Journal Article

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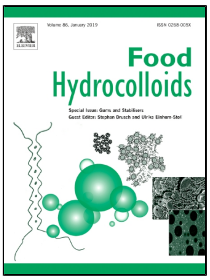

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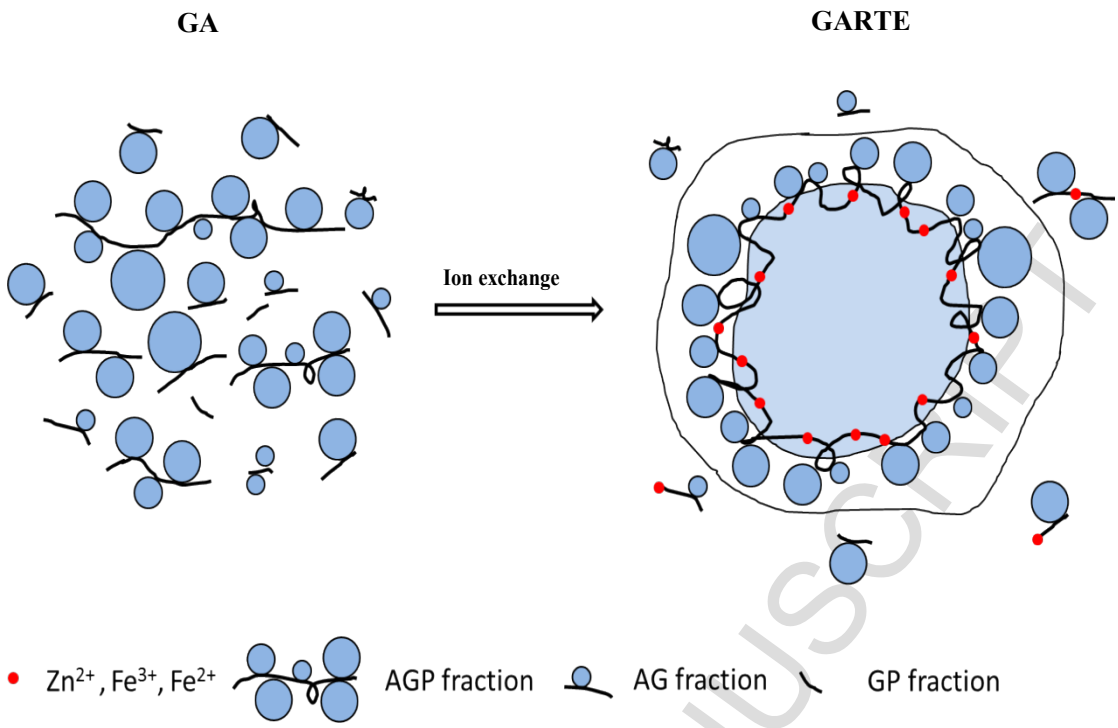

Preparation and emulsifying properties of trace elements fortified gum arabic

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Key words: Gum arabic, trace elements, emulsion.

Abstract

Gum arabic was enriched with trace elements (Zn^{2+}、Fe^{3+}、Fe^{2+}) by ion exchange against $ZnCl_2$, $FeCl_3$ and $FeCl_2$. Trace elements content, molecular parameters and emulsifying properties of the gum arabic rich in trace elements (GARTE) were characterized by flame atomic absorption spectrometry (FAAS), gel permeation chromatography-multi angle laser light scattering (GPC-MALLS), interfacial rheometer, laser particle analyzer and zeta potentiometry. With trace elements, molecular weight and arabinogalactan protein (AGP) content of gum arabic have increased probably due to the high surface energy leading to the aggregation of protein. GARTE has good emulsion stability performance with increasing molecular weight and AGP content compared to the control gum arabic. GARTE can be applied as a natural functional ingredient for trace element fortification, where the ferric ions and zinc ions are chelated by the self-assembled polymer host.

