diacetyl	[M]/[C]	Instant rice, rice cake	a, c, f, g, n
Others	2-Acetylfuran	[C]	Instant rice, fried rice	f, i
	2-Methoxy-4-vinylphenol	[T]	Instant rice	m
	2-Methylpyrazine	[M]	Instant rice, rice cake, fried rice	a, e, j, o
	2,3-Dimethylpyrazine	[M]	Instant rice, rice cake, fried rice	a, c, j, o
	2,5-Dimethylpyrazine	[M]	Instant rice, rice cake, fried rice	a, c, j, o
	2,6-Dimethylpyrazine	[M]	Instant rice, rice cake, fried rice	a, c, j, o
	4-Vinylguaiacol	[T]	Instant rice, rice cake	a, m
	4-Vinylphenol	[T]	Instant rice, rice cake	a, m
	Bis-(2-methyl-3-furyl)-disulfide	[M]/[T]	Instant rice	f, m
	Phenylacetic acid	[M]	Instant rice, fried rice	c, m
	Trimethylpyrazine	[M]	Instant rice, rice cake, fried rice	a, c, j, p
	Toluene	[C]	Instant rice, fried rice	c, m

[a]Buttery et al. (1999);
[b]Champagne (2008);
[c]Chang et al. (2020);
[d]Dody et al. (2014);
[e]Piyachaiseth et al. (2011);
[f]Verma et al., (2018);
[g]Whitfield and Mottram (1992);
[h]Yi et al. (2019);
[i]Sengar et al., (2014);
[j]Yajima et al. (2014);
[k]Xiong et al. (2015);
[l]Parker (2015);
[m]Yang (2007);
[n]Aguiar et al. (2015),
[o]Ho and Romero (2007),
[p]Van Boekel (2006). [M] Maillard Reaction; [C] Caramelization; [T] Other thermal reactions.

the known mechanisms of action, specific pathways by which starch contributes to the flavor properties of five rice-based instant foods were discussed in the following chapter. The main mechanisms involving starch contribution to the flavor properties of five rice-based instant foods are shown in Fig. 4, and the major flavor compounds derived by thermal reactions including Maillard reaction, caramelization and other thermal reactions reported previously are shown in Table 2.

Contributions of starch to instant rice flavor

Instant rice is becoming more popular nowadays, due to its properties similar to those of normal cooked rice in terms of taste, texture, stickiness, and color. According to the different processing technology, instant rice can be divided into dehydrated instant rice, non-dehydrated instant rice. Of these, fresh instant rice is the main category of non-dehydrated instant rice, including frozen instant rice, room-temperature instant rice, etc. In particular, room-temperature instant rice has increasingly attracted consumer's attention owing to its fast preparation, convenience, nutrition, sanitation, and safety. However, flavor deterioration of room-temperature instant rice during storage is inevitable, constraining industry development.

During cooking, the flavor of instant rice is mainly formatted via the Maillard reaction and thermal degradation. Endogenous enzymes and thermal treatment promote the partial decomposition of starch into reducing sugar, which can react with free amino acids, hydrolytic amino acid or peptides produced by degradation of proteins. The Amadori compounds, most important Maillard reaction intermediate products, could further rearrange and degrade, causing the formation of aldehydes, ketones, esters, et al. The key aroma molecule, 2-AP, is formed in this way. The endogenous starch-lipid complexes disintegrate and further produce free fatty acids during cooking. Some flavor compounds can be formed by the hydrolysis and degradation of fatty acids. Furthermore, it is generally considered that the formation of gelatinization could form a resistance effect on diffusion that hinders mass transfer (Błaszczak et al. 2013). During rice cooking, starch gelatinizes and changes the viscosity and water distribution in the rice system, which further alters the release behavior of flavor compounds.

During storage, the loss of odor-active flavor compounds and the formation and accumulation of off-flavor compounds produced by the oxidation and hydrolysis of lipids causes the deterioration of instant rice flavor. On the one hand, gelatinized starch could recrystallize and form complexes with lipids during cooling and storage. This process is helpful for reducing the oxidation and degradation of free fatty acids and thus decreasing the formation of deteriorated flavor compounds. On the other hand, starch could directly complex with flavor. Flavor molecules could enter the cavity of retrograded starch crystals or interact with starch chains. Ma et al. found that the recrystallized nuclei with heterogeneous and loose structures favor the retention of flavor, which provides theoretical guidance for increasing the retention of typical flavor compounds of instant rice (Ma et al. 2019a). In addition, many researchers have proved that the formation of starch-flavor complexes could affect the release behavior of flavor (Kasemwong et al., 2013; Yeo, Thompson, and Peterson 2016). Amylose-flavor complexes have a high thermal stability in common; thus, the combination between the two is considered to be tightly. However, the retrogradation of amylopectin is reversible and can be eliminated when rice is reheated (Wang, Li, et al. 2015). Therefore, these flavor compounds could be released by reheat. Generally, the non-uniformity of the matrix will eventually affect the non-equilibrium distribution of flavor compounds. In contrast to the gelatinization process, the retrogradation process could affect the process of water migration and lead to a decrease in viscosity, which can impact aroma partitioning (Fisk 2015). Arvisenet et al. studied physicochemical interactions between amylose and flavor compounds and found that the retention of flavor compounds depends on both the complex formation and the effect on viscosity (Arvisenet et al. 2002).

