Research Article

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Enhancing gypseous soil behavior using casein from milk wastes

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Abstract: Gypseous soil is a metastable soil that causes problems in the constructions built on it under wetting conditions. Due to the harmful effects of traditional soil binders such as lime or cement on the environment, alternative environmental-friendly materials have been used to decrease this impact. Casein biopolymer is introduced in this study as a new binder for gypseous soil improvement and milk waste minimizing purposes. The study focused on three primary soil features: compaction properties, shear strength, and collapse potential. These three soil properties are important in the ground improvement techniques. In this study, different casein concentrations were added to the soil with varying gypsum contents. According to the compaction results casein reduces the maximum dry density while increasing the optimum moisture content. Soil treated with casein had a collapse potential of 65–80% lower than untreated soil. The shear strength of casein-treated soil increased significantly in both dry and moist conditions. The current study results suggest the recycled casein as an eco-friendly additive for gypseous soil treatment rather than traditional chemical materials.

Keywords: biopolymers, casein, chemical binders, eco-friendly, gypseous soil

1 Introduction

In arid and semi-arid areas of the world, gypseous soil is one of the most widespread collapsible soils [1]. In dry conditions, it is a stable soil with high shear strength; however, when exposed to water, the cementation between soil particles breaks down, resulting in significant volumetric changes [2].

Chemical binders such as cement, lime, sulfur, sodium silicate, and acrylate have been widely used for improving the properties of problematic soil [3,4]. However, they cannot be considered eco-friendly materials because they emit gases that may be toxic and contaminate the ecosystem [4,5]. For instance, ordinary Portland cement (*i.e.*, the most used binding material) is considered one of the primary sources of dioxide emissions and contributes to about 7% of the total global emissions [6,7].

Meanwhile, several alternative techniques have been introduced for geotechnical and construction engineering applications like microbial-induced calcite precipitation (MICP) method, CO_2 absorption, bio-enzymes, and biopolymers [7–9]. MICP is the biological process of using microbes like *Sporosarcina pasteurii* to precipitate calcite ($CaCO_3$) between soil particles, resulting in a cement-like effect at a low cost and low carbon emissions [10,11]. The calcite precipitates can coat soil particles and form bonds at soil particle contacts to increase soil strength and reduce soil permeability [10,12]. On the other hand, disadvantages of the MICP technique are the requirement of special growth conditions, a high amount of ammonium chloride as a byproduct, and difficulty of application in fine-grained soils [13–15].

Therefore, several studies have focused on the direct usage of biologically made materials (*i.e.*, biopolymers) rather than inducing the bacteria into the soil. Environmental-friendly biopolymers are being utilized directly as stabilizers to improve soil characteristics and have shown a remarkable positive effect, even when applied in low concentrations (*e.g.* lower than 1% relative to the mass of soil) [16].

Biopolymers are natural organic polymers that are produced by plants and microorganisms [17]. In reality, the use of biopolymers is not specialized in geotechnical engineering applications. Natural polymers like lignin are effective additives in drilling oil wells and concrete. Also, starch and cellulose are applied extensively in

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various fields like construction of oil wells, tile adhesives, ceramics, lime plasters, and cement [18–20].

Biopolymers can be classified into three types, which are (1) polynucleotides (such as DNA and RNA), (2) polypeptides (such as proteins), and (3) polysaccharides (such as carbohydrates units); polysaccharides are the most commonly used biopolymer type in a wide range of applications [21,22].

Polysaccharides such as cellulose, beta-glucan, chitosan, xanthan gum, agar gum, and gellan gum have been studied in a variety of geotechnical engineering applications, including physical properties, erosion resistance, shear strength, compressive strength, and showed promise as soil binders in terms of sustainability [23,24]. Due to the high sensitivity of polysaccharides to the existence of water, the soil strength will remarkably decrease in the presence of water [25]. Hydrophobic biopolymers may be one solution to this issue. Recent studies have applied casein (*e.g.*, protein) as a new binder since such polymer has lower hydrophilic characteristics than polysaccharide type. Casein was used to evaluate unconfined compressive strengths of Korean residual soil under both dried (28 days) and soaked (24 h of wetness) conditions. The results indicate that 5% casein by mass increased the compressive strength in the dry state (*i.e.*, 4.34 MPa) and in the wet state was 15% of its dry strength value [26].

Fatehi *et al.* [27] examined the effect of casein on the mechanical properties of dune sand. The results indicated that after 14 days of curing time, the compressive strength of biopolymer-treated sand achieved its maximum value and the biopolymer content also increased. Also, it was anticipated that curing temperature had a positive effect on unconfined compressive strength up to 60°C.

Recent research has shown that biopolymers can be used to improve the strength of many types of soils; however, almost no studies have been done on using casein biopolymer to treat gypseous soil. The application of casein as soil binders may enhance the biopolymer-treated gypseous soil's resistance to water. Therefore, the purpose of this study is to determine the effect of casein on the properties of collapsible gypseous soil. A series of laboratory tests investigate the mechanical and geotechnical behavior of gypseous soil treated with casein.