1. Introduction

Trace elements have been classified as trace minerals (<100 mg/day intake) which are needed in small quantities and used by all living organisms. They are imperative for optimum host response. Amidst the array of micronutrients, trace elements make up about 4% of the body weight and are mainly present in the skeleton, enzymes and hormones. They help in regulating and maintaining the normal heart rhythm, muscle contraction, nerve conduction and the acid–base balance (Schifferle, 2010). Populations worldwide are prone to their insufficiency owing to lifestyle changes or poor nutritional intake. A growing list of trace element utilization pathways highlights the importance of these elements for life (Prentice, 2005; Swinburn & Ravussin, 1994). Zinc (Zn) is thought to be essential for all organisms and suggested to be a key element in the origin of life (Mulkidjanian, 2009). Zn is an integral component of a large number of macromolecules, where it can maintain the stability of the cell membrane and activate more than 200 kinds of enzymes, get involved in nucleic acid and energy metabolism, and promote sexual, anti-bacterial, anti-inflammatory functions (Dupont, *et al.*, 2010; Dupont, *et al.*, 2006; Gaither & Eide, 2001; Hantke, 2005; Murakami & Hirano, 2008; Prasad, 1995). Zn deficiency is more prevalent in children, elderly and patients with immunosuppressive disorders due to dietary deficiencies or poor absorption (Dawson, *et al.*, 2013). Its deficiency leads to the increase of frequency for infections and degenerative pathologies (Dawson, *et al.*, 2013; Meunier, *et al.*, 2005). Iron (Fe) compounds are ubiquitous in industrial applications, have vital functions in biological processes, and are essential in the human diet. They are crucial for erythropoiesis and haemoglobin and play an important role of oxygen transport in the blood (Schifferle, 2010). Fe is the active ingredient of many enzymes, metabolism and redox reactants (Hou, *et al.*, 2014; Listed, 1968; Matzner, *et al.*, 1979; Trumbo, *et al.*, 2001). If the human body lacks sufficient intake, iron deficiency and anemia develop, which are prevailing global health issues (Chakraborty, *et al.*, 2014; Mukhopadhyay & Mohanaruban, 2002; Touitou, *et al.*, 1985).

Gum arabic (GA) is one of the popular ingredients widely used in the food and pharmaceutical industries (Guan & Zhong, 2014). It is a branched-chain, complex polysaccharide, either neutral or slightly acidic, found as mixed calcium, magnesium and potassium salts of polysaccharidic acids (Ali, Ziada, & Blunden, 2009). Three different fractions could be separated from gum

arabic, namely, arabinogalactan (AG, ~90% of total mass), arabinogalactan protein (AGP, ~10% of total mass) and glycoprotein (GP, ~1% of total mass) (Randall, Phillips, & Williams, 1989). GA is commonly used as an emulsifier to stabilize emulsions, the emulsifying property of which is provided by an excellent interfacial property of AGP. The structure of AGP is represented by a 'wattle blossom-model', which has, upon suggestion, provided both hydrophobic polypeptide chain and hydrophilic carbohydrate blocks, conferring good emulsification characteristics (Castellani, Guibert, *et al.* ,2010; Gomes*, et al.*, 2010; Jayme, Dunstan, & Gee, 1999; Mahendran, *et al.*, 2008). The stabilizing function of GA is provided by repulsive electrostatic and steric interactions after the polypeptide moieties adsorb on to the oil droplet surface and the polysaccharide chains protrude in the aqueous phase (Dickinson, 2003). The high water solubility and low solution viscosity are two additional features making GA a popular ingredient (Gomes*, et al.*, 2010).

Balanced levels of trace minerals like zinc (Zn) and iron (Fe) are essential to prevent progression of chronic conditions (Zhang & Gladyshev, 2011). To overcome this problem, zinc and iron supplementation and food fortification strategies are being actively pursued (Allen, *et al.*, 2006; Hilty*, et al.*, 2010). The application of gum arabic as food-grade functional polymer hosts for complexation of trace elements into supramolecular structures could be an alternative strategy of immediate practical significance. Herein, we have developed a method to transform commercial gum arabic into the zinc and iron carrier by ion exchange against $ZnCl_2$, $FeCl_2$ and $FeCl_3$. Flame atomic absorption spectrophotometry (FAAS) confirms the transformation to GARTE, whereas all other ionic species remain at very low concentrations. The emulsifying performance of the GARTE (GA/Zn^{2+}, GA/Fe^{3+}, GA/Fe^{2+}) was investigated as well. The purpose of this study is to gain a natural functional polysaccharide containing essential trace elements, and investigate the impact of ionic binding on the emulsifying properties of GA.

2. Materials and methods

2.1 Materials

Gum arabic (GA) was provided by San-Ei Gen F.F.I. Inc. (Osaka, Japan) in a spray dried powder. GA contains 5.56% moisture. Zinc chloride ($ZnCl_2$), anhydrous ferric chloride ($FeCl_3$), iron dichloride tetrahydrate ($FeCl_2{\cdot}4H_2O$) were purchased from Chinese Medicine Group Chemical Reagent Co. Ltd. (Shanghai, China). Medium-chain triglyceride (MCT) was purchased from KLK OLEO Ltd., Malaysia. Hydrogen ion exchange resin was purchased from Sigma-Aldrich Trading Co. Ltd., USA. Doubly-distilled deionized water was used in all the experiments.