Contributions of starch to fermented rice cake flavor

Fermented rice cake is a kind of fermented steamed cake usually manufactured with rice flour, which is also called rice steamed sponge cake (Wu, Xu, et al. 2011). It is made by grinding powder, mixing auxiliary materials, fermenting and steaming. Based on its soft taste, elastic texture, and rich nutritional value, it has become welcomed by the consumers. Recently, research related to fermented rice cake features has mainly focus on the factors that influence its texture. A few studies on flavor have been performed. The flavor of fermented rice cake is distinctive, a combination of rice flavor and fermented wine flavor, and it is imparted mainly by alcohols, aldehydes, esters, as well as other compounds (Xiong et al. 2015).

It could be inferred that the effect of starch to the flavor of fermented rice cake is similar to the effect on instant rice, since they both undergo a similar steaming process. Apart from the contribution of starch to cooked rice flavor, fermentation plays an important role in improving the quality of fermented rice cake. Firstly, starch could be hydrolyzed by amylase or glycolysis by microorganisms, which could form small molecules of sugar and some flavor compounds. It has been reported that ethanol can be converted from starch or sucrose-based feedstock by yeast and contributes to alcoholic aroma of fermented rice cakes (Calvo et al. 2007; Gombert and van Maris 2015). Second, the action of microorganisms on starch leads to amylose leaching during fermentation, increasing the relative content of amylose, and changing the surface morphology of starch granules (Ye et al. 2019). In addition, lactic acids produced by fermentation can change the pH values of the matrix, which is conductive to the polymerization of starch. Therefore, the fermentation process is helpful for the formation of a composite gel network with good elasticity and fast forming speed. The complex network can also slow down the release of flavor compounds (Xiong et al. 2015). Combined with the fact that amylose is the main contributor of complex flavor compounds, starch has a more obvious effect on the flavor of fermented rice cake. Third, starch results separated from lipids and proteins during the fermentation process, which increases the formation of flavor compounds, and it was demonstrated to be beneficial in enriching the flavor of fermented rice cake (Meng and Kim 2020).

Contributions of starch to rice noodles flavor

Rice noodles is a traditional instant food popular in many Asian countries, also called rice pasta or rice vermicelli. According to the processing methods and the final performance of the products, rice noodles can be classified into fresh, dried and frozen versions (Sangpring, Fukuoka, and Ratanasumawong 2015). Traditionally, rice noodles could be produced in the following sequence: rice steeping, wet-milling, pre-cooking, extruding, shaping, cooking/steaming, retrogradation, acid-pickling, and drying (Yi et al. 2019). Among them, extrusion has become the main method for rice noodles production owing to its convenience and efficient.

Extrusion could shear the raw materials at high temperature. In this process, starch granules gradually absorb water and swell, with destruction of the hydrogen bonds between the starch molecules. At the same time, starch and protein degrade during extrusion, resulting in Maillard reaction and caramelization between degraded products, as well as thermal degradation of lipids. In the cooling stage, starch molecular chains, especially amylose, rearrange through hydrogen bonds and form a continuous three-dimensional network gel structure, which plays a certain role in embedding the flavor compounds produced during extrusion (Dalbhagat, Mahato, and Mishra 2019). In addition, some flavor compounds can enter the hydrophobic single helix cavity of amylose (Castro et al. 2016).

Contributions of starch to fried rice flavor

Frying/baking/roasting, traditional food processing methods, are widely used to produce various kinds of food based on cooking at high temperature with oil (Chen et al. 2019). Fried rice, mainly made from waxy rice, is very popular in southern China. It has the advantages of having a crispy taste, unique texture, flavor, and appearance. Fried rice is generally made in the following steps: raw material selection, soaking, pre-cooking, drying, roasting/frying/baking, and cooling. The most critical step is roasting/frying/baking. The Maillard reaction and caramelization in the process of roasting/frying/baking are key to the formation of the final product flavor and color characteristics (Chang et al. 2020). Accurate control of roasting/frying/baking time and temperature can improve the product quality and flavor.

In contrast to ordinary cooking, the changes of starch structure caused by oil and high temperature co-treatment are more severe and complex. During baking, the ordered structure of the starch granules decreases, accompanied by starch chain dissolution. In addition, the starch fragments degrading from starch chains could polymerize, cross-link, and react with each other or other components (Lu et al. 2020). Violent reactions of the Maillard reaction and caramelization occur in this process, with formation of flavor compounds (Verma and Srivastav 2018). The porous particle structure formed by baking also contributes to the release of flavor during storage, based on adsorption.

Contributions of starch to rice dumplings flavor

Rice dumplings, also called rice puddings or zongzi, are the traditional food eaten in the Dragon Boat Festival, with a history of more than 2000 years. Nowadays, they are being used as a hot daily food with a long shelf life at home and abroad (Sun et al. 2015b). Generally, the production process of rice dumplings mainly includes leaf selection and cleaning, waxy rice soaking, packaging, cooking, sterilization, cooling, and packaging. It can be divided into two categories, with and without fillings. The fillings could include meat, sweetened bean paste, red dates, and salted yolk. The flavor of rice dumplings is affected by both raw materials and processing techniques.

