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Comparative Study of Modified Soy Lecithins as Oil in Water (O/W) Emulsifiers

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CRUDE commercial soybean lecithin from two different sources named (A) and (C) were modified physically, chemically, and enzymatically using phospholipase A_2 enzyme (PLA_2) in order to improve their emulsification properties. All the modified lecithins were used in the preparation of oil-in-water (O/W) emulsions, in comparison with the crude lecithins as well as a standard acetone-insoluble lecithin purchased from the market. The emulsions stabilized by acetone-insoluble portion showed the best physical stability during 3 months of storage after preparation, along with a relatively low particle size (PS) and poly-dispersity index (PDI) and a zeta-potential values that indicates a good emulsion stability. Hydroxylated lecithin (H2A and H2C) showed the most stable Zeta-potential (-55.3 and -50.8 mV) respectively with a relatively low particle size and poly-dispersity index of 284.0 nm and 0.378 respectively for A and 268.4 nm and 0.391 for C, while hydrolyzed lecithin (ENZ A and ENZ C) that possessed the lowest particle size had a moderate zeta-potential of -34.8 and -32.2 for A and C respectively. These results showed that the modification of crude lecithin is essential for the production of tailor-made products with specific surface-active properties-stabilizing emulsions to be used in different purposes.

Keywords: Emulsions, O/W emulsions, Phospholipid modification, Commercial lecithin

Introduction

An emulsion is a thermodynamically unstable colloidal dispersion that consists of two immiscible liquids (e.g. water and oil) in which one liquid is dispersed in the other [1,2]the interactions between egg yolk granule and soybean lecithin and their emulsion properties were investigated. For egg yolk granule, the increase of solubility and negative zeta-potential and decrease of hydrophobicity could be observed with the increase of lecithin concentrations, indicating the interactions between granule protein and lecithin. Results from the z-average particle size and the AFM image showed that the increase of solution pH and addition of lecithin could destroy the aggregated structure of the egg yolk granule. The disrupted granule exhibited better emulsion stability than that of native granule due to the higher surface charge and lower particle size. Notably, appropriate addition of lecithin (less than 0.25%. Simple emulsions are categorized into two main types: oil in water (O/W) emulsions and water in oil (W/O) emulsions. In the latter, water is dispersed in a continuous oil phase. While in (O/W) emulsions, oil is dispersed in a continuous water phase. Milk, salad dressing, mayonnaise and sauces are considered as O/W emulsions, while butter and margarines are W/O emulsions.

According to Franco [3]emulsifier, and starch concentrations on the linear viscoelasticity of oil/water salad dressing emulsions were studied. Oil concentration ranged between 35 and 55 wt %. Emulsions were prepared using a mixture of egg yolk (0-6 wt %, emulsion stability is believed

to be the most important element in emulsion technology. Stability of an emulsion could be affected by physical and chemical forces [4], which could be controlled by the three aspects of an emulsion system: the dispersed phase, the continuous phase and the interfacial material (emulsifier) [5].

Emulsifiers are amphiphilic substances that can improve the stability of emulsions by forming a protective layer around emulsion droplets which lowers the surface tension of oil and water interface. During the emulsification process, the use of emulsifiers is crucial for the formation and stabilization of the emulsion; as they adsorb onto oil droplets, modify the viscosity of the continuous phase, reduce droplets size and act as interfacial impediment that prevents the aggregation of droplets by providing steric hindrance and repulsive forces between them as well as by forming interfacial membrane around them [1,6,7].

In this study, lecithin, a naturally occurring zwitter-ionic emulsifier was used. Lecithin can be extracted from vegetable sources such as soybean and rapeseed or from animal source e.g. egg yolk. The most commonly used lecithin in food industry is soybean lecithin because of its economic advantage [8]. Lecithin isn't just utilized in the strict scientific sense to portray pure phosphatidyl-choline, yet in addition to depict unrefined phospholipid blends containing phosphatidyl- choline(PC), phosphatidyl-

ethanolamine (PE), phosphatidyl-inositol (PI), different phospholipids, and an assortment of other compounds such as fatty acids, triglycerides, sterols, carbohydrates, and glycolipids. In the field of food industry, lecithin refers to a mixture of phospholipids (PLs) including lyso-phospholipids [9]. Phospholipids are amphiphilic aggravates in which the phosphate head-group composes the hydrophilic part, while the glycerol-backbones, as well as the fatty acids compose the hydrophobic part as shown in figure (1). This amphipathic property is the reason why phospholipids are considered as surfactants [10] possessing excellent emulsifying properties [11].

Each phospholipid (PL) component has its polarity and emulsification properties that are different than the others. Hence, lecithin modification is important for each application [9]. Making changes in the concentration of different PLs in lecithin can give lecithins with different PLs composition and consequently with different physicochemical and functional properties that can be used in different industries. For instance, weakly hydrophilic lecithin (PI enriched) can be used in the preparation of W/O emulsions, while highly hydrophilic lecithin (PC enriched) can be used in the preparation of O/W emulsions. Therefore, lecithin modification is of practical importance [9].