2.2 Preparation and characterization of GARTE

GARTE (GA/Zn^{2+}, GA/Fe^{3+}, or GA/Fe^{2+}) was prepared by ion exchange method. To prepare GA/Zn^{2+} as an example: hydrogen ion exchange resin was treated with 1 M HCl (400 ml) for 4 h and washed extensively with deionized water to remove free hydrogen ions. 0.5 M $ZnCl_2$ (800 ml) was added to the resin for 4 h, followed by deionized water rinse. 0.5 M $AgNO_3$ solution was used to confirm if free Cl^- ions in the resin were removed completely. 15% GA (200 g) solution was added to the resin for 4 h to allow Zn^{2+} exchange onto GA, followed by freeze drying. The same method was used to prepare GA/Fe^{3+} and GA/Fe^{2+} with $FeCl_3$ and $FeCl_2{\cdot}4H_2O$, respectively.

The control GA and GARTE samples were characterized by gel permeation chromatography coupled with multi-angle light scattering (GPC-MALLS). The GPC-MALLS system consisted of a Waters 515 HPLC pump (Waters Co., Massachusetts, USA), a Superose 6 10/300GL column (GE Healthcare, USA), a UV detector at 214 nm (Shimadzu Technologies, Kyoto, Japan), a DAWN HELEOS light scattering detector (Wyatt Technology Co., CA, USA) with a solid-state laser operating at 658 nm, and a refractive index detector (Optilab rEX, Wyatt Technology Co., CA, USA). 0.2 M NaCl solution was used as an eluent and delivered at a constant flow rate of 0.4 ml/min. 200 μl of 2 mg/ml GA solution (in 0.2 M NaCl) was injected for analysis after filtration through 0.45 μm filter. A refractive index increment dn/dc value of 0.145 was used for molecular parameter analysis of GA and GARTE. The data were analyzed with ASTRA software Version 5.3.4.14.

149 2.3 Elemental analysis

150 The element content analysis of GA and GARTE was carried out by atomic absorption
151 spectrometry equipped with a Zeeman background corrector (GBC Avanta M, Australia). An
152 atomizer with an air/acetylene burner in voltage under 220±10V was used for determining all the
153 elements investigated. The operating conditions were those recommended by the manufacturer,
154 unless specified otherwise. The acetylene flow rate and the burner height were adjusted in order to
155 obtain the maximum absorbance signal, while aspirating the analyte solution in methanol
156 containing 0.1 M nitric acid. For discrete volume sampling, a volume of 100 μL of the final
157 solution was introduced into the nebulizer of the spectrometer by a manual sample injector that
158 was connected to the nebulizer by the sample aspiration tubing. Absorbance signals as peak height
159 were measured (Chen & Teo, 2001; Tokalioğlu, Kartal, & Elçi, 2000). High purity reagents and
160 doubly-distilled deionized water were used for all the analyses. Standard stock solutions
161 containing 1000 μg/mL were prepared from sulfate of Zn^{2+}, Fe^{2+} in 1 M of HNO_3.

162 2.4 Interfacial adsorption and emulsion properties of GARTE

163 2.4.1 Interfacial tension measurements

164 The interfacial adsorption of GA and GARTE at the oil-water interface changing with time was
165 measured by a drop profile tensiometer (Teclis Tracker, France). The experiments were carried
166 out at 25 ± 1°C. A pendant drop of GA or GARTE solution was formed at the tip of the needle of
167 a syringe whose verticality could be controlled. The needle was submerged in an optical glass
168 cuvette containing MCT, which was located between a light source and a high-speed charge
169 couple device (CCD) camera. The drop profile was recorded by the CCD camera and analyzed
170 according to the Laplace equation (Castellani, Gaillard, *et al.*, 2010; Castellani, Guibert, *et al.*,
171 2010; Oscar, *et al.*, 2010).

172 2.4.2 GARTE emulsion preparation

173 Each 5%(w/w) GA or GARTE (GA/Zn^{2+}, GA/Fe^{3+}, GA/Fe^{2+}) solution was put on a roller mixer
174 at 25±1°C overnight. MCT was added to the gum solutions to achieve a final concentration of
175 5%(w/w) in the emulsions. The systems were pre-homogenized for 3 min at 26,000 rpm using a

high-speed blender (Polytron PT 2100, Switzerland). The primary emulsions were further homogenized with a high-pressure homogenizer (Microfluidic M-110L, USA) at 75 MPa for one pass. The homogenization was carried out in an ice bath to minimize the extent of lipid oxidation.

2.4.3 Droplet size distribution measurements

The droplet size distribution of the GARTE emulsions at 60°C was determined to evaluate the properties and stability using a laser diffraction technique (Master-Sizer 2000, Malvern Instruments Ltd.). The emulsions were diluted to achieve a laser obscuration slightly above 10% and stirred continuously to avoid multiple scattering effects. The refractive index of sample was 1.52 with an absorption coefficient of 0.01. The particle size is given as the volume-weighted mean diameter ($D[4, 3]$), $D[4, 3]= (\Sigma n_i d_i^4/\Sigma n_i d_i^3)$, where n_i is the number of droplets with diameter d_i. $D_{4,3}$ was reported as the average of triplicates.