For the rice dumplings without filling, rice is the only raw material. Thus, the contribution of starch to their flavor is similar to the effect on cooked rice. To put it crudely, starch may degrade to reducing sugars under the action of high temperature and endogenous enzymes and can provide substrates for Maillard reaction. During storage, starch can undergo retrogradation and formation a V-type crystal structure, encapsulating flavor compounds. Generally, the retrogradation rate of waxy starch is very slow, causing the poor encapsulation effect. However, starch of waxy rice is large and branched (Šárka and Dvořáček 2017). The entanglement and obstruction of flavoring substances also significantly affects their release. For the dumplings with filling, the filling can give rice dumplings a variety of flavors. Therefore, except for what mentioned above, there may be complex interactions between starch and stuffing. Moreover, plant leaves are helpful for improving the flavor (Lin et al. 2019). In addition, the flavor of rice dumplings could be affected by processing techniques. In particular, the density at which the rice dumplings are stuffed can affect the rate of water migration and the degree of starch gelatinization. Furthermore, the migration of starch chains is also affected during storage. This will lead to changes in texture characteristics and flavor release.

Conclusion and discussion

Starch plays an important role on flavor formation and release in rice-based instant foods. The common mechanisms by which starch contributes to flavor were summarized. In addition, five main categories of rice-based instant foods were also discussed. In terms of flavor formation, treatments such as high temperature, extrusion, fermentation, and endogenous enzymes reactions can promote starch degradation, gelatinization, and complex separation with lipids. The degradation products can participate in the Maillard reaction and caramelization. Starch gelatinization changes the viscosity and water molecules distribution in the food matrix and thus changes the flavor compounds formation rate. During cooking, the complex separation of starch and lipids can promote the formation of lipid-based flavor compounds, while the complexation of starch with lipids during storage can slow down lipid oxidation and thus decrease the formation of off-flavors. Starch granules structure, crystal structure, and molecular structure are all responsible for flavor release. Flavor compounds adsorption by particles and encapsulation by crystal structure as well as different distribution and migration of flavor molecules in starch during gelatinization and retrogradation also affect flavor release.

As of today, there is still confusion on the mechanisms of flavor distribution and equilibrium in food systems. In addition, traditional processing techniques always include high-temperature, high-pressure, or shearing treatments. Moreover, the safety of starch degradation products still needs to be considered. With the development of the economy, rice-based instant foods may become the staple foods. Researchers could exploit the controlled release technology of flavor compounds from starch crystals, or explore how to stabilize flavor compounds in terms of achieving a steady flavor and slow release. These technologies could solve the problem of flavor deterioration in rice-based instant foods and promote the conversion of traditional foods to industrial and innovative products.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was financially supported by the Ten Thousand Talent Program Youth Top-notch Talent Project – China.

ORCID

Zhengyu Jin http://orcid.org/0000-0002-7802-9722

References

Aguiar, C. L. d., A. L. B. Rocha, J. R. Jambassi, A. S. Baptista, and R. B. Lima. 2015. Factors affecting color formation during storage of white crystal sugar. *Focusing on Modern Food Industry* 4:1–10. doi: 10.14355/fmfi.2015.04.001.

Almeida, R. L. J., T. Dos Santos Pereira, V. de Andrade Freire, A. M. Santiago, H. M. L. Oliveira, L. de Sousa Conrado, and R. P. de Gusmao. 2019. Influence of enzymatic hydrolysis on the properties of red rice starch. *International Journal of Biological Macromolecules* 141:1210–9. doi: 10.1016/j.ijbiomac.2019.09.072.

Amagliani, L., J. O'Regan, A. L. Kelly, and J. A. O'Mahony. 2016. Chemistry, structure, functionality and applications of rice starch. *Journal of Cereal Science* 70:291–300. doi: 10.1016/j.jcs.2016.06.014.

Arvisenet, G., P. Le Bail, A. Voilley, and N. Cayot. 2002. Influence of physicochemical interactions between amylose and aroma compounds on the retention of aroma in food-like matrices. *Journal of Agricultural and Food Chemistry* 50 (24):7088–93. doi: 10.1021/jf0203601.

Asghari Ghajari, M., I. Katouzian, M. Ganjeh, and S. M. Jafari. 2017. Nanoencapsulation of flavors. In *Nanoencapsulation of food bioactive ingredients*, ed. S. M. Jafari, 261–96. London: Elsevier.

Azanza, M. P. 2014. Hydrocolloid sour taste control in pasteurized rice. *Journal of Food Science and Technology* 51 (12):3998–4004. doi: 10.1007/s13197-013-0947-5.

Belingheri, C., E. Curti, A. Ferrillo, and E. Vittadini. 2012. Evaluation of porous starch as a flavour carrier. *Food & Function* 3 (3):255–61. doi: 10.1039/C1FO10184F.

