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Structural and thermal properties of Konjac / Gum Arabic edible film containing VCO as Food Packaging

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KEYWORDS

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Virgin Coconut Oil (VCO)

ABSTRACT

With growing concerns about plastic pollution and environmental sustainability, the development of edible films presents an innovative solution for reducing plastic waste. An edible film is defined as a thin layer of edible material, either formed on a food as a coating, or preformed and then wrapped around a food or placed food components. Edible film is non-biodegradable and has a long drying time. Konjac glucomannan (KGM) is a good material for a biodegradable edible film. However, the strong hydrophilicity of KGM often resulted in poor water resistance and barrier properties of films. One way to overcome this drawback could be to prepare composited films by blending KGM with other polysaccharides with less hydrophilicity or certain hydrophobicity. Therefore, the aim of this study was to develop a novel emulsified edible film based on KGM (Konjac Glucomannan), GA (Gum Arabic) and VCO (Virgin Coconut Oil) using casting method and to characterize structural and thermal properties of emulsified edible film using FT – IR (Fourier – transform infrared spectroscopy) and TGA (Thermogravimetric Analysis). Using the casting approach, a unique emulsified edible film was successfully produced. FT-IR study suggests that strong intermolecular hydrogen bonding has formed in the KGM-GA-VCO edible film by the shift of hydroxyl group at 3397cm^{-1}. The TGA results demonstrated that introducing VCO into edible film enhances the film's ability to withstand thermal stress, providing compelling evidence for its positive influence on the film's performance and its potential applications in the food packaging industry.

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1.0 INTRODUCTION

Given that food packaging plays a crucial part in protecting and containing food, it is a crucial topic of food research. Traditionally, the majority of packaging material needs are met by polymers made from petroleum. Consumers today are more concerned about the risks that these synthetic polymers pose to their health and the environment. This calls for the use of alternative packaging materials that have special biodegradable and renewable properties. The edible film is seen as a way to substitute these synthetic polymers with bio-macromolecules like polysaccharides, proteins, and lipids that are readily available in nature [1]. The most common edible wrappings for fruits and vegetables are wax and SFAE mixes. They are, however, not equally effective for every produce. Another issue is that consumers are suspicious of waxy coatings. As a result, the development of alternative edible coatings that do not impart a waxy flavor is desirable.

Edible films are thin, flexible, and biodegradable materials made from natural polymers, primarily polysaccharides, proteins, and lipids, that can be consumed along with the food they protect. Among these natural polymers, polysaccharides have garnered significant attention due to their abundance, biodegradability, and non-toxic nature. Polysaccharide-based edible films offer several advantages, including excellent barrier properties, mechanical strength, and potential antimicrobial activity, making them suitable for food preservation and packaging [2]. Films made of polysaccharides also have been investigated as secure and eco-friendly food packaging solutions [3]. Recently, there has been a lot of study interest in polysaccharides-based edible films with bioactive oil addition. Mostly, such films belong to one type of the emulsified edible films, as the oil contents need to be emulsified during film preparation [4].

Konjac Glucomannan is a typical food ingredient that has been utilised in numerous industries, including the culinary, pharmaceutical, cosmetic, and chemical sectors [5]. In the food industry, glucomannan is generally recognised as safe (GRAS) by the FDA and can be used as an emulsifier [6], thickener [7], dietary supplement [8][9] and edible film ingredient [10][11]. Glucomannan can be a great edible film ingredient since it is a non-ionic polysaccharide that has a high molecular weight and relatively low branch number. However, glucomannan edible film has a high-water vapor transfer rate (WVTR) and solubility, which means that water can travel through the film and enter into the food products, causing the food to deteriorate faster, making it less desirable in industry. Furthermore, it is less elastic than any other edible film, including polypeptide-based edible polymers. [12]. Therefore, in order to boost the WVTR value of glucomannan film, another component that improves the water vapour barrier property of glucomannan film must be added.

