The effect of starch-hydrocolloid interaction on starch digestibility, pasting and physicochemical properties: A review

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Abstract. In complex food matrix, blending starch with non-starch hydrocolloids such as gum arabic, xanthan gum, guar gum, carrageenan, locust bean gum, and pectin may impact starch digestibility, pasting and physicochemical properties. The starch-hydrocolloids blending have specific application in the food product as an emulsifier, gelling agent thickener, stabilizer and inhibiting formation of ice and sugar crystal. As a thickener, hydrocolloid can increase the viscosity of food products and inhibit the accessibility of α-amylase to the starch granules. Effect of hydrocolloid on starch digestibility, pasting and physicochemical properties depends on starch source, type and concentration of hydrocolloid, and method of preparation starch-hydrocolloid mixture. This review summarized several studies about the effect of starch-hydrocolloid interaction on the starch digestibility, pasting and physicochemical properties. Furthermore, the mechanism of starch-hydrocolloid interaction and their applications in food product are also discussed. The purpose of this review is to provide information of several applications and recent utilization trend of starch-hydrocolloid blend in food systems.

Keywords: starch, hydrocolloid, starch digestibility, pasting properties, physicochemical properties

1. Introduction

Starch is a source of carbohydrate that has semi-crystalline structure which consist of two major types of α-glucan on molecular level, the linear amylose and the branched amylopectin [1]. Starch granules are insoluble in cold water and relatively dense, vary in shape, size (1 to 100 µm). Starch can be extracted from many commodities such as tubers (potato, cassava, sweet potato, etc), cereals (rice, sorghum, wheat), seeds (lotus seed, jackfruit seed, avocado seed) and fruits (banana, breadfruit, etc) [2, 3]. Structure and chemical composition of starch are dependent on its origin. Application of starch in a food product has to consider the presence of other components in food system such as protein, lipid, mineral, dietary fiber, phenolic compounds, non-starch polysaccharides, etc. These components can interact with
starch and affect digestibility and some properties of starch [4]. Several factors such as the type of starch and NSC, composition and concentration of starch-NSC mixture, processing condition determine the effect of NSC on starch properties [3, 5].

Hydrocolloids, the term used in this review is non-starch polysaccharides which is a heterogeneous group of long chain polymers characterized by a formation of viscous dispersions and/or gels when dispersed in water [6]. Hydrocolloids include xanthan gum, carrageenan, guar gum, gum arabic, pectin, locust bean gum, gellan, konjac-glucomannan, etc. Blending with hydrocolloids is one of the methods to modify the starch properties and the rheological properties of food properties [7]. The properties of starch-hydrocolloids mixture are dependent on the type of starch and hydrocolloids, concentration of starch and hydrocolloids, level and type of interaction, and preparation condition [8].

This review focuses on the effect of starch blending with hydrocolloids on digestibility, pasting and physicochemical properties of starch. In the food industry, the starch-hydrocolloids mixture has specific application as thickener, emulsifiers, gelling agent or stabilizer such as stabilization of emulsion and foams [7]. Some studies have reported the application of starch-hydrocolloid blending in food products such as oat starch-xanthan gum as a thickening agent [9], rice flour-xanthan gum as a thickening agent in gluten-free bread [10], wheat flour-arabic gum as an anti staling agent [11], chickpea flour-pectin as strengthening agent in pasta making [12].

The interaction between starch and hydrocolloids has a nutritional impact on food products. According to [13], starch-hydrocolloids interaction can alter food texture, structure, and viscosity, thereby changing the accessibility of enzymes to starch granules. This review purposes to summarize a number of studies on the interaction effect of starch and hydrocolloids such as carrageenan, xanthan gum, pectin, guar gum, gum arabic, locust bean gum, gellan, konjac-glucomannan on the digestibility, pasting and physicochemical properties of starch. The summary of studies on the effect of starch-hydrocolloid blending on starch digestibility, pasting and physicochemical properties is presented in table 1. This summary was based on the type of starch and hydrocolloid mixture and how the effect of its mixture on starch digestibility, pasting and physicochemical properties.