2.4.4 Zeta potential measurements

Zeta potential ζ of emulsion was measured on a Zetasizer Nano-ZS apparatus (Malvern Instruments, U.K.) equipped with an MPT-2 pH autotitrator (4mW He/Ne laser emitting at 633 nm). Electrophoretic mobility U_E of charged particles was measured by means of laser Doppler velocimetry (LDV), and ζ was calculated according to the Henry equation: (Li*, et al.*, 2012)

$$U_E = \frac{2\varepsilon\zeta f(Ka)}{3\eta} \quad (1)$$

where ε is the dielectric constant, η is the viscosity of medium, and $f(Ka)$ is the Henry function which possesses a value of 1.5 under the Smoluchowski approximation.

3. Results and discussion

3.1 Trace element content and molecular parameters of GARTE

Trace element contents of GA, GA/Zn^{2+}, GA/Fe^{3+}, GA/Fe^{2+} samples were shown in Table 1. The trace element contents of control GA sample (without ion exchange) from high to low are: K> Na> Ca> Mg> Zn> Fe> Cu. The content of corresponding target elements (Zn^{2+}, Fe^{3+}, Fe^{2+}) in GARTEs have significantly increased with other elements (K, Na, Ca, Mg) decreasing after ion exchange. The contents of Zn^{2+}, Fe^{3+} and Fe^{2+} in GARTEs increase respectively by 27, 162 and 1097 times, compared to control GA. The enrichment of Fe^{2+} by ion exchange method is the most efficient. It clearly reveals that the GARTE can be successfully prepared by ion exchange method. The molecular parameters of control GA and GARTEs are shown in Table 2. The molecular weights and AGP contents of GARTEs have increased after ion exchange, and from high to low are: GA/Fe^{2+} > GA/Fe^{3+} > GA/Zn^{2+}> GA. ~~There is strong evidence showing that metal ion binding to proteins tends to induce aggregation.~~ The increase in molecular weight of GARTEs may be due to metal ions binding to proteins, inducing partial aggregation of gum arabic fractions. Given that the increase in average molecular weight and the AGP content are relatively modest, the results indicate that GA molecules are still largely present in non-aggregated form in GARTES. According to relevant literature reports, Fe^{3+}, Fe^{2+} and Zn^{2+} have a significant effect on the mechanism of protein aggregation (Bonda*, et al.*, 2011; Sensi, *et al.*, 2009; Tõugu, Tiiman, & Palumaa, 2011; Timasheff, 1998). Multivalent metal ions are especially efficient in this stabilization by bringing together charged residues on the protein surface (Maclean, Qian, & Middaugh, 2002). The likely changes are illustrated schematically in Fig. 1. In the present system, metal ions binding might promote the folding of protein fraction of gum arabic into aggregation-prone conformations and thus accelerate their aggregation (Lang & Kohn, 1970; Vitos, *et al.*, 1998). Nevertheless, different metal ions have different effects on protein aggregation process. The results show that the effect of different metal ions of GARTE on protein aggregation process decreases in the order GA/Fe^{2+} > GA/Fe^{3+} > GA/Zn^{2+}. Jishnu and Umesh (Jishnu & Umesh, 2017) investigated that metal ions influences on the conformation and aggregation processes of bovine β-lactoglobulin (β-lg) at equimolar ratio under thermal condition. Fe^{3+} ion causes a more drastic perturbation of the conformation of native β-lg than Zn^{2+} ion. β-lg is prone to form irreversible

aggregates probably by the metal-complex formation. The β-lg aggregates with Zn^{2+} are fibrillar in nature while the higher molecular aggregates with Fe^{3+} ion are of different types. Therefore, the kinetic growth and the shape of the protein aggregates with different metals solely depend on the nature of the metal ions, not on the charge of the metal ions.

3.2 Emulsifying performance of GARTE

3.2.1 The kinetics of adsorption

The GA, GA/Zn^{2+}, GA/Fe^{3+} and GA/Fe^{2+} solutions were used as the aqueous phase with a concentration of 0.5% and MCT as the oil phase to determine the dynamic adsorption of GA and GARTE on the interface of MCT-water. The dynamics of GA and GARTE adsorption at an MCT–water interface was examined over the time scale ranging from seconds to several hours. Interfacial tensions measured during the adsorption of different GARTEs onto the MCT–water interface at 25 °C are shown in Fig. 2. It can be clearly observed that, the interfacial tension decreases progressively along with the adsorption time, with faster changes at earlier adsorption period, indicating a spontaneous adsorption of GA and GARTE at the interface. The decrease is initially steeper before an asymptotically plateauing after the interface is generated. This shape is characteristic for the interfacial tension evolution of the emulsifier laden oil/water interface. ~~It is attributed to a two stage process: the initial fast diffusion of emulsifier to the interface followed by a slower adsorption delayed by electrostatic and steric hindrance (Felix, Romero, Vermant, & Guerrero, 2016; Noskov, 2014).~~ However, the initial interfacial tension of GARTE is significantly higher than that of GA, indicating that the adsorption rate of GARTE at the MCT-water interface has decreased. The time required for reducing interfacial tension by 30% of the initial value at the MCT-water interface due to the adsorption of GA, GA/Zn^{2+}, GA/Fe^{3+} and GA/Fe^{2+} and the equilibrium interfacial tension at 40,000 s at 25°C are shown in Table 3. GA shows more rapid adsorption dynamics than GARTEs and better ability to reduce the equilibrium interfacial tension. It indicates that the adsorption rate of GARTE decreases with enriched Zn^{2+}, Fe^{3+} and Fe^{2+}. The interfacial tension of GARTE after the interface adsorption has reached its equilibrium is also significantly higher than the control GA. The magnitude of interfacial tension γ after adsorption equilibrium is as follows: γ (GA/Fe^{2+}) > γ (GA/Fe^{3+}) > γ (GA/Zn^{2+}) > γ (GA). Many factors such