Gum Arabic is a polysaccharide-based polymer obtained mostly from the stems and branches of the Acacia Senegal and Acacia Seyal trees. Because of the complicated combination of glycoprotein and ribose sugars, it is categorized in polysaccharide family. It is the most soluble and least viscous of the hydrocolloid family, and it is used in the commercial sector for emulsification, film making, and encapsulation [13]. Gum Arabic has recently gained popularity as a postharvest edible wrapping due to its ability to maintain freshness and extend the shelf-life of fresh vegetables. It is an efficient food preservative because of its emulsifying, stabilizing, binding, and shelf-life prolonging properties [14].

Virgin coconut oil (VCO) is an edible oil derived from the milk of newly harvested and fully matured coconut kernels (*Cocos nucifera L.*), a tropical plant in the Aceraceae (palm) family. VCO is odourless and has a coconut-like aroma. Recently, virgin coconut oil (VCO) has been employed in the manufacture of emulsion films to increase the water barrier qualities of the films [15]. Based on the previous study, VCO addition not only increased the water barrier qualities of potato starch-based film, but it also improved the elongation ratio at break (EAB) with insignificant changes in the film's tensile strength (TS) [16]. This boded well for the preparation of KGM-based emulsion films. In a previous work [17], we discovered that KGM/agar mix films had improved mechanical/hydrophilic capabilities, and the water barrier property of the film should be further strengthened by VCO addition, allowing for practical food packaging applications. Thus, the aim of this research was to create a unique emulsified film with desired water barrier qualities based on KGM, GA, and VCO. The effects of different concentrations of VCO on the structural and thermal properties of edible film were investigated and discussed, using FT-IR and TGA, respectively.

2.0 METHODOLOGY

2.1 Materials

The Konjac glucomannan (KGM) used in this study was acquired from Hubei Qiangsheng Konjac Technology Co., Ltd. located in Hubei, China. It was of food grade quality with a purity level of not less than 95%. The molar mass (Mw) of the KGM was approximately 1.01 × 10^6 g/mol. The molar ratio of mannose to glucose in the KGM was 1.6:1, while the degree of acetylation was measured to be 1.85%. Additionally, the viscosity of a 1% KGM solution was found to be 24000 mPa. Gum Arabic (GA) was supplied by San-Ei Gen F.F.I. Inc. based in Osaka, Japan. The GA also met food grade standards with a purity level of not less than 95%. Its molar mass (Mw) was approximately 9.50 × 10^5 g/mol, and it contained 11% AGP (arabinogalactan protein) based on the total mass. Glycerol was obtained from Sinopharm Chemical Reagent Co., Ltd., located in Shanghai, China. It was of chemically pure grade quality, with a purity level of not less than 99.5%.

2.2 Edible film preparation

The casting process was used to create the edible film. The emulsified film was prepared by incorporating VCO into the optimized formulation of KGM/GA film. 20 mL of deionized water were put first into the beaker to make sure the materials were absorbed carefully and Konjac (KGM) stock solution was made by dissolving 6 percent (w/w) of KGM and glycerol was integrated by adding 27 percent (w/w) into the 100 mL deionized water and stirring for 20 minutes at 500rpm. Gum Arabic (GA) were added to the solution by 2-3 percent (w/w) of GA with stirring continuously for 30 minutes at 500 rpm. VCO solution at concentration of 0.5 (w/w) were agitated at 500 rpm for 2 hours.

The KGM-GA solution was then poured onto petri dish (90 mm x 15 mm) and heated at 38 °C for at least 24 hours in a Venticell Oven. Then the sample pre-conditioned in a desiccator (24°C, 50% relative humidity (RH)) for at least 2 days [18]. VCO was graciously supplied by University College TATI. The primary saturated fatty acids' composition as well as their percentual presence (w/v) in VCO were supplied by the manufacturer.

2.3 Fourier Transform Infrared Spectroscopy (FT-IR)

The chemical characterization was carried out through the application of Fourier Transform Infrared (FT-IR) spectroscopy, utilizing a Nicolet 6700 Spectrometer to obtain spectra from the samples. For preparation, the samples were transformed into potassium bromide pellets at room temperature. To ensure precise data, 32 scans were averaged with a resolution of 4 cm−1, covering the spectra region from 4000 cm^{-1} to 400 cm^{-1}.