Crude commercial soybean lecithin has a triglycerides content of 34% approximately. De-oiling (physical modification) is thus used
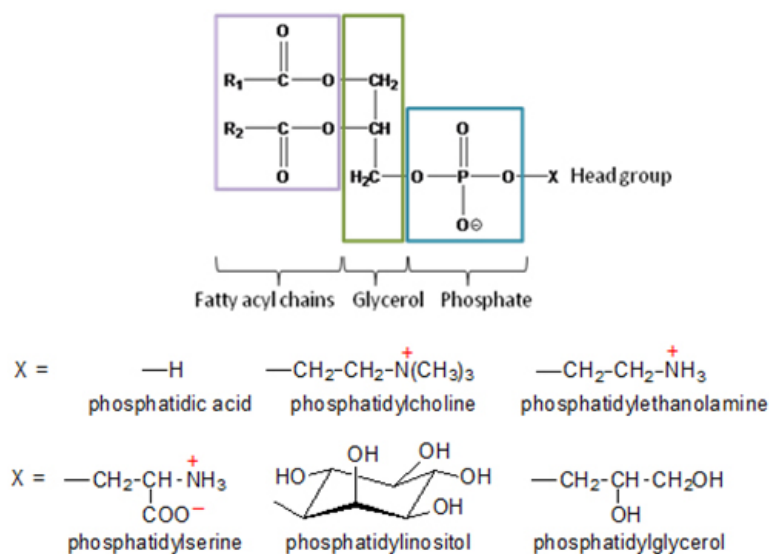
Fig.1. Chemical composition of phospholipids.

in order to get lecithin with high phospholipid content and low triglyceride content. Acetone de-oiling is considered as an ordinary strategy for expelling triglycerides [12]pharmaceutical and food industries have taken several initiatives in purification of phosphatidylcholine (PC based on the polarity difference that exists between triglycerides (acetone-soluble)and PLs (acetone-insoluble) [13,14]. De-oiled lecithin was found to be good O/W emulsifier [15].Another way for lecithin modification is done by hydroxylation (chemical modification), which is carried out by reacting lecithin with an organic weak acid e.g. lactic acid, and hydrogen peroxide in order to insert OH groups in the unsaturated fatty acid chains. Hydroxylated lecithins possess good O/W emulsifying properties as a result of the enhanced water dispersibility [16]. In the USA, hydroxylated lecithin is generally recognized as safe(GRAS), however, it is not listed in the European Union Food Additive Directive [8]. Also, the solubility and functionality of lecithin can be improved enzymatically. Two main groups of enzymes are used in the enzymatic modification of lecithin: lipases and phospholipases. Phospholipase A_2 is the prevalent phospholipase, which specifically hydrolyses the sn-2 position of the PL fatty acyl group[17] giving rise to lyso-phospholipids (lyso-PLs). Lyso-PLs are found to be highly hydrophilic and are thus regarded as better O/W emulsifiers [14,18].

The aim of the present study was evaluating the emulsification properties of modified lecithin obtained by physical, chemical and enzymatic modification of crude commercial lecithin.

Materials
All analytical grade reagents and solvents were purchased from Merck. Two crude soybean lecithin samples were supplied from two different sources: Sample (A) was obtained from the company of Extracted Oils and their Products - Alexandria - Egypt, and the second sample(C) was purchased from the local market (imported from Argentina via Mazecks company for export & import - Alexandria – Egypt). Standard acetone-insoluble lecithin was purchased from Acumedia (PL≥50%).

Methods
Crude commercial lecithins A and C were modified physically, chemically and enzymatically. Physical modification involved the preparation of the acetone-insoluble (AI) portion. The chemical modification was done by hydroxylation using two different methods of hydroxylation (H1 and H2). While hydrolyzed lecithins (ENZ A and C) were obtained by the enzymatic modification of crude lecithins using PLA_2 enzyme.

Preparation of acetone-insoluble (AI) portion from crude commercial lecithin (De-oiling)
De-oiling of crude lecithin was carried out according to Dunford [19]. Briefly, the method involves washing lecithin with sufficient amount of chilled acetone for several times until the decanted solution is almost clear. The acetone was then evaporated under vacuum and the residue (de-oiled lecithin) was dried under reduced pressure.

Hydroxylation of crude commercial lecithin
Hydroxylation was done using two different methods: The first one (named H1) was according to Vandana [20]. It was done by adding 0.3g lactic acid and 1.5ml of hydrogen peroxide to 10g of crude lecithin. The mixture was then subjected to stirring for 8 hours at 70°C, and finally dried under reduced pressure till it became moisture free.

The second method (named H2) was according to Gorecki [21], and was done by stirring 5 g crude lecithin with 15 ml distilled water, 0.3 ml lactic acid and 1.5 g of hydrogen peroxide for 15 min at 20°C. The mixture was then neutralized using 1.1 ml of 20% NaOH and then evaporated under vacuum at 40°C. After evaporation, extraction was done for three times using methanol. The extracted material was filtered and then dried to constant weight under vacuum.

Enzymatic modification of crude commercial lecithin using PLA2 enzyme
The enzymatic modification of crude lecithin was carried out by mixing 27 g of crude lecithin in a beaker with 18 ml of 0.4 M $CaCl_2$, and their initial pH was adjusted to 7 by the addition of (4 N) sodium hydroxide solution. The resulting mixture was then set at 60°C, after that PLA_2 solution (2.0 ml PLA_2/100 g of lecithin) was introduced in the reaction mixture. The beaker was kept under continuous agitation using mechanical stirrer for five hours. The progression of the hydrolysis process was followed by measuring the change in pH from neutral to acidic. A sudden decrease in temperature was done in order to quench the hydrolysis process[22]. Finally, acetone was used for de-oiling according to Dunford [19]. Hydrolyzed lecithin was then evaluated by measuring its acid value according to AOCS method (Ja 6-55, reapproved 2017) [23].