Belingheri, C., A. Ferrillo, and E. Vittadini. 2015. Porous starch for flavor delivery in a tomato-based food application. *LWT - Food Science and Technology* 60 (1):593–7. doi: 10.1016/j.lwt.2014.09.047.

BeMiller, J. N., and R. L. Whistler. 2009. *Starch: Chemistry and technology*, 3rd ed., 149–92. London, UK: Elsevier.

Błaszczak, W., T. A. Misharina, D. Fessas, M. Signorelli, and A. R. Górecki. 2013. Retention of aroma compounds by corn, sorghum and amaranth starches. *Food Research International* 54 (1):338–44. doi: 10.1016/j.foodres.2013.07.032.

Bonto, A. P., R. N. Tiozon, Jr., N. Sreenivasulu, and D. H. Camacho. 2021. Impact of ultrasonic treatment on rice starch and grain functional properties: A review. *Ultrasonics Sonochemistry* 71:105383. doi: 10.1016/j.ultsonch.2020.105383.

Buttery, R. G., W. J. Orts, G. R. Takeoka, and Y. Nam. 1999. Volatile flavor components of rice cakes. *Journal of Agricultural and Food Chemistry* 47 (10):4353–6. doi: 10.1021/jf990140w.

Cai, C., B. Wei, Y. Tian, R. Ma, L. Chen, L. Qiu, and Z. Jin. 2019. Structural changes of chemically modified rice starch by one-step reactive extrusion. *Food Chemistry* 288:354–60. doi: 10.1016/j.foodchem.2019.03.017.

Calvo, M., I. Castillo, V. Diazbarcos, T. Requena, and J. Fontecha. 2007. Effect of a hygienized rennet paste and a defined strain starter on proteolysis, texture and sensory properties of semi-hard goat cheese. *Food Chemistry* 102 (3):917–24. doi: 10.1016/j.foodchem.2006.06.028.

Castro, N., V. Durrieu, C. Raynaud, A. Rouilly, L. Rigal, and C. Quellet. 2016. Melt extrusion encapsulation of flavors: A review. *Polymer Reviews* 56 (1):137–86. doi: 10.1080/15583724.2015.1091776.

Cervantes-Ramirez, J. E., A. H. Cabrera-Ramirez, E. Morales-Sanchez, M. E. Rodriguez-Garcia, M. L. Reyes-Vega, A. K. Ramirez-Jimenez, B. L. Contreras-Jimenez, and M. Gaytan-Martinez. 2020. Amylose-lipid complex formation from extruded maize starch mixed with fatty acids. *Carbohydrate Polymers* 246:116555. doi: 10.1016/j.carbpol.2020.116555.

Champagne, E. T. 2008. Rice aroma and flavor: A literature review. *Cereal Chemistry Journal* 85 (4):445–54. doi: 10.1094/CCHEM-85-4-0445.

Chang, C., G. Wu, H. Zhang, Q. Jin, and X. Wang. 2020. Deep-fried flavor: Characteristics, formation mechanisms, and influencing factors. *Critical Reviews in Food Science and Nutrition* 60 (9):1496–514. doi: 10.1080/10408398.2019.1575792.

Chen, L., R. Ma, Z. Zhang, D. J. McClements, L. Qiu, Z. Jin, and Y. Tian. 2019. Impact of frying conditions on hierarchical structures and oil absorption of normal maize starch. *Food Hydrocolloids* 97:105231. doi: 10.1016/j.foodhyd.2019.105231.

Chen, J., Y. Wang, J. Liu, and X. Xu. 2020. Preparation, characterization, physicochemical property and potential application of porous starch: A review. *International Journal of Biological Macromolecules* 148:1169–81. doi: 10.1016/j.ijbiomac.2020.02.055.

Concepcion, J. C. T., S. Ouk, A. Riedel, M. Calingacion, D. Zhao, M. Ouk, M. J. Garson, and M. A. Fitzgerald. 2018. Quality evaluation, fatty acid analysis and untargeted profiling of volatiles in Cambodian rice. *Food Chemistry* 240:1014–21. doi: 10.1016/j.foodchem.2017.08.019.

Dalbhagat, C. G., D. K. Mahato, and H. N. Mishra. 2019. Effect of extrusion processing on physicochemical, functional and nutritional characteristics of rice and rice-based products: A review. *Trends in Food Science & Technology* 85:226–40. doi: 10.1016/j.tifs.2019.01.001.

Handoko, D. D., L. Methven, J. Stephen Elmore, and D. S. Mottram. 2014. *Comparison of the Maillard derived aroma volatiles of cooked milled and brown rice*. United States: Elsevier Publishing, (Chapter 14.

Fang, C., J. Huang, Q. Yang, H. Pu, S. Liu, and Z. Zhu. 2020. Adsorption capacity and cold-water solubility of honeycomb-like potato starch granule. *International Journal of Biological Macromolecules* 147:741–9. doi: 10.1016/j.ijbiomac.2020.01.224.

Feng, T., H. Wang, K. Wang, Y. Liu, Z. Rong, R. Ye, H. Zhuang, Z. Xu, and M. Sun. 2018. Preparation and structural characterization of different amylose-flavor molecular inclusion complexes. *Starch - Stärke* 70 (1–2):1700101. doi: 10.1002/star.201700101.