2 Materials and methods

2.1 Soils

The soil used in this research is disturbed natural gypseous soil. Three samples were selected from different locations in Salah-Aldin Governorate. The samples were taken from a depth of 1 m below the natural ground level. The first sample was taken from Tikrit city with the highest amount of gypsum (55%) and referred to as soil 1. The second one was taken from Samarra city with a medium amount of gypsum (35%) and referred to as soil 2. The third sample was taken from Tikrit city with the lowest amount of gypsum (26%) and referred to as soil 3. The three soil samples were classified as poorly graded sand (SP) in accordance with the Unified Soil Classification System. Tables 1 and 2 describe the physical and chemical characteristics of soils, respectively. Particle size distribution curves of three soils are represented in Figure 1.

2.2 Casein

Casein is a protein biopolymer that accounts for 80% of the proteins in cow's milk. It is typically found as a suspension of particles known as "casein micelles" [28,29]. Calcium ions and hydrophobic interactions stabilize these

Table 2: Chemical characteristics of soils

Soil No.	Gypsum content (%)	Organic matters (%)	TDS (%)	pH
Soil 1	55	0.12	62	8.01
Soil 2	35	0.62	38	8.07
Soil 3	26	0.51	31	8.12

Table 1: Physical properties of soils

Soil No.	Field density (kN/m^3)	Atterberg's limits		Grain size distributions		Compaction test	
		LL%	PL%	C_U	C_C	$\gamma_{d\ max}$ (kN/m^3)	OMC (%)
Soil 1	14.5	33	N.P	4	1.7	16.8	13
Soil 2	15.2	32	N.P	5.3	1.4	18.2	10.2
Soil 3	15.8	35	N.P	20	2.9	18.5	10.5

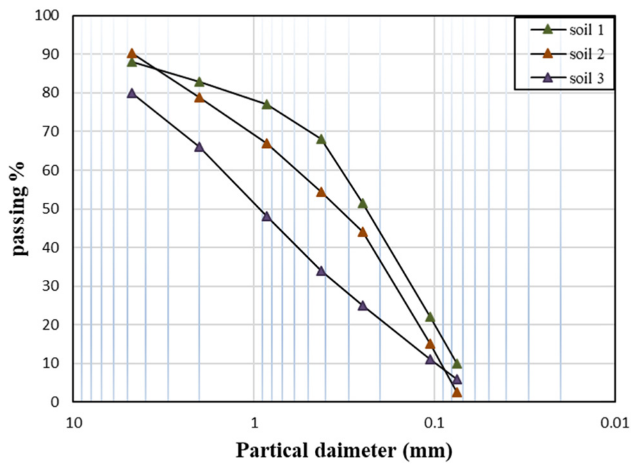

Figure 1: Particle size distribution curve.

casein micelles. Casein has a pH of around 6.6 and an isoelectric point of 4.6 [27]. The ratio of milk waste and losses is 18.1% of overall global production as a result of insufficient storage, freshness (expiration date), inadequate market facilities, transportation, and control of temperature [30]. Currently, the most common technique of milk waste management is disposing a high amount of milk waste into landfills which increase considerations concerning groundwater pollution and disturbance of the ecosystem [26]. Therefore, to offer an eco-friendly soil improvement technique, the employment of casein could be a potential approach for recovering and making use of the existing amount of waste milk. For this reason, casein was prepared from spoiled milk in this study.

2.3 Casein biopolymer preparation

The best quality casein is achieved if the milk fat and acid quantity are within the lowest content. Therefore, the skimmed milk (*i.e.*, from the entire milk the fat has been removed in the form of cream) was used for this purpose. The first step in the preparation of casein was separating the casein from skimmed milk. Rennet was added to warm milk (40–50°C) to bring pH value to about 4.6, at this value, maximum precipitation of curd occurs, while the other part is known as whey [31,32].

After separating the whey, the curd is washed with water at a temperature of 45–60°C (the washing method is completed in two or three stages), drained, and then dried with hot air. Finally, dried casein is milled and packed to create granules of a size of 0.1–0.5 mm. The produced casein is white to slightly yellow [31–33]. Figure 2 presents the procedure of casein preparation from spoiled milk in this study.