2.4 Thermogravimetric analysis (TGA)

The investigation will involve conducting Thermogravimetric analysis (TGA) on the KGM-GA-VCO edible film, an analytical technique aimed at studying its thermal behaviour. During the TGA procedure, the edible film samples were subjected to a gradual temperature increase, spanning from 25 to 600°C. To ensure controlled and precise conditions, a heating rate of 10°C/min was applied throughout the experiment. Additionally, a continuous flow of nitrogen at a rate of 50 mL/min was maintained, serving to create an inert atmosphere and prevent any unwanted reactions during the analysis. By employing these carefully chosen parameters, the TGA analysis seeks to unravel the thermal stability and decomposition patterns of the KGM-GA-VCO edible film, contributing valuable insights to the field of food science and material research.

3.0 RESULTS AND DISCUSSION

3.1 Preparation of edible film

The successful fabrication of an emulsified edible film was accomplished through the implementation of the casting method, wherein a precise composition of key ingredients, including 6% of KGM, 27% of GLYCEROL, 2% of GA, and 0.5% of VCO, was utilized. As shown in Figure 1, the resulting film exhibited exceptional stability, remaining entirely intact even when manually handled. Moreover, it is noteworthy that the sample's colour appeared immaculately clean and maintained a remarkable level of transparency.

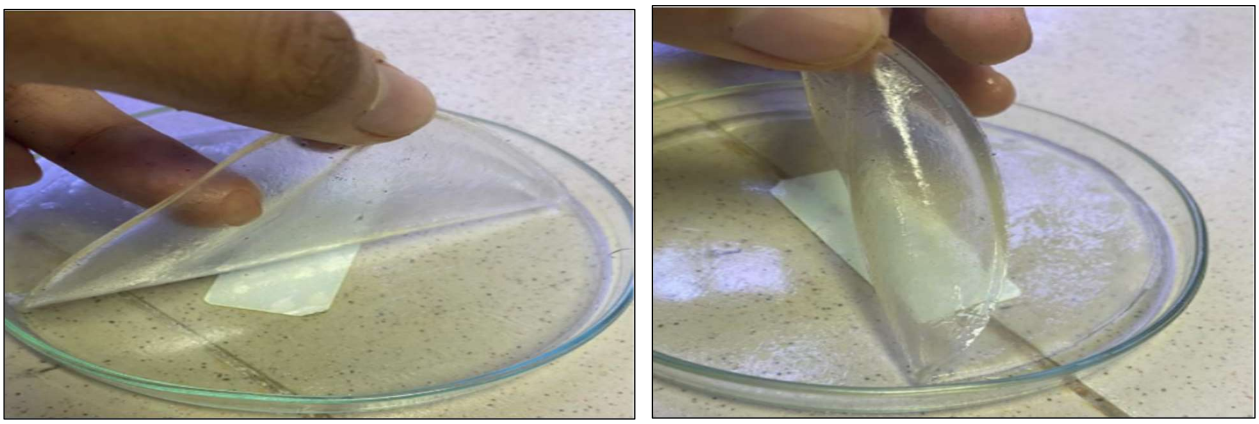

Figure 1 : KGM/GA/VCO sample film of edible film

3.2 Structural properties of edible film

The investigation of structural distinctions in the development of the KGM-GA-VCO edible film was meticulously conducted using FTIR analysis, revealing distinctive spectral features. Figure 2 shows the infrared spectra of pure KGM, GA, VCO and the edible film. Characteristic absorption peaks of KGM were observed at 3319, 2923, 1732, and 807, 870 cm^{-1} which were attributed to stretching vibrations of the O–H group, C–H group, acetyl group, and mannose unit, respectively [19][20]. Meanwhile, the FTIR spectrum of GA showed absorption peaks at 3424 (O–H stretching vibration), 2930 (C–H stretching vibrations), 1617 and 1420 (–COO- stretching vibrations), 1050 (C–O stretching vibrations), 840 and 772 cm−1 (O–H stretching vibrations) [21][22][23].

According to the FTIR spectra (Fig 1), the characteristic peaks for VCO at 2925 and 2854 cm^{-1} were associated with the stretching vibrations of the C–H groups, representing the presence of saturated fatty acid chains. The peaks at 1747, 1466 and 1378, 1161, and 722 cm^{-1} were related to the C=O stretching vibrations of the fatty acid esters, C–H stretching vibrations, C–O stretching vibration in esters, C=C stretching vibration, respectively [24].

