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Microwavable expanded-snack from native rice starch: Influence of inulin and amylose content

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Abstract

This study investigated the effects of dry basis amylose content (AC) of 4-28% w/w and inulin content (IC) of 5-25% on the structure and physical properties of microwavable rice starch-based expanded products. It was found that the structure and physical properties of rice-based products is influenced by the interaction between AC and IC. Expanded products can be obtained by using 10% shortening. Snack products were expanded in a 660 W microwave oven. It was generally observed that maximum expansion occurs in products of 4% AC and 25% IC. The highest expansion of product related to the lowest relative crystallinity (RC) in the starch gel and lowest gel hardness. With constant IC, the RC and gel hardness increased with AC. However, a constant AC, with increasing IC resulted in a lower RC and gel hardness. The higher AC resulted in greater hardness and bulk density, but a lower degree of expansion in the product. At a constant AC, increasing the IC resulted in a lower hardness and bulk density, but higher degree of expansion of products and provided uniformity of air cell size and fine structure.

Introduction

As people become busier in fast-paced modern societies, the tendency to consume snack food has increased considerably in recent years. Sales of snack foods have thus increased and this growth is likely to continue. Many snack products are expanded, as expansion of food polysaccharides improves the texture and palatability of snack making them crispy and more appealing. One area in which studies are few is the category of microwave expansion. Microwave heating is an advanced process that provides desirable texture and may be used for snack expansion (Singh and Singh, 1999). The main factors that affect porosity/air cell and expansion during microwave heating are starch (amylose/amylopectin) content and other ingredients. The effects of microwave heating have been studied mainly on amylopectin pellets (Ernoult *et al*., 2002; Boischot *et al*., 2003; Sjoqvist and Gatenholm, 2007), corn pellets (Gimeno *et al*., 2004) and corn kernel pop (popcorn) (Lin and Anantheswaran, 1988; Singh and Singh, 1999). Amylose/amylopectin is the major polymer in snack products and is the ingredient essentially concerning the development of the expansion (Gimeno *et al*., 2004; Jiamjariyatam *et al*., 2015).

Applications of microwave heating is one of the processes used in manufacturing the snack. Starch network or pellet was obtained from amylose-amylopectin re-arrangement. The baking, deep frying or microwave heating was the procedure that can provide pellets further expanded (Ernoult *et al*., 2002; Boischot *et al*., 2003). The addition of fat in pellets as an ingredient have a beneficial effect on expansion of products (Ernoult *et al*., 2002). There were various form of lipid such as hydrogenated oil and butter used in microwave expanded-product (Singh and Singh,1999). The pellets that contained 6% solid fat provided a maximum expansion ratio of snack. The use of fat on expansion was shown to reduce the internal friction of starch network by lubricity of fat. Therefore, the wall of starch network was more flexible. Many hydrocolloids were also used in pellets (Gimeno *et al*., 2004). Gimeno *et al*. (2004) reported that the addition of xanthan gum or carboxy methyl cellulose can enhance the homogeneity of the microwave expanded-products. The pore of starch network was due to hydrocolloid molecules that interrupted the arrangement of the amylose/amylopectin chains, which led to a more extended structure of the starch network and the creation of cavities in the network (Gimeno *et al*., 2004).

In food manufacturing, inulin is prebiotic hydrocolloid that can be utilized as a fat replacer, thickener, gelling agent, bulk agent and water retention enhancer in bakery product s and dairy products (Zimeri and Kokini, 2002; Glibowski, 2010). Inulin is a linear chain of fructose or fructan with a degree of polymerization from 2-60. Inulin is less soluble

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than oligofructose due to its longer chain length. It is capable of forming crystals when dispersed in water. These crystals don't have a different mouthfeel. The crystals contribute to the formation of a smooth and creamy texture. Inulin has therefore been used advantageously as a replacement for several products. Inulin also provides body and humectancy to soft baked goods and enhances crispness of the product. In food industry, it is widely used to modify desirable texture, replace fat or as a sweetener (Kaur and Gupta, 2002). Oligo-fructose is more commonly used as a sweetener and longer chain inulin is used mostly as a substitute/replacer for fat and as a texture modifier (Kelly, 2008). Some examples of inulin use in non-dairy foods are in breads, biscuits, cereals and meat products (Kuntz *et al*., 2013; Gonzalez-Herrera *et al*., 2015; Karimi *et al*., 2015; Rodriguez-Furlan *et a*l., 2015).