| Starch (es)     | Hydrocolloid (s)                          | Some Finding and Conclusions                                                                 | Reference |
|-----------------|-------------------------------------------|-----------------------------------------------------------------------------------------------|-----------|
| High amylose    | CMC                                       | Hydrocolloids decreased rapid rises in blood glucose levels.                                   | [14]      |
| Rice starch     | Guar gum                                  |                                                                                               |           |
|                 | Xanthan gum                               |                                                                                               |           |
| Rice starch     | Agar                                      | Non-starch polysaccharides (NSP) had suppressive effect on starch digestibility due to not only the rigidity of the gel, but also the interaction between starch and NSP | [15]      |
|                 | Xanthan gum                               |                                                                                               |           |
|                 | Konjac-glucomannan                        |                                                                                               |           |
| Gelatinized     | Xanthan gum                               | The presence of hydrocolloids significantly reduced starch hydrolysis even over a short reaction time and the effect on the blood glucose level after ingestion was dependent on the type of hydrocolloid. Higher hydrocolloids concentration led to a higher increase in the peak and final viscosities. Xanthan and guar gum were more effective in increasing starch paste viscosity than pectin and konjac-glucomannan | [16]      |
| potato starch   | Guaran                                    |                                                                                               |           |
|                 | Pectin                                    |                                                                                               |           |
|                 | Konjac-glucomannan                        |                                                                                               |           |
| Corn starch     | Pectin                                    | Pectin decreased starch digestibility and induced reduction in rapidly digestion starch        | [17]      |
Corn starch  Pectin  The presence of pectin decreased starch digestion rates, mainly due to pectin/amylglucosidase interaction  [1]

Lotus seed starch  Guar gum (GG)  The presence of guar gum decreased starch digestion in vitro and rapidly digestible starch, conservely increased resistant starch, especially when 0.30% guar gum was added to 30% lotus seed starch. Pasting and physicochemical properties of lotus seed starch-guar gum mixture depends on concentration of guar gum  [18]

Wheat  Arabic gum  High-methoxyl pectin  Hydroxypropylmethylcellulose (HPMC)  Hydrocolloids had no greater effect on pasting properties of starch  [19]

Pea starch  Carboxymethylcellulose (CMC)  Methylcellulose (MC)  Hydroxypropylmethylcellulose (HPMC)  Guar gum  Xanthan gum  Sodium alginate  Generally, hydrocolloids decreased pasting temperature and increased peak viscosity.  [20]

Rice starch  Konjac-glucomannan (KGM)  KGM increased viscosities of starch paste suggesting KGM inhibited granule association. KGM inhibited rice starch gel retrogradation which was effective in inhibiting sineresis of rice starch gels.  [21]

Potato starch  Pectin  Inulin  The presence of pectin and inulin decreased starch transition enthalpy after retrogradation  [22]

Maize starch  Galactomannan  The presence of galactomannan affect swelling power and solubility but increased gelatinization temperature and decreased gelatinization enthalpy of HMT maize starch  [23]

Wheat/potato starch mixture  Pectin  Hydroxypropylmethylcellulose (HPMC)  Arabic gum  Konjac-glucomannan  The presence of hydrocolloids decreased water solubility index, water absorption capacity and syneresis  [8]

Corn starch  Arabic gum  Guar gum  Xanthan gum  Type of hydrocolloids influenced starch swelling  [24]

Maize and wheat starch  Arabic gum  Carrageenan  Guar gum  Pectin  Xanthan gum  Hydrocolloids restricted water availability/mobility in starch-hydrocolloid mixture system and then caused restricted gelatinization and swelling of maize and wheat starch  [25]
ome molecules naturally occurring in the previous studies have been shown to inhibit starch hydrolysis. When the starch granules are heated, they undergo a process called gelatinization, which changes the structure of the starch, making it more susceptible to hydrolysis by enzymes. Some molecules, such as pectin, which are commonly found in fruits and vegetables, can bind with pectin, inhibiting the access of the enzyme to inner starch granule. Physical rather than chemical factors are also important. They have explained that the presence of hydrocolloids can alter the pattern of starch digestion by decreasing the rate and extent of starch digestion. The other factors may play a role as well.