A conspicuous absorption band in the range of 3000–3700 cm^{-1} indicated extensive hydroxyl group vibrations. The peak at 2476 cm^{-1} was indicative of characteristic hydroxyl stretching, while peaks at 3368 cm^{-1}, 2928 cm^{-1}, 1647 cm^{-1}, and 1023 cm^{-1} corresponded to various molecular vibrations. All film' FTIR spectra showed similar absorption peak positions, indicating that no new chemical linkages were created between components.

Notably, the incorporation of VCO altered hydrogen bonding between polymers, as indicated by shifts in hydroxyl group peaks. In comparison to the FTIR spectra of KGM-GA-VCO film, additional peaks at around 2849 and 1741 cm^{-1} were developed in the edible films, and the intensities of both peaks rose with increased VCO's content, indicating the existence of VCO in the film. Peaks at 1623 cm^{-1} and 1064 cm^{-1} further confirmed VCO presence. Comparative analysis of KGM-GA-VCO edible film and native KGM unveiled widened peaks at 3400 cm^{-1} and shifts at 3397 cm^{-1}, suggesting alterations in hydroxyl group environments. This study contributes to a deeper understanding of structural changes within the KGM-GA-VCO edible film and its chemical properties.

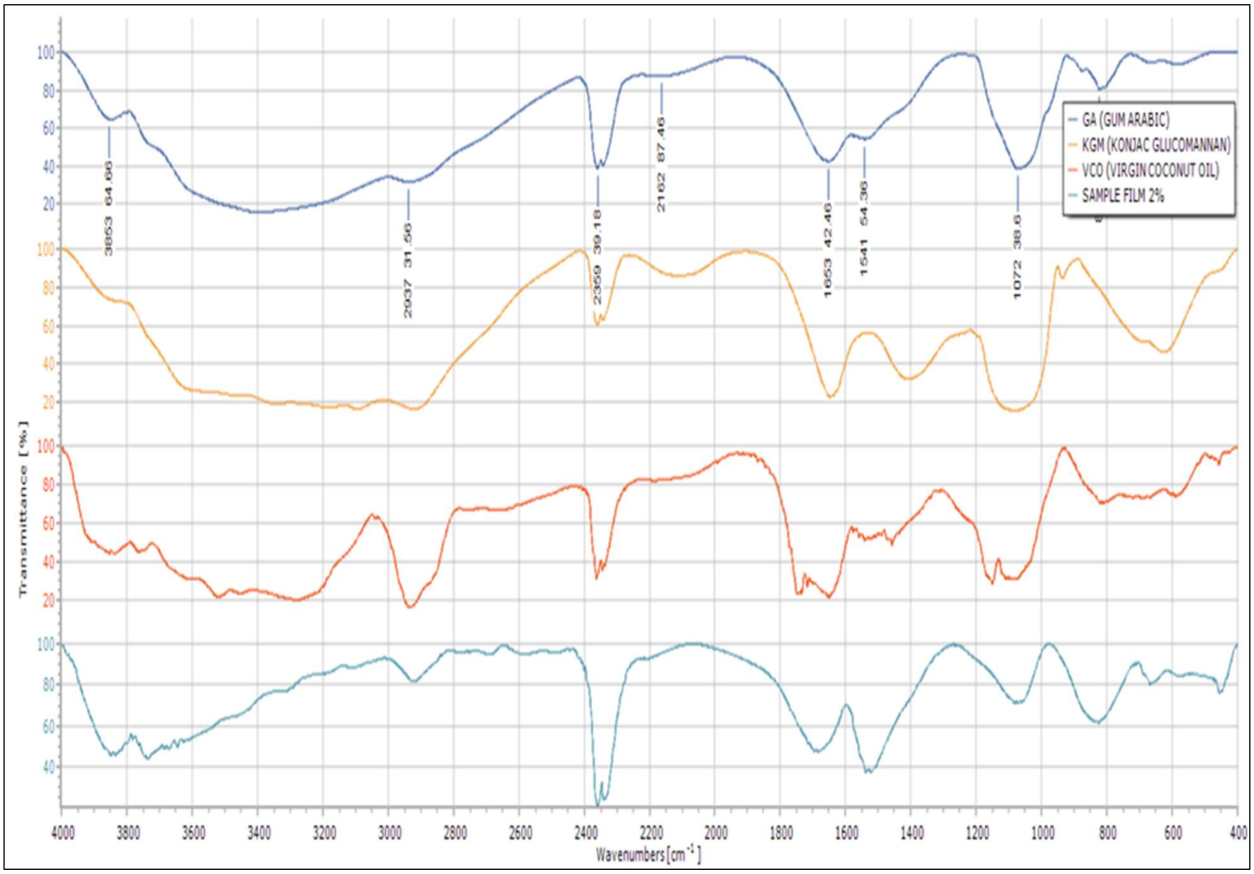

Figure 2: FT-IR spectra of KGM, GA, VCO and KGM-GA-VCO sample film

3.3 Thermal properties of edible film

Thermogravimetric analysis (TGA) was employed as a crucial method to assess the thermal stability of the KGM-GA-VCO edible film. The primary objective behind utilizing thermogravimetric analysis (TGA) was to effectively investigate and identify the thermal stability and behaviors of the edible film. Comprehensive data on thermal degradation and stability of the edible film can be found in Table 1, while a graphical representation of these findings is presented in Figure 3 and Figure 4. Figure 2 shows the thermogram for pure KGM and VCO, meanwhile Figure 4 demonstrates the thermal profile for KGM-GA-VCO edible film with different VCO concentrations.