Emulsions preparation

Emulsions were prepared by emulsifying sunflower oil (purchased from the market) into deionized water as an aqueous phase, with a ratio of 1:9 respectively in the presence of the prepared modified lecithins as emulsifiers [9]. Emulsions were prepared at ambient temperature using Brawn blender (Type 4191 – 600 watts – 12X – 22000 rpm) for 5 min. Lecithin and deionized water were first mixed in a beaker using the blender, then the oil was poured drop by drop during the five minutes of mixing. To determine the optimum lecithin concentration, a preliminary study was done using different concentrations of the prepared lecithin (0.1%, 0.5%, 1%, 1.5%, 2%, 3% and 5%) and stability was assessed for several days. As a result of this study 2% lecithin was used in all the prepared emulsions; as it gave the best emulsion stability.

Emulsions properties

- *Particle size (PS), Poly-dispersity index (PDI) and Z-potential:*

Dynamic Light Scattering (DLS) sizing and zeta potential measurements were performed at 25°C on a nano-zeta sizer (Malvern Instrument ZS-Nano, UK) [24].

- *Physical stability:*

The physical stability of prepared emulsions was studied in terms of creaming index (CI). Samples were put in a 10ml cylinder at 4°C for 3 months, and CI was measured weekly and determined using the following equation: CI % = H_S/H_E X 100

Where H_S was the height of cream layer and H_E was the total height of the emulsion [25].

- *Transmission electron microscope (TEM)*

Samples were first diluted and sonicated in a water bath sonicator for 5 minutes. After sonication, a single drop of each sample was placed on a carbon-coated copper grid (200 mesh), and left to dry for about 5 minutes before examination using JEOL JEM-1230 high performance, high contrast, 40-120kV transmission electron microscope.

- *Rheological properties of emulsions:*

The rheological properties of the prepared emulsions were examined via an Anton-Paar Rheoplus rheometer equipped with a 50 mm stainless steel parallel plate geometry and a zero-gap of 0.7 mm. Emulsions were studied at 25 °C after 48 hours from their preparation and their flow curves were obtained by exposing the emulsions to shear rates ranging from 4.74 to 300 sec^{-1} using up-down-up steps [26].

Statistical analysis

Experiments were performed in triplicates. Data were analyzed using Microsoft Excel 2010. One-way analysis of variance (ANOVA) was used, and the significance level was set at 0.05% [27].

Results and Discussion

Emulsions particle size

The particle size and charge of emulsions are important indicators influencing their stability [1]. In this study, the smallest particle size was achieved for (ENZ A) sample with 218 nm while the biggest particle size was achieved for the crude samples (A) and (B) with 356.3nm and 340.6nm respectively, as shown in Table (1). PS has an effect on the emulsion stability, i.e. an extremely big PS leads to sedimentation and thereby instability of the emulsion[15].

Theoretically, a mean droplet size that ranges from 200 - 500 nm is a range of high emulsion stability [28]. Reducing the droplet size leads to an increase in the rate of self-diffusion to a point where tiny droplets may be protected from creaming by diffusional mixing. All the prepared emulsions were having a particle size that so far fall in the above mentioned range. Nano-emulsions containing hydrolyzed lecithin as emulsifier exhibited the smallest particle size compared with those containing crude, hydroxylated, and acetone-insoluble lecithin as emulsifiers.

2- Emulsions zeta-potential

Zeta-potential which is a measure of the electrostatic force on the surface of the oil droplets, was measured for all the prepared emulsions; as it indicates to some degree their stability. The values for all the emulsions as showed inTable (1) were all possessing a negative charge, which indicates that the oil droplets were carrying a negatively charged surface too. This result agrees with that of others who also observed negative zeta potential for O/W emulsions in which lecithin was used as emulsifier and that fall in a pH range of 3-7 [29–31].

Nimesh [32] classified the stability behavior of emulsions according to their zeta-potential values into five main categories as shown in Figure (2). Accordingly, emulsions stabilized by hydroxylated lecithin (H2A and H2C) are of good stability as their zeta-potential lies in the range of

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±40 to ±60 mV. All the other prepared emulsions in this study are of moderate stability with a zeta-potential that ranges between ±30 to ±40 mV.

The increase in charge leads to an increase in the repulsion among droplets, and therefore avoid sticking [15]. According to that mechanism, sample stabilized by H2A (-55.3 mV) should be more stable than that of ENZ A and C (-34.8 mV and -32.2 mV respectively). In general, lower zeta-potential values are associated with lower repulsive forces between droplets and thereby lower emulsion stability [26] and thus the higher zeta-potential values observed in the present study can lead to higher emulsion stability.

TABLE 1. Particle size, poly-dispersity index and zeta-potential of prepared emulsions.

Samples	Particle size (nm)	PDI	Zeta-potential (mV)
Crude A	356.348.04±	0.458	-37.16.33±
Crude C	340.6107.5±	0.442	-41.47.55±
Standard A.I.	347.0126.6±	0.453	-44.06.66±
AI A	304.461.30±	0.393	-43.18.49±
AI C	255.034.26±	0.371	-48.65.52±
ENZ A	218.856.97±	0.408	-34.810.43±
ENZ C	232.347.94±	0.572	-32.25.44±
H1A	270.786.19±	0.377	-36.46.05±
H1C	264.539.67±	0.332	-39.26.77±
H2A	284.033.93±	0.378	-55.37.29±
H2C	268.466.03±	0.391	-50.86.78±

(AI: Acetone-insoluble lecithins – ENZ: Hydrolyzed lecithins – H1 and H2: Hydroxylated lecithins) Each value represents the mean ±SD (n=3).