Starch is an ingredient that also added to products acting as a thickener and gelling agent, playing appropriate texture in products. Information about interactions between inulin and starches such as maltodextrin and waxy corn starch (Van Duynhoven *et al*., 1999; Zimeri and Kokini, 2002) has been published. However, study on the application of inulin in starchy products has focused mostly on bakery product and pasta (Brennan *et al*., 2004), while there is a limited number of studies focused on ready-to-eat snack products. Little attention has been paid to the interactions between rice starch or amylose and inulin. This paper presents a study of the interactions between amylose content and inulin and their effects on the structure and textural properties of both rice starch-inulin gels and microwaved-expanded snack with widely differing concentrations of inulin and proportions of amylose components. Therefore, it aims at identifying the effects of AC and IC on a) the RC and the hardness of starch gel, b) the physical properties of microwave expanded-products and c) the structure of expanded products.

Materials and Methods

Materials

Inulin Orafti® GR from the DPO international company (Thailand) containing 97.2% dry matter (d.m.), 98.7% carbohydrate content and 91% inulin, with a degree of polymerization of about 10 was used for this study. Rice of two different colors was purchased from the Bank for Agriculture and Agricultural Cooperatives in Bangkok, Thailand.

Rice starch isolation

Starch was isolated from either black waxy rice or red non waxy rice by wet milling (distilled water per rice ratio was 5 and 1 in weight) with a stone mill according to the method described in Jiamjariyatam *et al*. (2015). The starch was then dried at 60±1°C for 12 h in a hot air oven (HA–100S, Yeoheng Co., Ltd., Thailand), pulverized into powder with a blender (HR2001, Philips, Belgium), and then sifted through a 200-mesh screen sieve. The colored waxy starch and non-waxy starch were packed in aluminum foil bags and stored at 4±1°C.

Starch mixture preparation

The colored rice starch mixtures were obtained from mixing waxy starch and non-waxy starch at a weight ratio of 100:0, 80:20, 50:50, 20:80, and 0:100. The amperometric titration method was used to determine the AC of the prepared rice starch samples that had been isolated from waxy and non-waxy starches and their mixture. The AC of starch was found to be 4.02% w/wdry starch for waxy rice starch and 28.05% w/wdry starch for non-waxy rice starch. The AC for their mixtures was found to be 10.04, 16.03, and 22.03% w/wdry starch for a weight ratio of waxy starch to non-waxy starch of 80:20, 50:50, and 20:80, respectively. These mixtures of starch were packed in aluminum foil bags and stored at 4±1°C.

Preparation of rice starch gel and pellet

Rice starch gel was prepared according to the method by Jiamjariyatam (2016) with the following formulation: 70% water and 20% rice starch with 10% rice bran oil shortening (King, Bangkok, Thailand) added. Starch gels from rice starch were formulated with 4, 10, 16, 22, 28% amylose content (w/w d.m.) and 5, 10, 15, 20, and 25% inulin (w/w d.m.). The starch gels were then kept for 24 h at 4^{o}C. To evaluate the texture of prepared gels, TA.XTi2 (Godalming, UK) texture analyzer, equipped with Texture Expert 1.05 (Stable Microsystems) software was used to penetrate the gel samples. The gels were measured with a stainless steel cylinder probe with a diameter of 25 mm at a speed of 1mm/s to reach a 75% strain. The maximum force was calculated as the hardness of gels. The moisture content of all prepared gels was measured and found to be 43.5% w/w on a dry basis. To prepare the starch pellet, the starch gel was then dried at 50^{o}C for 2 h in a hot air oven (Binder, Germany) to obtain a moisture content of 28% w/w on a dry basis.

Microwave expansion

Prior to expanding the puffed snacks, the water was heated at 1000 W for 10 min in microwave oven

(Brand LG, Model no LCS0712ST) Then the starch pellets were taken in four positions on a mark plate. After removal from a vacuum food container, the starch pellets were heated for 60s at a microwave power of 660 W. The expanded-products were kept in a vacuum food container and stored in 25°C until required for physical analysis.