KGM degradation is typically separated into three weight loss phases. The first stage (in the 50-200 °C range) is associated with water volatilization and evaporation. KGM's hydrophily causes water loss in the first stage [25]. This intriguing thermal behaviour within the mentioned temperature range was found to be closely linked to the degradation of saccharide rings, as well as the dissolution of polymer chains present in the KGM structure. At the second stage (in the 200-325 °C), all films showed significant mass loss due to thermal degradation of KGM, GA and VCO. At roughly 330 °C, the weight loss of the KGM film was considerably slowed [26].

The results revealed that significant mass loss was recorded within the temperature range of 200 °C to 400 °C, primarily attributed to decomposition linked to saccharide ring degradation and polymer chain dissolution. Further analysis of TGA results demonstrated that the film's fabrication from pure polymer did not affect its inherent thermostability, aligning with previous research by Genevro [27]. The addition of 1% and 1.5% virgin coconut oil (VCO) improved the film's thermal stability, possibly due to interactions between gum Arabic (GA) and VCO, consistent with findings by Ismail [28]. This study unequivocally established that introducing VCO enhances the film's ability to withstand thermal stress, providing compelling evidence for its positive influence on the film's performance and its potential applications in the food packaging.

Table 1: Thermal analysis of KGM, VCO, and KGM/GA edible film in an N_2 atmosphere

Concentration (% w/w)			% Weight loss									
KGM	GA	VCO	27 °C	47 °C	67 °C	87 °C	107 °C	207 °C	307 °C	407 °C	507 °C	597 °C
6	2	0.5	47	-0	-1	-2	-4	-11	-26	-29	-30	-31
		1.0	212	212	211	211	210	204	184	179	178	178
		1.5	55	55	55	54	54	42	11	1	0.45	0.23
KGM POWDER							5	8	36	58	74	76
VCO (VIRGIN COCONUT OIL)							1	2	16	92	100	100