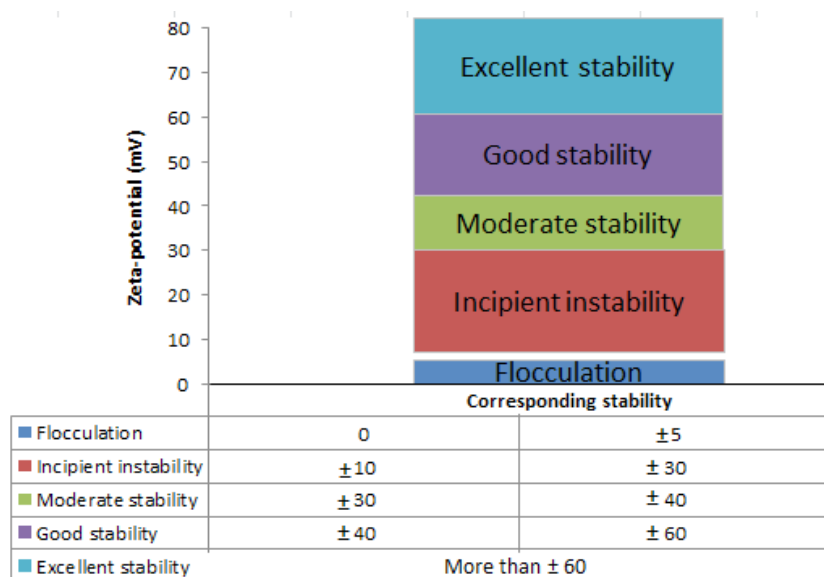|		
Flocculation	0	±5
Incipient instability	±10	±30
Moderate stability	±30	±40
Good stability	±40	±60
Excellent stability	More than ±60	

Fig.2. Relation between Zeta-potential and stability behavior of emulsions.

As mentioned before, hydrolyzed lecithin is considered as good O/W emulsifier. Accordingly, it was expected for the emulsions stabilized by hydrolyzed lecithin to achieve one of the highest zeta-potential values among the other samples. However, they possessed the lowest value of zeta-potential when compared to the emulsions stabilized by hydroxylated, acetone-insoluble or even crude lecithin. The acid value of the prepared lyso-lecithin can interpret such unexpected result; as it was reported by Reddy [18] that lecithin with minor hydrolysis (possessing an acid value less than 50 mg KOH/g) is considered as good W/O emulsifier and not as O/W emulsifier. In this study, the prepared hydrolyzed lecithins were of minor hydrolysis as their acid values lie between 33 and 35 mg KOH/g (for ENZ C and A respectively), and this could explain the reason for which the emulsions stabilized by hydrolyzed lecithins possessed a lower zeta-potential than that of emulsions stabilized by hydroxylated or even crude lecithin. Low acid values of ENZ A and C could be attributed to the enzyme activity, as it is known that the degree of hydrolysis is dependent on the activity of the used enzyme.

It is worth noting also that the emulsion preparation method is considered as a main factor that could affect zeta-potential of an emulsion[28]. This includes the apparatus used for emulsification as well as the ratio between the dispersed and continuous phase.

Emulsions poly-dispersity index

PDI is an indicator of aggregation in the particles as it gives an indication about the homogeneity or quality of the dispersion. It has values that lies between 0 – 1. Values closer to zero, indicate a mono-disperse system, while values closer to 1 show a poly-disperse system that have a greater tendency to aggregation than a mono-disperse system [33]. The lowest PDI value was achieved by H1C emulsion, while ENZ C possessed the highest PDI value of 0.572 as shown in Table (1).

Emulsions pH

As it is shown in Figure (3), all the emulsions showed a pH lower than 7. Hydroxylated lecithins-stabilized emulsions were having a pH that ranged from 4.55 to 5.47, while the emulsions stabilized by hydrolyzed lecithins possessed a pH range of 5.60 to 5.66. The emulsions stabilized by AI and crude lecithins were having a pH range of 6.37 (for AI A) to 6.72 (for AI C).
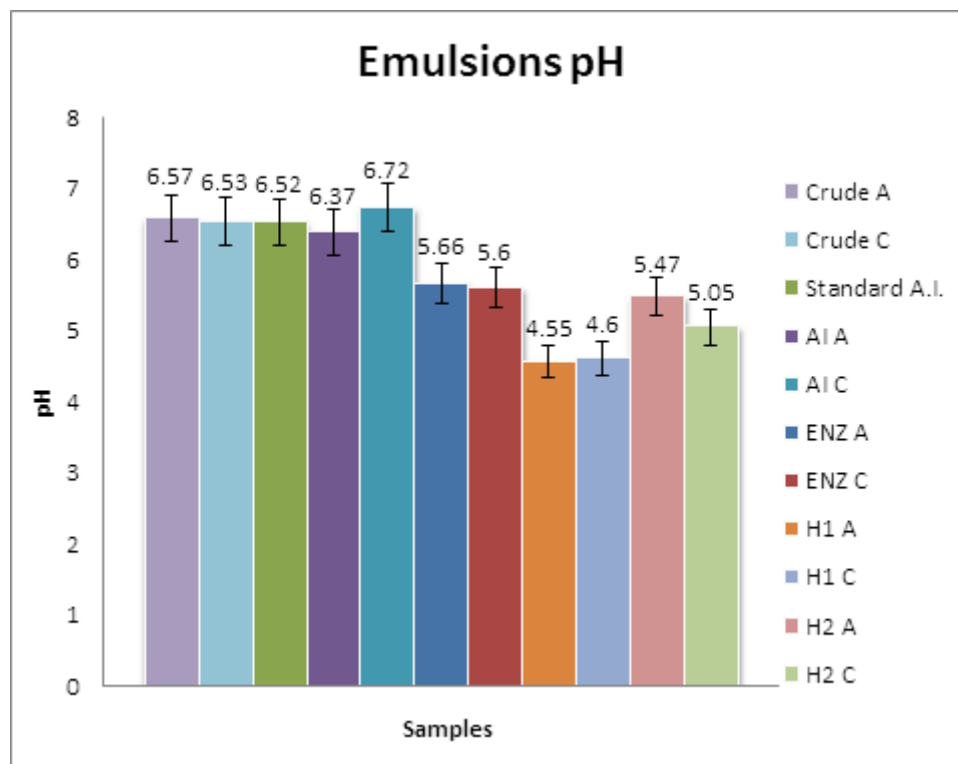

Fig. 3. pH of prepared emulsions.