Relative crystallinity of starch pellets

The RC of starch pellets was determined using an X-ray diffractometer (D5005, Siemens AXS, Germany). The condition of measurement was set at 40 kV and 40 mA and at a copper Kα wavelength of 0.154 nm. The data were collected from 5° to 45° (2Ø) at 0.02° intervals. The scanning rate was 0.04°/s. A peak-fitting software (Origin-version 8.0, Microcal Inc., USA) was used to determine the RC of starch pellets.

Hardness of gel

The texture analyzer (TA.XTi2, Godalming, UK) was used to determine the gel hardness. The cylinder probe (P/25) and a compression rate of 1.0 mm/s was set before measurement. The maximum force was defined as gel hardness.

Degree of expansion

The degree of expansion of the microwave-expanded snack was determined by the unheated and microwave-expanded samples volume as percentage. The percentage change was calculated as a ratio of the difference between final volume and initial volume over initial volume (Boischot *et al*., 2003).

Bulk density

Bulk density was measured applying the seed displacement method using millet seeds (Jiamjariyatam, 2016).

Hardness of expanded- product

The maximum force was determined by a texture analyzer and defined as hardness of expanded-product. A spherical probe (P/0.25s) at the compression rate of 1.0 mm/s was used for breaking the samples.

Structure of the microwave-expanded products

Images of the structure of the expanded snacks were prepared by cutting over the cross section of the snack prior to obtaining images using SEM (JEOL: JSM-5800LV, Jeol Ltd., Tokyo, Japan) and taken by an image analyzer (Nikon SMZ 1000, Japan).

Statistical analysis

Each treatment was repeated three times. SPSS software was used to determine the differences between treatment means using Duncan multiple range test. Treatment means were considered significantly different at $p \leq 0.05$ unless otherwise stated.

Results and Discussion

Relative crystallinity of starch pellets

An increase in RC was found with an increased amount of AC. On the contrary, the addition of IC significantly decreased in RC of the starch pellets (Figure 1a). Increased RC with increasing AC indicated that there are re-association of amylose chain which formed crystalline units in a new network after cooling process (Jiamjariyatam *et al*., 2015). Amylose helices interact with inulin or amylopectin and form semi-crystalline units which randomly aggregate into starch networks (Putaux *et al*., 2000). Additional IC seemed to inhibit the starch gel network by disrupting amylose-amylose, amylose-amylopectin re-crytallisation.

Starch gel hardness

Starch gels with higher AC had significantly higher gel hardness ($p \leq 0.05$) than others. Higher IC in starch gels caused lower gel hardness (Figure 1b). These results correspond to the RC of the starch gel. Higher levels of AC starch promoted the retrogradation of the starch gel after gelatinization and aging (Jiamjariyatam *et al*., 2015). Therefore, the RC increased and hence, gel hardness increased with higher AC. A higher IC, on the other hand, resulted in less re-association or re-organization of starch molecules. Therefore, less retrogradation occurred which was confirmed by a lower RC, which yielded softer gels. In gels with lower AC and IC, both polysaccharides (amylose and inulin) freely paste and further form loose network by amylose-inulin interaction. This was due to sufficient amount of water in the system. In contrast, at higher AC and IC values, water was the limiting factor because amylose and inulin were binding water and formed a compact network.

Lower hardness of starch gel with inulin could be caused by the ability of inulin to form soft gels. Inulin with long chain could make gels becoming harder. Moreover gel hardness after cooling is also affected by retrogradation of amylose (Goesaert *et al*., 2008). A delay in gelatinization caused by inulin could inhibit amylose leaching from the starch granules. Hence, there is insufficient amount of amylose in the final gel. Inulin plays a major role in gelling texture in food systems. The inulin microcrystal has a