Fisk, I. D. 2015. Aroma release. In Flavour development, Analysis and perception in food and beverages, ed. J. K. Parker, J. S. Elmore, and L. Methven, 105–23. Kidlington: Woodhead Publishing.

Fu, Z., J. Chen, S. Luo, C. Liu, and W. Liu. 2015. Effect of food additives on starch retrogradation: A review. *Starch - Stärke* 67 (1–2):69–78. doi: 10.1002/star.201300278.

Funsueb, S., C. Krongchai, S. Mahatheeranont, and S. Kittiwachana. 2016. Prediction of 2-acetyl-1-pyrroline content in grains of Thai Jasmine rice based on planting condition, plant growth and yield component data using chemometrics. *Chemometrics and Intelligent Laboratory Systems* 156:203–10. doi: 10.1016/j.chemolab.2016.06.008.

Gao, P., W. Xia, X. Li, and S. Liu. 2020. Optimization of the Maillard reaction of xylose with cysteine for modulating aroma compound formation in fermented tilapia fish head hydrolysate using response surface methodology. *Food Chemistry* 331:127353. doi: 10.1016/j.foodchem.2020.127353.

Gao, Q., B. Zhang, L. Qiu, X. Fu, and Q. Huang. 2020. Ordered structure of starch inclusion complex with C10 aroma molecules. *Food Hydrocolloids* 108:105969. doi: 10.1016/j.foodhyd.2020.105969.

Gombert, A. K., and A. J. van Maris. 2015. Improving conversion yield of fermentable sugars into fuel ethanol in 1st generation yeast-based production processes. *Current Opinion in Biotechnology* 33:81–6. doi: 10.1016/j.copbio.2014.12.012.

Gupta, R. K., K. Gupta, A. Sharma, M. Das, I. A. Ansari, and P. D. Dwivedi. 2016. Maillard reaction in food allergy: Pros and cons. *Critical Reviews in Food Science & Nutrition* 56:1–19.

Hamzalı oğlu, A., and V. Gökmen. 2020a. 5-Hydroxymethylfurfural accumulation plays a critical role on acrylamide formation in coffee during roasting as confirmed by multiresponse kinetic modelling. *Food Chemistry* 318:126467. doi: 10.1016/j.foodchem.2020.126467.

Hamzalıoğlu, A., and V. Gökmen. 2020b. Potential reactions of thermal process contaminants during digestion. *Trends in Food Science & Technology* 106:198–208. doi: 10.1016/j.tifs.2020.10.014.

Han, Z., R. Shi, and D.-W. Sun. 2020. Effects of novel physical processing techniques on the multi-structures of starch. *Trends in Food Science & Technology* 97:126–35. doi: 10.1016/j.tifs.2020.01.006.

Hellwig, M., and T. Henle. 2014. Baking, ageing, diabetes: A short history of the Maillard reaction. *Angewandte Chemie International Edition* 53 (39):10316–29. doi: 10.1002/anie.201308808.

Ho, C. T., and M. K. Romero. 2007. *Maillard reaction in flavor generation*. 2nd ed. Britain: Blackwell Publishing, (Chapter 20).

Hu, X., L. Lu, Z. Guo, and Z. Zhu. 2020. Volatile compounds, affecting factors and evaluation methods for rice aroma: A review. *Trends in Food Science & Technology* 97:136–46. doi: 10.1016/j.tifs.2020.01.003.

Huang, Y., and H.-M. Lai. 2014a. Characteristics of the starch fine structure and pasting properties of waxy rice during storage. *Food Chemistry* 152:432–9. doi: 10.1016/j.foodchem.2013.11.144.

Huang, H., H. Sheu, W. Chuang, U. S. Jeng, A. Su, W. Wu, K. Liao, C. Chen, S. Chang, and H. Lai. 2014b. Correlated changes in structure and viscosity during gelatinization and gelation of tapioca starch granules. *IUCrJ* 1 (Pt 6):418–28. doi: 10.1107/S2052252514019137.

Jezussek, M., B. O. Juliano, and P. Schieberle. 2002. Comparison of key aroma compounds in cooked brown rice varieties based on aroma extract dilution analyses. *Journal of Agricultural and Food Chemistry* 50 (5):1101–5. doi: 10.1021/jf0108720.

Jouquand, C., V. Ducruet, and P. Lebail. 2006. Formation of amylose complexes with C6-aroma compounds in starch dispersions and its impact on retention. *Food Chemistry* 96 (3):461–70. doi: 10.1016/j.foodchem.2005.03.001.

Kasemwong, K., and T. Itthisoponkul. 2013. Encapsulation of flavor compounds as helical inclusion complexes of starch. In *Advances in applied nanotechnology for agriculture*, ed. B. Park and M. Appell, Chapter 14, 235–45. Washington, DC: American Chemical Society.

Keatkrai, J., N. Lumdubwong, S. Chaiseri, and W. Jirapakkul. 2017. Characteristics of menthone encapsulated complex by mungbean, tapioca, and rice starches. *International Journal of Food Properties* 20 (4):810–20. doi: 10.1080/10942912.2016.1183129.