as emulsifier size, hydrophobicity, instability, charge, and disulfide bonds are considered in determining adsorption rate among the different emulsifiers. Beverung *et al.* investigated adsorption kinetics of different proteins (bovine serum albumin, β-Casein and ovalbumin) at the oil-water interface by dynamic interfacial tension measurements (Beverung, Radke, & Blanch, 1999). Their results showed that higher molecular weight proteins have a higher interfacial tension at the initial stage and a slower rate of interfacial tension decrease than smaller molecular weight proteins. The adsorption rates of GA and GARTE are possibly associated with the molecular weights of GA, GA/Zn^{2+}, GA/Fe^{3+} and GA/Fe^{2+}, due to the fast adsorption of low molecular weight species during droplet formation (Gould & Wolf, 2017). As shown in Fig. 1, partial aggregation of proteins caused by metal ions binding increases the large molecular weight components (AGP) in GARET and decreases the small molecular weight component (AG and GP). This might explain the different interfacial adsorption behaviors of GA and GARET, and further their emulsifying performance to be discussed below.

3.2.2 Droplet size and distribution

The droplet size distributions and volume mean diameters (D[4, 3]) of the freshly prepared and accelerated emulsions stabilized by GA and GARTE were determined and compared for the evaluation of their emulsifying capacity (Fig. 3 and Fig. 4). The emulsions contain 5.0% GA or GARTE with 5% MCT as mentioned in experimental section. These emulsions have similar droplet size distribution at 60°C over a week. The emulsion freshly prepared with GA alone exhibits a small droplet size (d≈0.41μm), which could be related with the relatively high surface activity of GA at the oil-water interface. The accelerated emulsion shows a little increase in droplet size (d≈0.51μm) with a slight shift of size distribution profiles to the right. When incorporated with trace elements, the freshly prepared GARTE emulsions show a smaller particle size ($p < 0.05$) than GA. Noticeably, no significant ($p > 0.05$) changes in particle size for accelerated emulsion D[4, 3] are observed during storage time up to 7 days, indicating a high stabilizing ability of GARTE against coalescence. Visual observation of the emulsions prepared with GA and GARTE is shown in Fig. 3B. Emulsions prepared with GARTE all exhibit excellent bulk stability during acceleration. Castellani *et al*. investigated the emulsifying properties and the adsorption behaviors at the n-hexadecane–water interface of conventional arabic gum and those

after thermal maturation (EM1 and EM2) (Castellani, Gaillard, *et al.*, 2010; Castellani, Guibert, *et al.*, 2010). They found that thermal maturation resulted in an increase in average molecular weight and arabinogalactan protein (AGP) content. It further led to a decrease in interfacial adsorption kinetics but a more homogenous and stable emulsion. The emulsifying performance of matured gum seems to be similar with that of GARTE. The improved emulsifying property might be related to the better interfacial steric stabilizing effect of aggregated GA molecules in GARTE, which form a thicker interfacial layer and more efficiently prevent emulsion droplets from coalescence. This resulted in emulsions with smaller droplets and better stability.