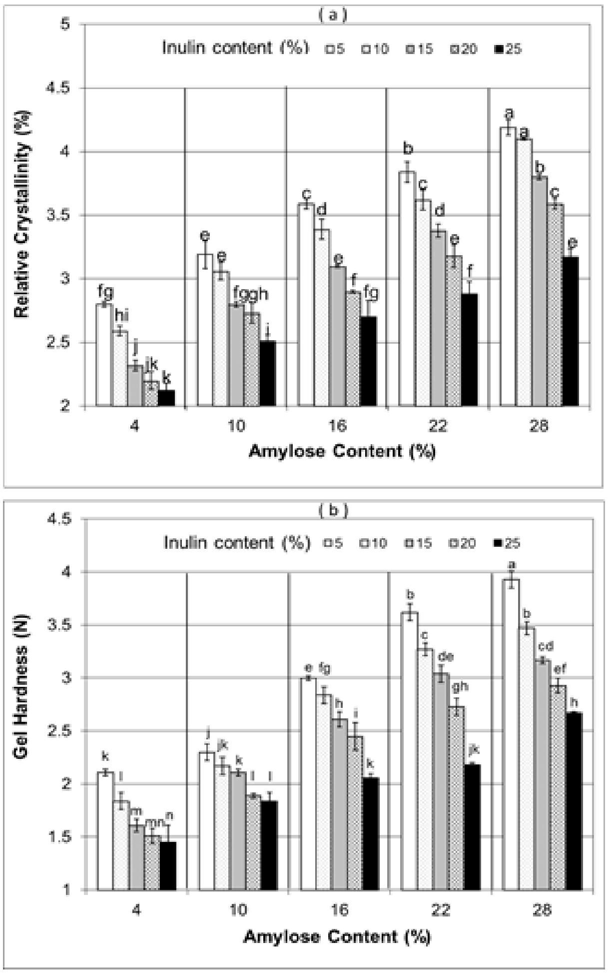

Figure 1. Effects of amylose and inulin content on relative crystallinity (a) and hardness (b) of rice starch gel

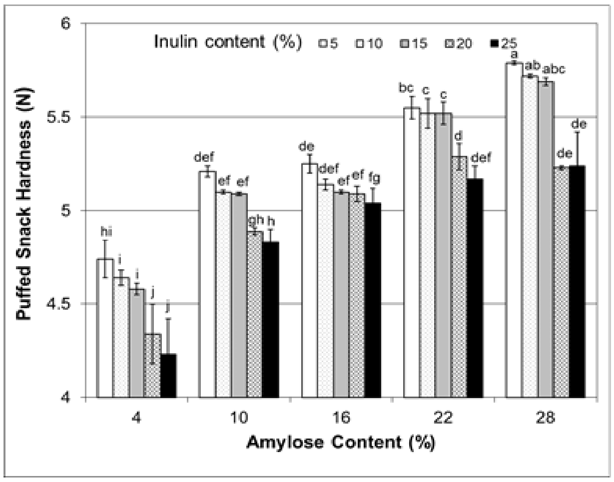

Figure 2. Effects of amylose and inulin content on hardness of expanded product

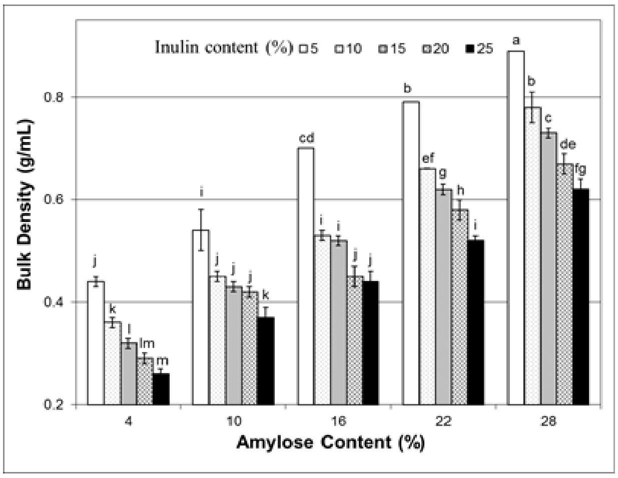

Figure 3. Effects of amylose and inulin content on bulk density of expanded product

synergistic effect on gelation with starch (Gonzalez-Herrera *et al.*, 2015). However, most commercial inulin is an amorphous type with lower crystallinity. Thus, the inulin gel forms by weak covalent bond between polysaccharide chains (Vervoort *et al.*, 1999; Mensink *et al.*, 2015).