Kocadagli, T., and V. Gokmen. 2016. Multiresponse kinetic modelling of Maillard reaction and caramelisation in a heated glucose/wheat flour system. *Food Chemistry* 211:892–902.

Lacerda, L. D., D. C. Leite, and N. P. da Silveira. 2019. Relationships between enzymatic hydrolysis conditions and properties of rice porous starches. *Journal of Cereal Science* 89:102819. doi: 10.1016/j.jcs.2019.102819.

Lin, F., B. Luo, B. Long, and C. Long. 2019. Plant leaves for wrapping zongzi in China: An ethnobotanical study. *Journal of Ethnobiology and Ethnomedicine* 15 (1):63. doi: 10.1186/s13002-019-0339-7.

Li, H., F. Zhai, J. Li, X. Zhu, Y. Guo, B. Zhao, and B. Xu. 2021. Physicochemical properties and structure of modified potato starch granules and their complex with tea polyphenols. *International Journal of Biological Macromolecules* 166:521–8. doi: 10.1016/j.ijbiomac.2020.10.209.

Li, C., R. Zhang, K. Fu, C. Li, and C. Li. 2017. Effects of high temperature on starch morphology and the expression of genes related to starch biosynthesis and degradation. *Journal of Cereal Science* 73:25–32. doi: 10.1016/j.jcs.2016.11.005.

Lopez, C. A., A. H. de Vries, and S. J. Marrink. 2012. Amylose folding under the influence of lipids. *Carbohydrate Research* 364:1–7. doi: 10.1016/j.carres.2012.10.007.

Lu, X., R. Xu, J. Zhan, L. Chen, Z. Jin, and Y. Tian. 2020. Pasting, rheology, and fine structure of starch for waxy rice powder with high-temperature baking. *International Journal of Biological Macromolecules* 146:620–6. doi: 10.1016/j.ijbiomac.2020.01.008.

Malekzadeh, H., and M. H. Fatemi. 2015. Analysis of flavor volatiles of some Iranian rice cultivars by optimized static headspace gas chromatography–mass spectrometry. *Journal of the Iranian Chemical Society* 12 (12):2245–51. doi: 10.1007/s13738-015-0703-z.

Ma, R., Y. Tian, L. Chen, C. Cai, and Z. Jin. 2019a. Effects of cooling rate on retrograded nucleation of different rice starch-aromatic molecule complexes. *Food Chemistry* 294:179–86. doi: 10.1016/j.foodchem.2019.05.077.

Ma, R., Y. Tian, L. Chen, and Z. Jin. 2020. Impact of cooling rates on the flavor of cooked rice during storage. *Food Bioscience* 35:100563. doi: 10.1016/j.fbio.2020.100563.

Ma, R., Y. Tian, H. Zhang, C. Cai, L. Chen, and Z. Jin. 2019b. Interactions between rice amylose and aroma compounds and their effect on rice fragrance release. *Food Chemistry* 289:603–8. doi: 10.1016/j.foodchem.2019.03.102.

Meng, L. W., and S. M. Kim. 2020. Effects of different proteins on the rheological properties of rice batter and characteristics of fermented rice cakes. *Journal of Food Processing and Preservation* 44 (11):1–11. doi: 10.1111/jfpp.14857.

Mo, Z., S. Lei, U. Ashraf, I. Khan, Y. Li, S. Pan, M. Duan, H. Tian, and X. Tang. 2017. Silicon fertilization modulates 2-acetyl-1-pyrroline content, yield formation and grain quality of aromatic rice. *Journal of Cereal Science* 75:17–24. doi: 10.1016/j.jcs.2017.03.014.

Montero, M. L., S. Sablani, J. Tang, and C. F. Ross. 2020. Characterization of the sensory, chemical, and microbial quality of microwave-assisted, thermally pasteurized fried rice during storage. *Journal of Food Science* 85 (9):2711–9. doi: 10.1111/1750-3841.15384.

Newton, A. E., A. J. Fairbanks, M. Golding, P. Andrewes, and J. A. Gerrard. 2012. The role of the Maillard reaction in the formation of flavour compounds in dairy products-not only a deleterious reaction but also a rich source of flavour compounds. *Food & Function* 3 (12):1231–41. doi: 10.1039/c2fo30089c.

Nooshkam, M., M. Varidi, and D. K. Verma. 2020. Functional and biological properties of Maillard conjugates and their potential application in medical and food: A review. *Food Research International (Ottawa, ON)* 131:109003. doi: 10.1016/j.foodres.2020.109003.

Ozbekova, Z., and A. Kulmyrzaev. 2019. Study of moisture content and water activity of rice using fluorescence spectroscopy and multivariate analysis. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy* 223:117357. doi: 10.1016/j.saa.2019.117357.

Parker, J. K. 2015. Thermal generation or aroma. In *Flavour development, analysis and perception in food and beverages-thermal generation or aroma*, 151–85. London, UK: Elsevier.