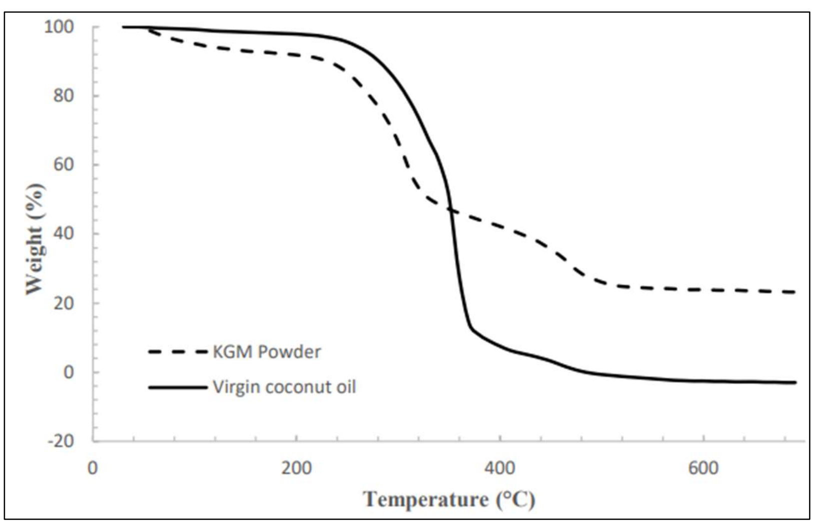

Figure 2: TGA thermograms of virgin coconut oil and KGM powder

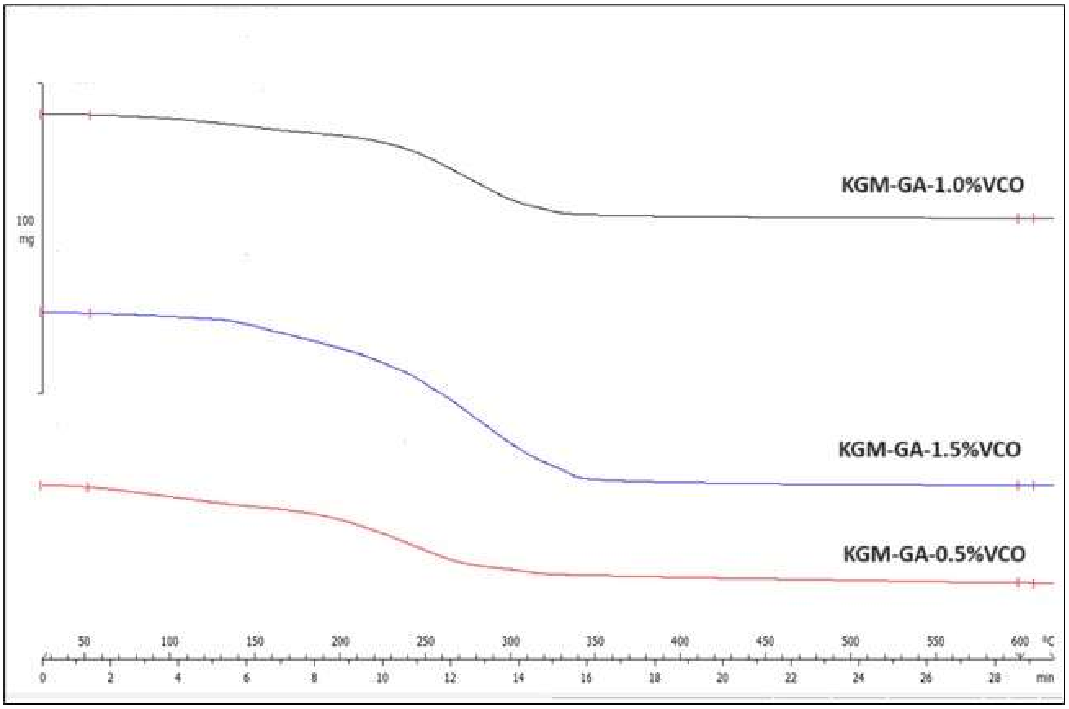

Figure 6: TGA thermograms of 0.5%, 1.0%, 1.5% (w/w) KGM edible film containing Gum Arabic and Virgin Coconut Oil

4.0 CONCLUSIONS

An edible film made from konjac glucomannan, gum Arabic and virgin coconut oil has developed using casting method. The FT-IR results demonstrated that KGM-NaOH and VCO have a significant intermolecular hydrogen bond interaction, indicating that KGM-NaOH loaded with VCO is compatible. The edible showed good thermal stability according to thermogravimetric analysis. In conclusion, this research has highlighted the potential of KGM-GA-VCO edible films as eco-friendly food packaging. Their versatility in food preservation and quality enhancement makes them appealing to the food industry. Embracing edible films aligns with growing environmental concerns and consumer demand for sustainable packaging, promising a more eco-conscious future for the food industry.

Author Contribution

A. Mohamad Ezam: Conceptualization, methodology, investigation, writing and editing. M. Hajaratul Najwa: Methodology, supervision, writing, and editing.

Conflict of Interest

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

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