Texture of microwave-expanded product

The hardness of the expanded products increased with increasing AC. Generally, hardness (Figure 2) and bulk density (Figure 3) decreased with increasing IC. The hardness of the expanded snack depended on the content of both amylose and inulin. The increase in AC of starch gel from 4 to 28%, at constant IC, resulted in a progressive increase in its hardness and bulk density. Decreasing hardness and bulk density could be observed with increased IC (5 to 25%). These observations were confirmed by the RC of the starch gel and gel hardness. Moreover, the degree of expansion increased with increasing IC (Figure 4). The expansion changes investigated in the texture of the expanded-snack product can be related to the aforementioned changes in gel hardness. When samples with lower gel hardness were heated, the products were soft and their texture was more expanded.

The high retrograded starch content inhibited expansion of expanded product (Chen and Yeh, 2001). As mentioned earlier, a higher value of hardness, and bulk density and a lower expansion ratio are related to the degree of RC. As expected from earlier research, a higher retrogradation of starch gel resulted in a higher hardness and bulk density of puffed products but lower expansion ratio.

Degree of expansion

The degree of expansion (of starch pellets) was also strongly influenced by the quantity of AC and IC (Figure 4). Increasing AC decreased the degree of expansion from 90% to 60%. Puffiness was also found to increase with increasing IC again indicating that there is a relationship between inulin and degree of expansion. Moreover, one of the key factors for expansion process is AC of starch suspension.

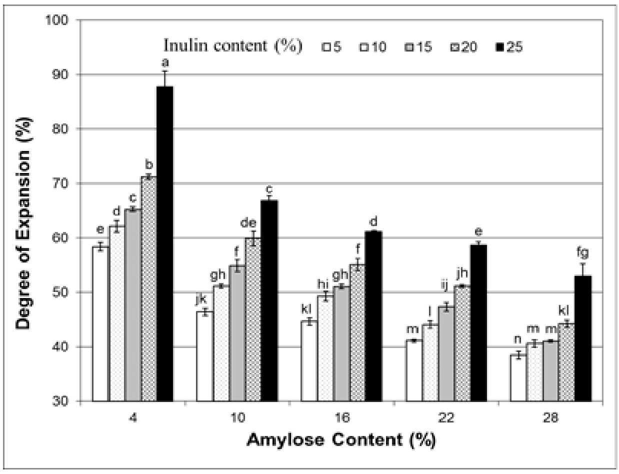

Figure 4. Effects of amylose and inulin content on degree of expansion of expanded product

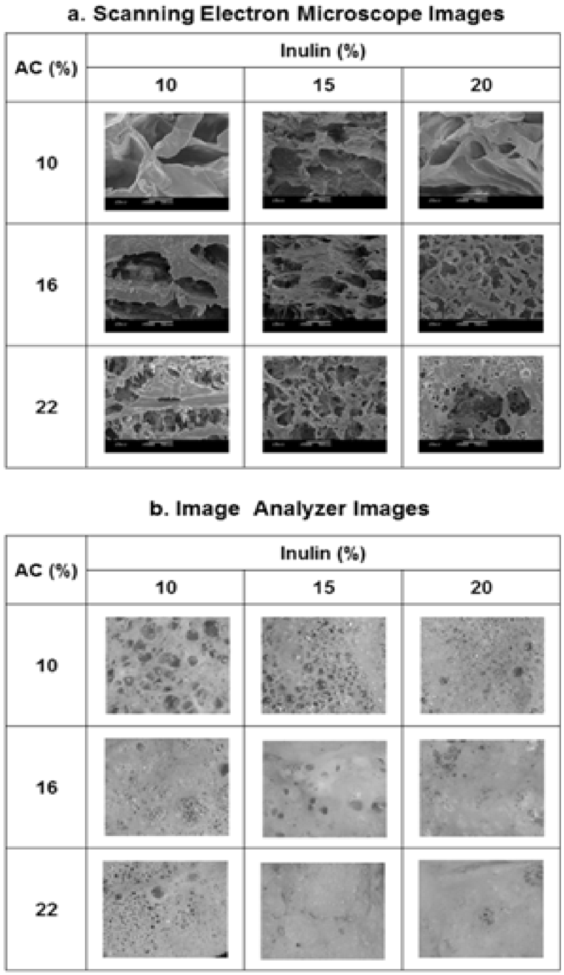

Figure 5. Image analyzer images (a) and Scanning Electron Microscope images of expanded-products