Pastoriza, S., J. A. Rufian-Henares, B. Garcia-Villanova, and E. Guerra-Hernandez. 2016. Evolution of the Maillard reaction in glutamine or arginine-dextrinomaltose model systems. *Foods* 5 (4):86–600. doi: 10.3390/foods5040086.

Piyachaiseth, T., W. Jirapakkul, and S. Chaiseri. 2011. Aroma compounds of flash-fried rice. *Kasetsart Journal - Natural Science* 45:717–29.

Pozo-Bayon, M. A., B. Biais, V. Rampon, N. Cayot, and P. Le Bail. 2008. Influence of complexation between amylose and a flavored model sponge cake on the degree of aroma compound release. *Journal of Agricultural and Food Chemistry* 56 (15):6640–7. doi: 10.1021/jf800242r.

Putseys, J. A., L. Lamberts, and J. A. Delcour. 2010. Amylose-inclusion complexes: Formation, identity and physico-chemical properties. *Journal of Cereal Science* 51 (3):238–47. doi: 10.1016/j.jcs.2010.01.011.

Quintas, M. A. C., J. F. Fundo, and C. L. M. Silva. 2010. Sucrose in the concentrated solution or the supercooled "State": A review of caramelisation reactions and physical behaviour. *Food Engineering Reviews* 2 (3):204–15. doi: 10.1007/s12393-010-9022-4.

Ruckriemen, J., U. Schwarzenbolz, S. Adam, and T. Henle. 2015. Identification and quantitation of 2-acetyl-1-pyrroline in manuka honey (Leptospermum scoparium). *Journal of Agricultural and Food Chemistry* 63 (38):8488–92. doi: 10.1021/acs.jafc.5b03042.

Saifullah, M., M. R. I. Shishir, R. Ferdowsi, M. R. Tanver Rahman, and Q. Van Vuong. 2019. Micro and nano encapsulation, retention and controlled release of flavor and aroma compounds: A critical review.