Also it can be seen that as the pH of the sample is more acidic (lower pH) the zeta-potential decreases which agrees with the findings of Lim [34]. It was noticed that H1A and C are more acidic than H2A and C. This may be attributed to the presence of lactic acid traces in the reaction medium; since the reaction in case of H2A and C was carried out in the presence of water.

A relation between zeta potential and the pH of the samples can be observed. Samples with pH range from 4.55 to 5.74 exhibited a lower negative charge that ranged from -32 to -39 (ENZ A and C), whereas for H2 samples with a pH of 5.47 and 5.05 for A and C respectively, the zeta potential exhibited a higher negative charge (-55.3 and -50.8 respectively).

Emulsions physical stability

During the storage of O/W emulsions, a destabilization phenomenon known as creaming occurs [35] as a result of the difference in density between the continuous and the dispersed phase [7,15,36]. Conceptually, creaming is «the process by which buoyant emulsion droplets tend to rise to the top of a container» [37]. Thus, measuring the creaming index of an emulsion could give us an indication about its physical stability; as they are inversely proportional to each other. For example, an emulsion that has creaming index of 10% has a physical stability of 90%.

Accordingly, the physical stability of all the prepared emulsions was measured over 3 months as shown in Figure (4). Although a relatively small PS and low PDI were obtained, the prepared emulsions did not remain physically stable for a long period of time; since it started to make a creaming layer during the first week after preparation. During that week, all the samples showed a physical stability that ranged from 88% (ENZ C) to 98% (crude A and C). Although emulsions containing crude lecithins A and C were having the highest physical stability during the first week after preparation, their stability has decreased abruptly during the subsequent three weeks to reach about 84%, then it became constant without any other changes. Whereas the other samples (that possessed a relatively lower physical stability than that of crude A and C during the first week of preparation) exhibited a nearly constant physical stability after that.

It is worthy to mention that according to the results of zeta-potential, the hydroxylated samples H2A & C were expected to have the highest physical stability; as they possessed the highest zeta-potential values of -55.3 mV for A and -50.8 mV for C. However, this was not the case, suggesting that zeta-potential alone may not be sufficient for explaining the stability of O/W emulsion against creaming as reported by Xie
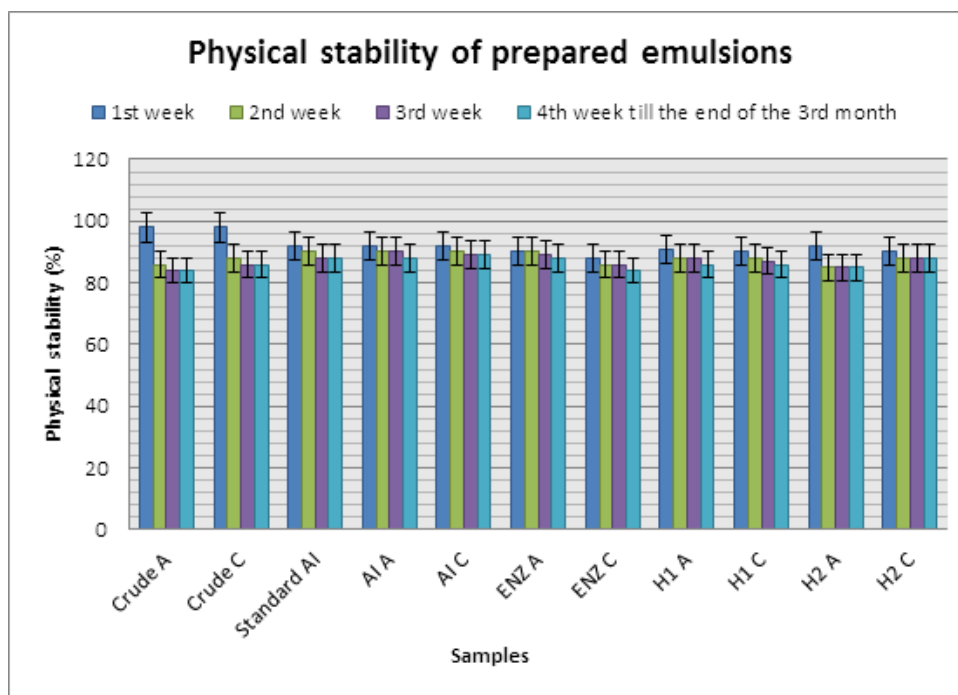

Fig.4. Physical stability of prepared emulsions

[35]. The stability of an emulsion may be rather associated with the composition and properties of the emulsifier used in its stabilization, as it determines its zeta-potential and consequently the droplet-droplet repulsion, which is one of the mechanisms for emulsion stabilization [28].

Hydrolyzed lecithin-stabilized emulsions showed a lower physical stability compared to emulsions where hydroxylated lecithin was used, this could be attributed to the presence of calcium ions arising from the calcium chloride that was added during the hydrolysis reaction; as PLA_2 enzyme is considered as a calcium-dependent enzyme [38], and it was reported by Nieuwenhuyzen [39] that divalent ions such as calcium ions may cause destabilization of emulsions. However, a closer look in Figure (4) reveals that the decrease in stability during the whole storage period (3 months) was too small so as it can be neglected in ENZ A and ENZ C samples.