(Jiamjariyatam *et al*., 2015). Moisture content of starch gels before expansion was 28.3% which is also an important factor. The optimum moisture content in starch gel/pellets could allow the superheated steam (its vapor pressure) to generate expansion during microwave heating (Ernoult *et al*., 2002; Sjöqvist and Gatenholm, 2005). Fats is applied in extruded snack products in order to improve snack quality by desirable texture. Fat in the form of shortening was added at 10%. Solid fat favours expansion and affects the water distribution in the starch paste (Ernoult *et al*., 2002; Gimeno *et al*., 2004). High amylopectin starch or low AC starch allows light, elastic, and homogeneous expanded textures, while a high AC provides hard and less expanded snack. Low AC starches are not as hard as high AC starches at the same moisture content, which also favors expansion (Kokini *et al*., 1992; Jiamjariytatam *et al*., 2015; Jiamjariyatam, 2016).

Microstructure of the expanded product

Scanning Electron Microscope (SEM) images of a puffed snack are shown in Figure 5a. The images show that inulin forms a continuous and homogenous starch matrix in expanded snacks. Heated samples with higher IC had a starch structure consisting of dense air cells made up of many small air cells which were separated by very thin walls (Figure 5a). In contrast, samples with lower IC resulted in expanded-snack products with a structure composed of a highly expanded-starch network with pores of large-sized cells divided by very thin cell walls. The microstructure was due to vapor pressure or steam escaping from internal area of network during microwave heating. Moisture release built up in the pellets lubricated by fat. Therefore, pellets further contributed to enhanced expansion. Fat contributed to a fine microstructure of the expanded products without breaking or rupture (Chen and Yeh, 2000). Upon heating in microwave, moisture changes to the superheated steam, which accumulates at the center of starch matrix. The high pressure was responsible for a phase transition from glassy to rubbery state and expansion takes place. At the final step of microwave heating, the moisture is lost from the starch, the starch degenerates to the final structure without collapse (Boischot *et al*., 2002).

Structure of microwave-expanded products

Expansion of the snack was dependent on both AC and IC. In addition the physical appearance of the snack products changed according to the level of AC and IC. The expanded-snack products had different sizes of air cells (Figure 5) depending on level of AC and IC. The thickness of the cell wall of expanded snack was due to evaporation of water and moisture released from inside out in the form of steam during microwave heating. The images of the puffed products from the image analyzer as seen in Figure 6b shows that higher levels of IC gave a more homogeneous network in the puffed products with smaller pore size. More opacity indicated higher density of the network. The more uniform pore distribution and size in the gels with higher AC resulted in more uniform air cell distribution and size. A greater starch retrogradation at higher AC and with longer aging time resulted in more continuity of the network and smaller air cells.

Drying of starch gels causes moisture loss, a dense starch network and crust formation. The stronger network provides sufficient integrity of air cells during their expansion. The starch gel having smaller pores produced a fine network in the puffed products with smaller air cells and greater homogeneity. Moisture is the key factor in microwave expansion of pellets. During microwave heating, glassy cereal pellets simultaneously lose moisture and expand (Chen and Yeh, 2000; Lee *et al*., 2000; Boischot *et al.*, 2002; Ernoult *et al.*, 2002). The low moisture content in pellets corresponds to expanded products with a fine structure, a large number of relatively small cells, and thin cell walls (Chen and Yeh, 2000; Ernoult *et al.*, 2002). Chen and Yeh (2000) showed that the expansion ratio increased at the lower level of dextrin in the rice pellets. It is expected that the viscosity of the pellets impacts the microwave expansion process. In this research, the addition of inulin with an average degree of polymerization of 10 caused an increase in expansion. It was likely that inulin was solubilized and hold the air cell within pellet structure. Therefore, inulin can increase the stability of air retention and form highly expanded air cellular structure of the final product (Rosell *et al*., 2010).

Conclusion

The microstructure and other characteristics of expanded products were found to be strongly affected by AC in this study. A higher level of AC resulted in higher gel hardness and RC of starch pellets while a higher IC tended to decrease gel hardness and RC. Increased AC increased hardness, and bulk density of the products, and vice versa for the expansion ratio. Incontrast, the hardness, bulk density and expansion ratio of puffed products decreased with increasing IC.

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