3.2.3 Zeta potential of GA and GARTE emulsion

The surface charge of the GA and GARTE stabilized droplets was assessed through measuring zeta potentials (see Fig. 5 for the results). The data were acquired following the dilution of each emulsion with water and all GA and GARTE stabilized emulsions show a relatively high negative zeta potential. A zeta potential of 30 mV is often reported as a critical value below which emulsions are seen to flocculate (Grumezescu, 2016), requiring the addition of thickening agents to prevent creaming. Here, while the absolute values of the zeta potential of the GA and GARTE stabilized emulsions are more than 30 mV, the emulsions show no coalescence or flocculation over 7 days at 60°C. The zeta potential absolute values of fresh and accelerated emulsions of GA/Zn^{2+} and GA/Fe^{2+} were lower than GA emulsions. This might be due to GA/Zn^{2+} and GA/Fe^{2+} binding positively charged Zn^{2+} and Fe^{2+} ions after ion exchange, thereby reducing the absolute value of zeta potential. Although the zeta potential of GA/Zn^{2+} and GA/Fe^{2+} is slightly reduced compared with GA, it is still large enough to provide an effective electrostatic stabilizing effect (> 45 mV). Additionally, as discussed above, the aggregation in GA/Zn^{2+} and GA/Fe^{2+} tends to provide a better interfacial steric stabilizing effect. These together led to a better stability of emulsions stabilized with GA/Zn^{2+} and GA/Fe^{2+} (Castellani, Guibert, *et al.*, 2010). In the case of the GA/Fe^{3+} stabilized emulsions, the absolute value of the zeta potential was significantly higher compared to the other emulsions. The reason for this is unknown at the present stage, and is possibly due to the fact that the binding affinity of Fe^{3+} with GA is weaker than those of Zn^{2+} and Fe^{2+} and other divalent cations such as Ca^{2+} and Mg^{2+}, leading to a larger extent of dissociation from GA and therefore a higher zeta potential. Nevertheless, long term stability of GARTEs,

comparable to GA stabilized emulsions, can also be assumed. These results indicate that the use of GARTEs as an emulsifier is comparable, if not more efficient, to GA, offering a trace element source of natural functional polysaccharide for food emulsion formulations.

4. Conclusions

This research has combined organic and inorganic materials to produce cost-effective trace element–polysaccharides. It can be validated that GA can be effective carriers for trace elements for food fortification. The resulting hybrid materials can be utilized to stabilize o/w emulsions without significant droplet coalescence for a period of at least a week under harsh environment. The stability in o/w emulsions combined with its low cost demonstrate that the zinc or iron–polysaccharides are promising novel trace elements fortificants in food products.

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Fig. 3 Particle size distribution (A) and visual observation (B) of fresh and accelerated emulsions stabilized with GA, GA/Zn^{2+}, GA/Fe^{3+} and GA/Fe^{2+} at 60^{o}C for 7 days.

Fig. 4 Time evolution in $D[4, 3]$ of GA, GA/Zn^{2+}, GA/Fe^{3+}, GA/Fe^{2+} stabilized emulsions during storage at 60^{o}C. Error bars represent the standard deviation of at least two independent replicates.

Fig. 5. Zeta potential of GA, GA/Zn^{2+}, GA/Fe^{3+}, GA/Fe^{2+} stabilized emulsions during storage at 60^{o}C. Error bars represent the standard deviation of at least two independent replicates.

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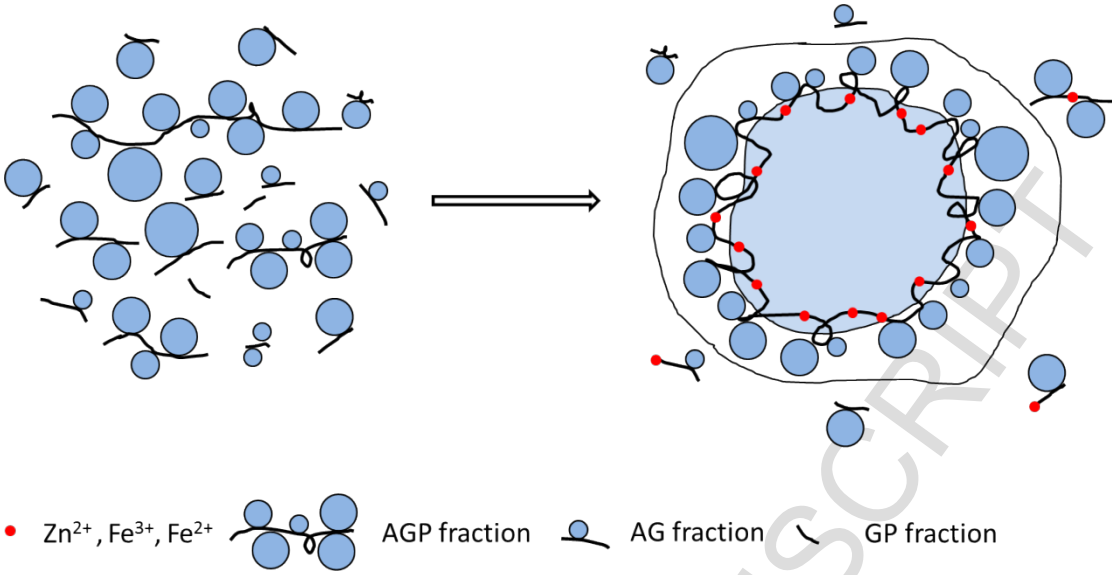
347 **Fig. 1**