The above results can be summarized as follows: Hydrolyzed lecithin based emulsions possessed the lowest particle sizes along with an intermediary PDI values and a zeta potential that could be linked to a moderate emulsion stability, while the highest zeta potential values were achieved by the emulsions stabilized by H2A and H2C, with a relatively low particle sizes of 284.0 and 268.0 nm respectively and low PDI values of 0.378 for H2A and 0.391 for H2C. Whereas, the lowest PDI value was achieved by the emulsion stabilized by AI C, this sample had a relatively low particle size of 255.0 nm and a high zeta-potential value of -48.6 mV which is a value that could be linked with a good emulsion stability as mentioned before. It is worthy to mention that this sample (AI C) had the highest pH of 6.72, and regarding its physical stability, the results revealed that it had a physical stability of 92% during the first week of storage and a value of 89% after 3 months of storage. Although the emulsions stabilized by crude lecithins possessed the highest physical stability in the first week, their physical stability has dropped to 85% by the end of the storage period. It is worthy to mention also that regarding the physical stability, (AI A) and the standard AI were having the same physical stability of 92% as (AI C) during the first week but during the twelfth week of storage their physical stability was slightly lower than that of (AI C) with a percentage of 88%. And that may be attributed to the difference in pH between these

samples; as (AI C) had the highest pH with a lower PS and PDI and higher zeta-potential than that of (AI A) and the standard, while (AI A) and the standard AI stabilized emulsions possessed a lower pH of 6.3 and 6.5 respectively with a higher PS and PDI and a lower zeta-potential when compared to (AI C) stabilized emulsion**.**

Transmission-electron microscope (TEM)

The morphology of prepared emulsions was examined using TEM. The obtained results revealed a structure that was in agreement with the emulsions particle size. As shown in figure (5), O/W emulsions prepared in this study showed an almost uniform distribution of round droplets dispersed in the emulsion system. Emulsion stabilized using ENZ C has a round and closely-packed droplets that are uniformly dispersed in the continuous phase of the emulsion. Whereas, the emulsion stabilized by H1C has particles that are distorted in shape. The oil droplets of the AI-stabilized emulsions as well as those stabilized using hydroxylated and hydrolyzed lecithin were smaller than those stabilized by crude lecithin (A) and (C). These results uphold the previously discussed particle size analysis, and it could also reflects the creaming phenomenon of the emulsions.

Rheological properties of prepared emulsions

Rheology is the science of deformation and flow of matter. Studying the rheological properties of emulsions is important as they are extremely valuable in the structural characterization of particle–liquid systems, and in the determination of how particle–particle interactions affect their stability [40]. Also, knowing such properties helps in determining the appropriate conditions that should be followed while designing a delivery system for a specific food application [41].