Konjac-glucamannan, agar, and xanthan gum decreased starch hydrolysis rate which was inversely to the concentration of hydrocolloid. Each of hydrocolloid has the optimum concentration to reduce the starch hydrolysis. At the same concentration, xanthan gum and konjac-glucamannan had the highest suppressing effect on starch hydrolysis than agar. The presence of hydrocolloids alter the blood glucose level after ingestion which were dependent on the hydrocolloid type. The presence of xanthan gum decreased the blood glucose levels at 30 min, whereas pectin and guar gum decreased the level at 60 min. Xanthan gum had the most suppressive effect on starch digestibility among other hydrocolloids such as konjac-glucamannan, pectin, and guar gum. Furthermore, tester and Sommerville have reported that konjac-glucamannan, pectin, gum arabic, and guar gum on the restriction of normal maize starch hydrolysis.

The addition of guar gum inhibited in vitro starch digestion, decreased rapidly digestible starch and increased resistant starch, especially when 0.30% guar gum was added to 30% lotus seed starch. Bai et al. found that the decrease of starch digestibility in the presence of pectin might be due to physical rather than chemical factors. They have explained that two possible factors were (1) enzyme bound with pectin, inhibiting the access of the enzyme to inner starch granule and (2) the presence of pectin increased viscosity of starch suspension which caused lower diffusion rate of enzyme. The mechanism of reducing starch digestibility by blending with hydrocolloids might be dependent on type of hydrocolloids. The properties of hydrocolloids solution are influenced by its molecular size, concentration, distribution, and charge.

### 2. Impact of starch-hydrocolloid interaction on digestibility

The presence of other components influences the rate and extent of starch digestibility in a food matrix. Inhibitory effect during starch hydrolysis might be caused by some molecules naturally occurring in food system. Hydrocolloids have the potential effect to increase the viscosity of food products which altered the accessibility of starch granules to the α-amylase. Blending starch with hydrocolloids is expected to alter the rate and extent of starch digestion. Some previous studies have reported that hydrocolloids decreased starch hydrolysis in gels as reported in the studies on the addition of agar, konjac-glucamannan (KG), and xanthan gum to the rice starch and guar gum, xanthan gum, KG, and pectin to high-amylose corn starch. The other studies also found that hydrocolloids reduced the blood glucose response of waxy maize and potato starch and some type of hydrocolloids inhibited starch digestibility and altered the pattern of starch digestion. Moreover, Sasaki and Kohyama have reported that the higher viscosities and retarding enzyme diffusion were not the only factors as underlying mechanism of starch digestibility reduction in the presence of hydrocolloids. The other factors may play a role as well.

Adding hydrocolloid interaction can alter pasting properties of starch. Some studies have reported that starch-hydrocolloid interaction can alter pasting properties of starch. Different type and concentration of hydrocolloids often have different effects on the pasting properties of starch, such as the addition of guar gum increased peak, final, breakdown and setback viscosities of potato, yam, yam bean and sweet potato starches, gum arabic decreased peak viscosity of wheat starch, fenugreek gum increased peak viscosity time, setback and final viscosities and decreased breakdown of corn starch, xanthan increased peak and final viscosities, breakdown and setback of rice starch, guar gum decreased final and setback viscosities of lotus seed starch, pectin decreased breakdown and setback of corn starch, β-glucans increased peak, final,
breakdown and setback viscosities of rice starch [36]. Whereas hydrocolloid had little effect on pasting properties [19]. Effect of hydrocolloid on pasting properties of starch is dependent on several factors such as: type of starch or hydrocolloid, ratio of starch and hydrocolloid, preparation methods of starch-hydrocolloid blending, and measurement conditions [31].

Pasting properties of starch with the presence of hydrocolloid often vary with the starch and hydrocolloid type and its concentration. Pectin at lower concentration (0.5 and 1.0%) decreased peak viscosity, inversely at higher concentration (above 2%) increased peak viscosity of corn starch [17]. Final and setback viscosities of lotus seed starch decreased by the addition of 0.03% and 0.15% guar gum, conservatively increases by the addition of 0.30%, 0.60%, and 90% guar gum [18]. Addition of arabic gum decreased peak viscosity, breakdown and setback value of all type of tapioca starch but had no effect on setback of cationic tapioca starch [37]. Ravindran and Matia-Merino [34] have reported that breakdown decreased and peak viscosity time, setback and final viscosity increased with increasing concentration of hydrocolloid. Furthermore, Weber et al [38] have reported that addition of guar gum decreased peak, final, breakdown and setback viscosities on corn starch, conversely addition xanthan increased peak, final, breakdown and final viscosity of corn starch.