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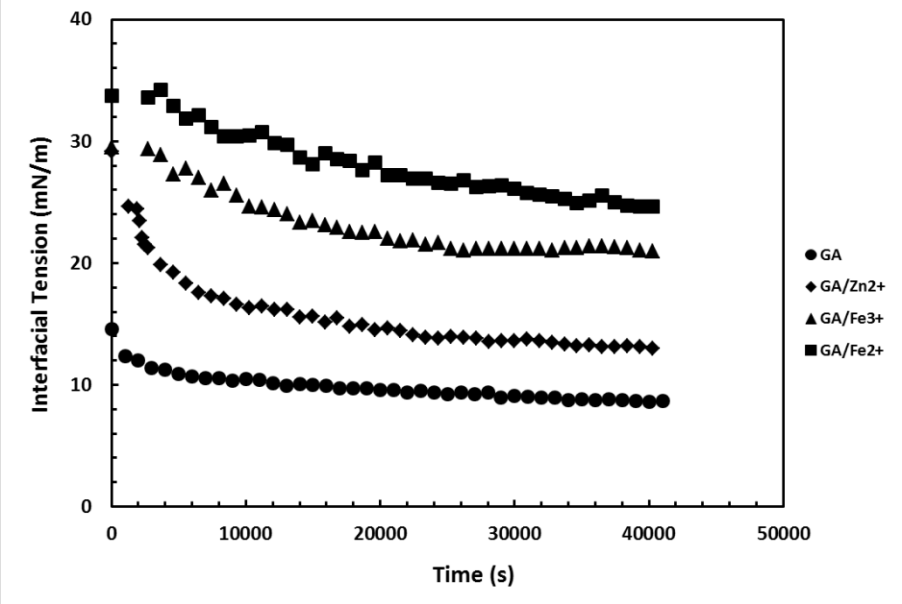
350 **Fig. 2**



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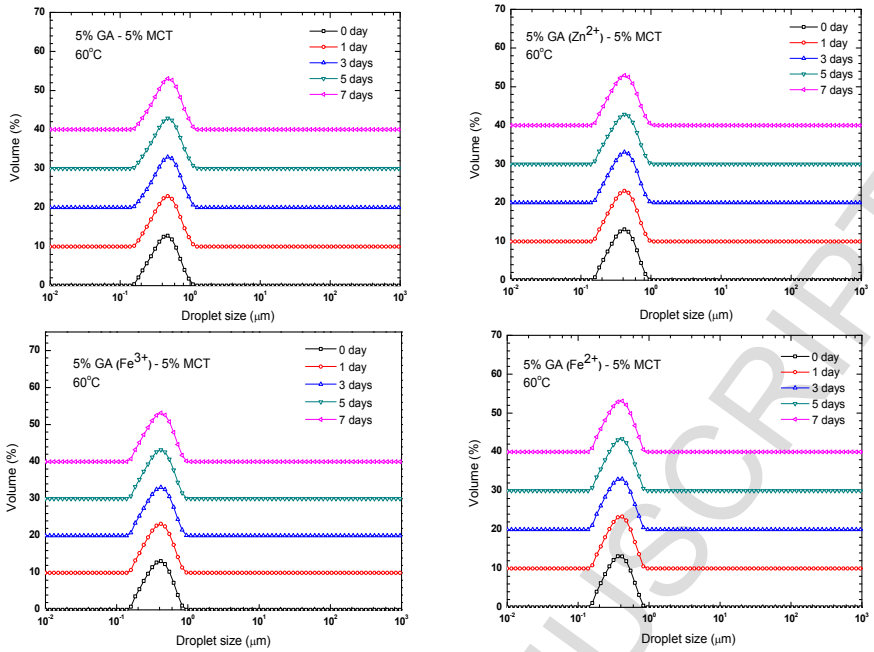
353 **Fig. 3**

A



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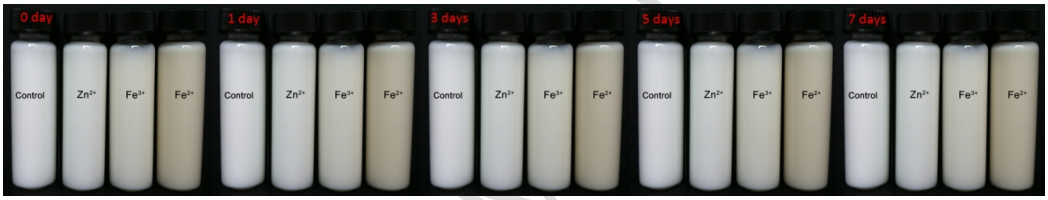