The rheological properties of prepared emulsions expressed in shear rate – shear stress as shown in Figure (6), and shear rate – apparent viscosity (η) as shown in tables (2A and 2B). All the emulsions exhibited a non-Newtonian behavior, depending upon the composition, particle size, charge and viscosity[42]. The shear rate and the shear stress are directly proportional to each other as shown in (Fig. 6), which agrees with the results obtained by Belayneh [26]. A shear thinning behavior was observed for all the emulsions at shear stress lower than 100sec⁻¹, which agrees with the findings of Goyal [25]. However at higher shear stress, shear thickening behavior was observed for all the emulsions except
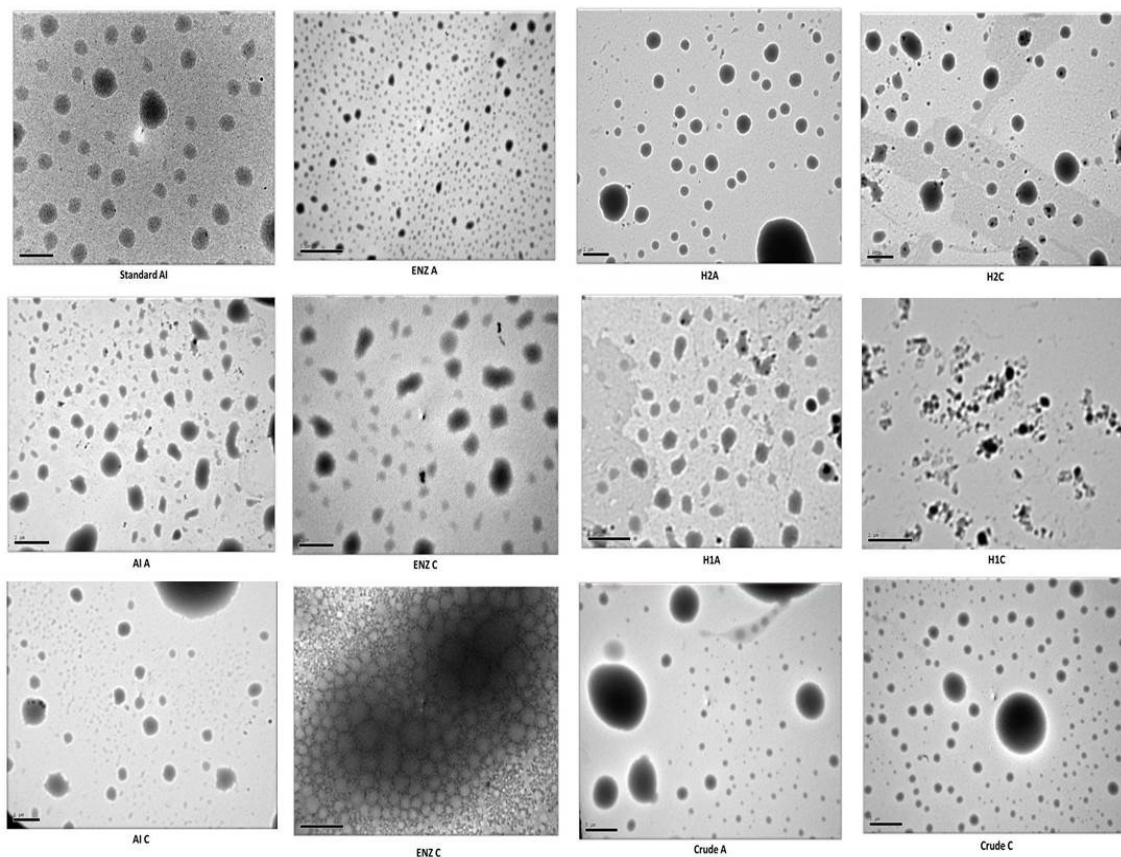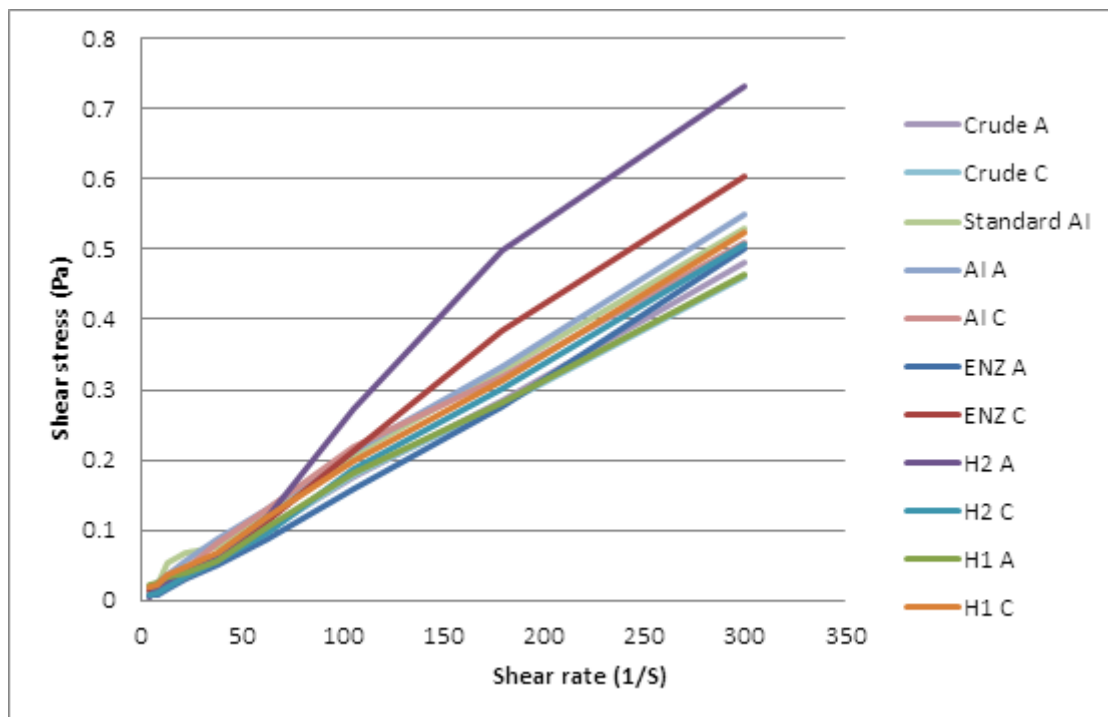
Fig.5.TEM of prepared emulsions.

Fig. 6. Shear rate and shear stress of prepared emulsions

that stabilized using (AI A) which exhibited a high shear thinning behavior; as its results revealed an inversely proportional relation between shear stress and viscosity at all shear rate values that ranged from 4.74 to 300 sec^{-1} (Table 2A and 2B). However, all the other emulsions exhibited a fluctuated behavior that vacillated between shear thinning and shear thickening.

Normally, high emulsion viscosity is obtained from increasing the droplet size or total solids concentration. For most non-Newtonian liquids, viscosity and shear rate are inversely proportional, giving rise to what is known as pseudo-plasticity or shear thinning behavior [25], which can be observed as a result of irreversible deformation and breakdown of flocs under the shear stress [43]. However, a peculiar effect, namely shear-thickening, sometimes occurs with suspensions of small particles of approximately homogeneous size. All the explanations of shear-thickening rely on a general idea suggesting that there is some kind of structure jamming beyond some critical shear rate [44]1992.

It was reported that the rheological properties of emulsions could be influenced by the droplet charge (zeta-potential), also it was found that high shear stress is associated with a relatively small PS and a more uniform distribution which results in a lower poly-dispersity index [25]. This applies to H2A stabilized emulsion that exhibited the highest shear stress with a relatively low particle size and PDI of 284 nm and 0.378 respectively. While the emulsion stabilized by crude C possessed a particle size of 340.6 nm and a PDI value of 0.442 as it exhibited the lowest shear stress.

Conclusion

In this study, the emulsifying properties of several emulsions prepared using modified lecithins were investigated. And based on all the above mentioned results, we can conclude that the emulsions stabilized by the acetone-insoluble portion gave by far the best results in terms of PS, PDI, Zeta-potential, pH values and stability indices. However, this doesn't negate that emulsions stabilized by hydroxylated (H2A and C) and hydrolyzed lecithins possess a good emulsification properties too. And this confirms beyond any reasonable doubt the feasibility and importance of modifying commercial crude soybean lecithin in order to produce tailor-made products with specific surface-active properties-stabilizing emulsions so as to be used in different purposes.