Several mechanisms were proposed to explain the effect of hydrocolloid on pasting properties of starch. The pasting properties of starch-hydrocolloid mixture are influenced by: (1) the network structure of molecules in the continuous phase, (2) the characteristics of the hydrocolloid in the continues phase, (3) granule swelling in the starch-hydrocolloid system, (4) interactions between swollen starch granule and granule fragments, interaction between the continues phase and dispersion phase, any electrostatic interaction between starch granule and hydrocolloid molecules [24, 39]. In addition, hydrocolloid structural characteristics such as molecular weight, the degree of branching, molecular flexibility, and presence and type of an anionic charge may be some factors that influence of hydrocolloids to interact with a starch polymer [31, 40]. The alteration of pasting properties of starch by adding gum that due to an association of the swollen starch with the gum or with the fractions of soluble amylose and low molecular weight amylopectin in starch paste, and competition of the starch with the gum for the free water in the system [38].

4. Effect of starch-hydrocolloid interaction on functional properties

As well as pasting properties, effect of starch-hydrocolloid interaction on functional properties of starch depends on several factors, such as type of starch and hydrocolloid, ratio of starch and hydrocolloid mixture, methods of preparation, etc. Some studies found that the presence of hydrocolloid increase granule swelling [39, 41]. The other studies have opposite results that the presence of hydrocolloid molecules caused strengthen granules and restrict granule to swell [24, 32, 37]. Swelling power (SP) and solubility of starch-hydrocolloid mixture was influenced by type and concentration of hydrocolloid. SP of lotus seed starch decreased by the presence of 0.03% and 0.15% guar gum, conversely by the presence of 0.30%, 0.60% and 0.90% guar gum [18]. SP and solubility of tapioca starch, anionic tapioca starch and cationic tapioca starch decreased by addition gum arabic, whereas the extend of the decrease in SP and solubility by gum arabic addition depends on type of an anionic charge of tapioca starch [37]. The presence of guar gum and locust bean gum slightly decreased of SP for tuber starches and the presence of guar gum also decreased solubility of tuber starches except yam starch [32]. Yellow mustard mucilage and buckwheat and pea starches interacted by hydrogen bond to restricted starch granule swelling and solubility [42].

Decrease in SP might be caused by several factors. Tapioca starch were completely wrapped by xanthan gum layer, which delayed granule swelling, limitation of increase in viscosity and inhibit starch granule to gelatinize [39]. A similar mechanism for gum arabic and starch mixture was also reported by cationic tapioca starch were wrapped tightly by a guar gum and prevent amylose leach out. Therefore, Chen et al [40] have speculated that decreased in SP of starch-galactomannan blending was caused by interaction between galactomannan with inner molecules on the surface of the starch granules and galactomannan coated on the surface of the starch granules.
Freeze-thaw stability is an important functional property of starch that was used to evaluate the stability of starch gel during freezing and thawing. Freeze-thaw stability was measured by water that separates from starch pastes or gels (syneresis) [43]. Some previous studies found that the presence of hydrocolloid increased the stability of starch gel or reduced starch syneresis [8, 21, 33, 44] and another study found the opposite result [37]. Muadklay and Charoenrein [43] found that different types of hydrocolloid have a different effect on syneresis of starch gels; 0.25% and 0.50% of xanthan gum was more effective in reducing syneresis than konjac-glucomannan and locust bean gum.

5. Conclusions
Effect of hydrocolloid on starch digestibility, pasting and physicochemical properties depends on starch source, type and concentration of hydrocolloid, and method of preparation starch-hydrocolloid mixture. Generally, addition of hydrocolloid decreases starch digestibility, alters pasting and physicochemical properties. Hydrocolloid structural characteristics such as molecular weight, the degree of branching, molecular flexibility, and presence of an anionic charge, type of an anionic charge influence the interaction of hydrocolloids with starch polymer.

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