Trends in Food Science & Technology 86:230–51. doi: 10.1016/j.tifs.2019.02.030.
Sangpring, Y., M. Fukuoka, and S. Ratanasumawong. 2015. The effect of sodium chloride on microstructure, water migration, and texture of rice noodle. *LWT - Food Science and Technology* 64 (2):1107–13. doi: 10.1016/j.lwt.2015.07.035.
Šárka, E., and V. Dvořáček. 2017. New processing and applications of waxy starch (a review). *Journal of Food Engineering* 206:77–87. doi: 10.1016/j.jfoodeng.2017.03.006.
Sengar, G., and H. K. Sharma. 2014. Food caramels: A review. *Journal of Food Science and Technology* 51 (9):1686–96. doi: 10.1007/s13197-012-0633-z.
Shahidi, F., and A. Abad. 2019. Lipid-derived flavours and off-flavours in food. In *Encyclopedia of food chemistry*, eds. L. Melton, F. Shahidi, and P. Varelis, 182–92. Oxford: Academic Press.
Sun, J., D. Wu, J. Xu, S. K. Rasmussen, and X. Shu. 2015a. Characterisation of starch during germination and seedling development of a rice mutant with a high content of resistant starch. *Journal of Cereal Science* 62:94–101. doi: 10.1016/j.jcs.2015.01.002.
Sun, J., H. Xun, J. Yu, F. Tang, Y. Yue, and X. Guo. 2015b. Chemical constituents and antibacterial properties of indocalamus latifolius McClure leaves, the packaging material for "Zongzi". *Molecules (Basel, Switzerland)* 20 (9):15686–700. doi: 10.3390/molecules200915686.
Tapanapunnitikul, O., S. Chaiseri, D. G. Peterson, and D. B. Thompson. 2008. Water solubility of flavor compounds influences formation of flavor inclusion complexes from dispersed high-amylose maize starch. *Journal of Agricultural and Food Chemistry* 56 (1):220–6. doi: 10.1021/jf071619o.
Ulbrich, M., J. M. Daler, and E. Floter. 2019. Acid hydrolysis of corn starch genotypes. I. Impact on morphological and molecular properties. *Carbohydrate Polymers* 219:172–80. doi: 10.1016/j.carbpol.2019.05.010.
Van Boekel, M. A. 2006. Formation of valuable maillard flavour compounds by model reactions and fermentation. PhD Thesis., Ghent University.
Verma, D. K., and P. P. Srivastav. 2018. *Science and technology of aroma, flavor, and fragrance in rice*. Ontario, Canada: Apple Academic press.
Verma, D. K., and P. P. Srivastav. 2020. Bioactive compounds of rice (Oryza sativa L.): Review on paradigm and its potential benefit in human health. *Trends in Food Science & Technology* 97:355–65. doi: 10.1016/j.tifs.2020.01.007.
Wang, S., C. Chao, J. Cai, B. Niu, L. Copeland, and S. Wang. 2020a. Starch-lipid and starch-lipid-protein complexes: A comprehensive review. *Comprehensive Reviews in Food Science and Food Safety* 19 (3):1056–79. doi: 10.1111/1541-4337.12550.
Wang, S., C. Li, L. Copeland, Q. Niu, and S. Wang. 2015. Starch retrogradation: A comprehensive review. *Comprehensive Reviews in Food Science and Food Safety* 14 (5):568–85. doi: 10.1111/1541-4337.12143.
Wang, W., and Y.-C. Shi. 2020. Gelatinization, pasting and retrogradation properties of hydroxypropylated normal wheat, waxy wheat, and waxy maize starches. *Food Hydrocolloids* 106:105910. doi: 10.1016/j.foodhyd.2020.105910.
Wang, X., F. Wen, S. Zhang, R. Shen, W. Jiang, and J. Liu. 2017. Effect of acid hydrolysis on morphology, structure and digestion property of starch from cynanchum auriculatum royle ex wight. *International Journal of Biological Macromolecules* 96:807–16. doi: 10.1016/j.ijbiomac.2017.01.002.
Wang, X., Y. Yuan, and T. Yue. 2015. The application of starch-based ingredients in flavor encapsulation. *Starch - Stärke* 67 (3-4):225–36. doi: 10.1002/star.201400163.
Wani, A. A., P. Singh, M. A. Shah, U. Schweiggert-Weisz, K. Gul, and I. A. Wani. 2012. Rice starch diversity: Effects on structural, morphological, thermal, and physicochemical properties-a review. *Comprehensive Reviews in Food Science and Food Safety* 11 (5):417–36. doi: 10.1111/j.1541-4337.2012.00193.x.
Whitfield, F. B., and D. S. Mottram. 1992. Volatiles from interactions of Maillard reactions and lipids. *Critical Reviews in Food Science and Nutrition* 31 (1-2):1–58. doi: 10.1080/10408399209527560.
Wulff, G., G. Avgenaki, and M. S. P. Guzmann. 2005. Molecular encapsulation of flavours as helical inclusion complexes of amylose. *Journal of Cereal Science* 41 (3):239–49. doi: 10.1016/j.jcs.2004.06.002.
Wu, P., X. Xu, Y. Xu, Q. Chen, and S. Pan. 2011. Brettanomyces as a starter culture in rice-steamed sponge cake: A traditional fermented food in China. *Current Microbiology* 63 (5):458–63. doi: 10.1007/s00284-011-9997-y.
Wu, F., N. Yang, H. Chen, Z. Jin, and X. Xu. 2011. Effect of germination on flavor volatiles of cooked brown rice. *Cereal Chemistry Journal* 88 (5):497–503. doi: 10.1094/CCHEM-04-11-0057.
Xiong, Q., T. Hu, S. Zhao, and Q. Huang. 2015. Texture and flavor characteristics of rice cake fermented by Brettanomyces custersii ZSM-001. *Journal of Food Science and Technology* 52 (11):7113–22. doi: 10.1007/s13197-015-1813-4.
Yajima, I., T. Yanai, M. Nakamura, H. Sakakibara, and T. Habu. 2014. Volatile flavor components of cooked rice. *Agricultural and Biological Chemistry* 42 (6):1229–33.
Yang, T. S. 2007. Rice flavor chemistry. PhD Thesis., University of Georgia.
Ye, F., L. Xiao, Y. Liang, Y. Zhou, and G. Zhao. 2019. Spontaneous fermentation tunes the physicochemical properties of sweet potato starch by modifying the structure of starch molecules. *Carbohydrate Polymers* 213:79–88. doi: 10.1016/j.carbpol.2019.02.077.
Yeo, L., D. B. Thompson, and D. G. Peterson. 2016. Inclusion complexation of flavour compounds by dispersed high-amylose maize starch (HAMS) in an aqueous model system. *Food Chemistry* 199:393–400. doi: 10.1016/j.foodchem.2015.12.054.
Yi, C., H. Zhu, L. Tong, S. Zhou, R. Yang, and M. Niu. 2019. Volatile profiles of fresh rice noodles fermented with pure and mixed cultures. *Food Research International* (*Ottawa, ON)* 119:152–60. doi: 10.1016/j.foodres.2019.01.044.
Zeng, Z., H. Zhang, T. Zhang, S. Tamogami, and J. Y. Chen. 2009. Analysis of flavor volatiles of glutinous rice during cooking by combined gas chromatography–mass spectrometry with modified headspace solid-phase microextraction method. *Journal of Food Composition and Analysis* 22 (4):347–53. doi: 10.1016/j.jfca.2008.11.020.
Zhang, X., F. Chen, and M. Wang. 2013. Impacts of selected dietary polyphenols on caramelization in model systems. *Food Chemistry* 141 (4):3451–8. doi: 10.1016/j.foodchem.2013.06.053.
Zheng, M., Y. Lin, H. Wu, S. Zeng, B. Zheng, Y. Zhang, and H. Zeng. 2020. Water migration depicts the effect of hydrocolloids on the structural and textural properties of lotus seed starch. *Food Chemistry* 315:126240. doi: 10.1016/j.foodchem.2020.126240.
Zhu, B., J. Zhan, L. Chen, and Y. Tian. 2020. Amylose crystal seeds: Preparation and their effect on starch retrogradation. *Food Hydrocolloids* 105:105805. doi: 10.1016/j.foodhyd.2020.105805.