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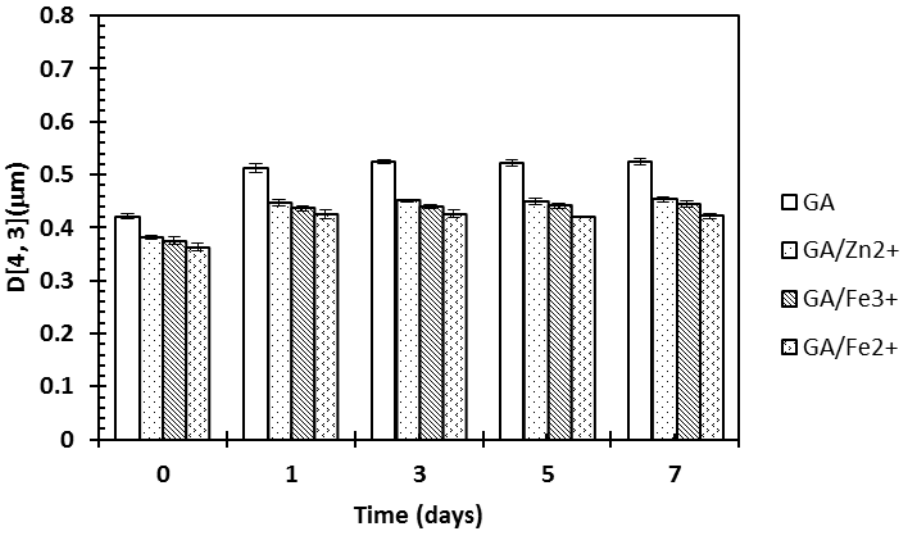
356 **Fig. 4**



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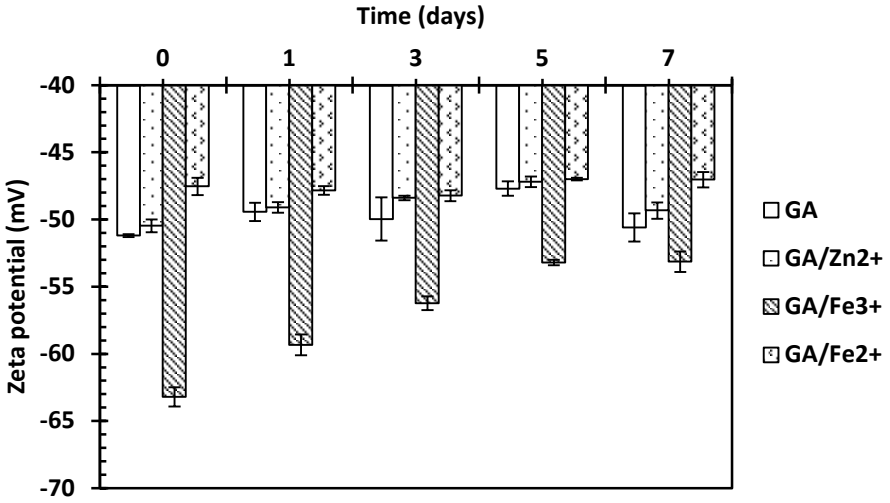
359 **Fig. 5**



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362 Table 1.

Sample	Cu (ppm)	Zn (ppm)	Fe (ppm)	K (ppm)	Na (ppm)	Ca (ppm)	Mg (ppm)
GA	<0.01	130.40	5.20	11524.30	8569.90	8287.27	2986.00
GA/Zn^{2+}	5.13	3571.40	92.50	2392.40	5380.00	512.82	425.82
GA/Fe^{3+}	<0.01	33.99	844.88	3020.20	2399.20	130.72	631.81
GA/Fe^{2+}	<0.01	80.79	5705.30	3624.70	3666.50	193.91	232.70

363

364 Table 2.

Sample	Whole fraction	AGP fraction		AG+GP fraction	
	M_w (g/mol)	Percentage (wt.%)	M_w (g/mol)	Percentage (wt.%)	M_w (g/mol)
GA	9.43×10^5	16.86	3.99×10^6	83.14	3.11×10^5
GA/Zn^{2+}	9.99×10^5	17.11	4.23×10^6	82.89	3.35×10^5
GA/Fe^{3+}	1.06×10^6	17.70	4.50×10^6	82.30	3.32×10^5
GA/Fe^{2+}	1.37×10^6	18.51	5.71×10^6	81.49	3.42×10^5

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366 Table 3.

Emulsion sample	T (s)	Equilibrium interfacial (mN/m)
GA	4974	8.67
GA/Zn^{2+}	7587	13.11
GA/Fe^{3+}	8427	20.98
GA/Fe^{2+}	38911	24.62

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Highlights

1) Gum arabic was enriched with trace elements (Zn^{2+}、Fe^{3+}、Fe^{2+}) by ion exchange against $ZnCl_2$, $FeCl_3$ and $FeCl_2$.
2) Gum arabic rich in trace elements (GARTE) has good emulsion stability performance with increasing molecular weight and AGP content compared to the control gum arabic.
3) Gum arabic rich in trace elements (GARTE) offering a trace element source of natural functional polysaccharide for food emulsion formulations.