TABLE 2A. Shear rate vs. Shear stress and viscosity for hydrolyzed and hydroxylated lecithin-stabilized emulsions

Shear rate (1/s)	ENZ A		ENZ C		H2A		H2C		H1A		H1C	
	Shear stress (Pa)	η (Pa.s)	Shear stress (Pa)	η (Pa.s)	Shear stress (Pa)	η (Pa.s)	Shear stress (Pa)	η (Pa.s)	Shear stress (Pa)	η (Pa.s)	Shear stress (Pa)	η (Pa.s)
4.74	0.00736	0.00155	0.0139	0.00293	0.00349	0.000736	0.00786	0.00166	0.0207	0.00437	0.0201	0.00424
7.96	0.00861	0.00108	0.0156	0.00196	0.0176	0.00222	0.0108	0.00136	0.0259	0.00326	0.023	0.00289
13.4	0.0149	0.00112	0.025	0.00187	0.0241	0.0018	0.0182	0.00136	0.0326	0.00244	0.036	0.0027
22.4	0.0298	0.00133	0.0346	0.00154	0.0393	0.00175	0.0318	0.00142	0.0389	0.00173	0.0475	0.00211
37.7	0.0516	0.00137	0.0583	0.00155	0.0643	0.00171	0.0556	0.00147	0.0572	0.00152	0.068	0.0018
63.3	0.0867	0.00137	0.112	0.00177	0.12	0.00189	0.0953	0.00151	0.104	0.00164	0.118	0.00186
106	0.159	0.00149	0.212	0.002	0.274	0.00258	0.186	0.00175	0.183	0.00172	0.199	0.00187
179	0.277	0.00155	0.383	0.00214	0.499	0.0028	0.302	0.00169	0.282	0.00158	0.314	0.00176
300	**0.5**	0.00167	0.605	0.00202	0.733	0.00244	0.506	0.00169	0.465	0.00155	0.525	0.00175

ENZ: Hydrolyzed lecithins – H1 and H2: Hydroxylated lecithins

TABLE 2B. Shear rate vs. Shear stress and viscosity for crude and AI lecithin-stabilized emulsions

Shear rate (1/s)	AI A		AI C		Std. AI.		Crude A		Crude C	
	Shear stress (Pa)	η (Pa.s)	Shear stress (Pa)	η (Pa.s)	Shear stress (Pa)	η (Pa.s)	Shear stress (Pa)	η (Pa.s)	Shear stress (Pa)	η (Pa.s)
4.74	0.0178	0.00376	0.0163	0.00343	0.0168	0.00355	0.0181	0.00382	0.00537	0.00113
7.96	0.0236	0.00297	0.0106	0.00134	0.0214	0.00268	0.0109	0.00137	0.0188	0.00237
13.4	0.0362	0.00271	0.0249	0.00186	0.0542	0.00406	0.0237	0.00177	0.0246	0.00184
22.4	0.0566	0.00252	0.0439	0.00196	0.0661	0.00295	0.0378	0.00168	0.0377	0.00168
37.7	0.0866	0.0023	0.0805	0.00213	0.0755	0.002	0.0596	0.00158	0.0579	0.00154
63.3	0.13	0.00205	0.13	0.00206	0.122	0.00192	0.103	0.00163	0.0982	0.00155
106	0.213	0.00201	0.218	0.00205	0.207	0.00195	0.177	0.00166	0.18	0.00169
179	0.334	0.00187	0.318	0.00178	0.326	0.00182	0.285	0.0016	0.278	0.00155
300	0.549	0.00183	0.509	0.0017	0.529	0.00176	0.482	0.00161	0.462	0.00154

AI: Acetone-insoluble lecithins

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دراسة مقارنه لليسيثين الصويا المطور كمادة استحلاب لمستحلبات الزيت في الماء

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تم الحصول على ليسيثين فول الصويا التجاري الخام من مصدرين مختلفين (A) و (C). تم تحوير الليسيثين التجاري الخام لتحسين صفاته و خصائصه الإستلاحبيه باستخدام طرق طبيعية، كيميائية و إنزيميه. تم استخدام جميع أجزاء الليسيثين المحورة في تحضير مستحلبات الزيت في الماء (O / W) و مقارنتها مع الليسيثين الخام وكذلك الليسيثين القياسي الغير قابل للذوبان في الأسيتون و الذي تم شراؤه من السوق. أظهرت المستحلبات المعاملة بواسطة الليسيثين الغير قابل للذوبان في الأسيتون أفضل نتائج خلال فترة تخزينها لمدة ثلاثة أشهر من حيث الثبات و صغر حجم الجسيمات (Particle size) و كذلك نتائج Poly-dispersity index (PDI) و قيم zeta-potential. أظهر الليسيثين المحور كيميائيا عن طريق hydroxylation أعلى قيم zeta-potential (55.3mV and -50.8mV) لعينتي H2A و H2C على التوالي. كما أظهر حجم جسيمات منخفض نسبيًا (284.0 nm and 268.4 nm) ومؤشر تشتت متعدد (PDI) يبلغ (0.378) للعينه H2A و (0.391) للعينه H2C. في حين أن الليسيثين المحور إنزيميا باستخدام إنزيم الفوسفوليبيز A₂ و الذي يمتلك أدنى حجم للجسيمات كان لديه إمكانات زيتا معتدلة من (34.8mV-) للعينه H2A و (32.2mV-) للعينه H2C. يتضح من هذه النتائج أن تحوير الليسيثين الخام ضروري لإنتاج مستحلبات ذات خصائص سطحية محددة لاستخدامها في أغراض مختلفة.