2.4 Casein solution creation

Casein solubility increases in alkaline solutions (pH higher than 7). Therefore, an appropriate alkaline solution was

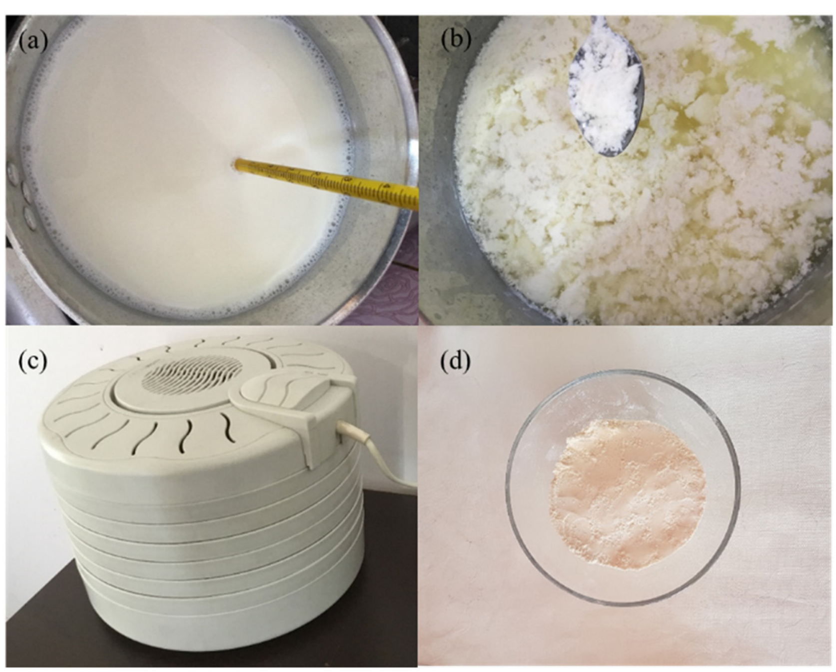

Figure 2: The procedure of casein preparation: (a) warming, (b) precipitation, (c) drying with air dryer, and (d) grinding to powder.

prepared to homogeneously dissolve the casein. 1 Molarity of sodium hydroxide (NaOH) solution was prepared to confirm a suitable soil–casein mixture. For improving casein dissolvability, the (NaOH) solvent was heated up to 70°C [31]. Casein powder was added to the NaOH solution and continuously stirred via a magnetic stirrer till the powder was completely dissolved and formed a homogeneous casein solution.

3 Experimental program

3.1 Casein-treated soil specimens

Casein-treated soil samples were prepared at casein contents of 2, 4, and 6% of the total mass of soil. To achieve sufficient solubility with high pH, casein was dissolved in NaOH solvent (20% soil mass) as previously mentioned. To provide homogenous casein solution, a laboratory magnetic stirrer was utilized. The casein solution was mixed thoroughly with the dry soil. The soil–casein solution was poured and formed into produced metal molds for direct shear tests. In dry conditions, soil specimens were extracted and allowed to cure at lab temperature for a period of 14 days. While in soaked conditions, the cured specimens were soaked for 24 h in distilled water and then the direct shear test is applied. For collapsibility testing, the soil–casein solution was poured into metal molds and allowed to cure at laboratory temperature for 14 days. The field density was used to prepare all soil specimens.

3.2 Laboratory tests

The compaction modified Proctor test (ASTM D1557) was used to estimate the maximum dry density (γ_{dmax}) and corresponding optimum moisture content (OMC) for each soil. A series of direct shear tests were conducted following the ASTM D3080 to determine the shear strength parameters of the soil samples in both dry and soaked states. Collapse tests were performed using the odometer device according to the ASTM D5333 standards. A double oedometer test is used to determine the soil's collapse potential (CP). The term "collapse potential" describes the identified state of collapsibility in soil. According to a guide [34], the severity values for collapse potential were determined as shown in Table 3. In this study, the collapse potentials have been calculated at 200 kPa stress.

Table 3: Collapse potential identifying [34]

Severity	No problem	Moderate	Trouble	Severe	Very severe
"CP" (%)	0–1	1–5	5–10	10–20	>20

4 Results and discussion

4.1 Compaction tests

The changes in the maximum dry density and OMC with the casein are presented in Figures 3 and 4, respectively. The maximum dry density of untreated gypseous soils ranged between 16.8 and 18.5 kN/m^3, while the OMC varied from 10.2 to 13%. Thus, the maximum dry density of soil reduces as the amount of gypsum in the soil increases. The results indicate that increasing the amount of casein biopolymer reduces the maximum dry density while increasing the OMC. The results from the present study are consistent with the results from previous studies [3,35] using xanthan gum biopolymer. The maximum dry density of casein-treated soil 1 decreased from 16.8 to 15.9 kN/m^3 as the casein concentration increased from 0 to 6%. Casein-treated soil 2 has a density reduction of 16.6 from 18.1 kN/m^3 when casein is increased from 0 to 6%. At 0–6% casein biopolymer, the density of casein-treated soil 3 decreased from 18.5 to 16.7 kN/m^3.

In the case of soil 1, the OMC changed from 13.3 to 15% when the casein concentration was increased to 6%. While it raised from 10% to 13.5% for soil 2 at the same casein content. In the case of soil 3, it increased from 10.5 to 15%.

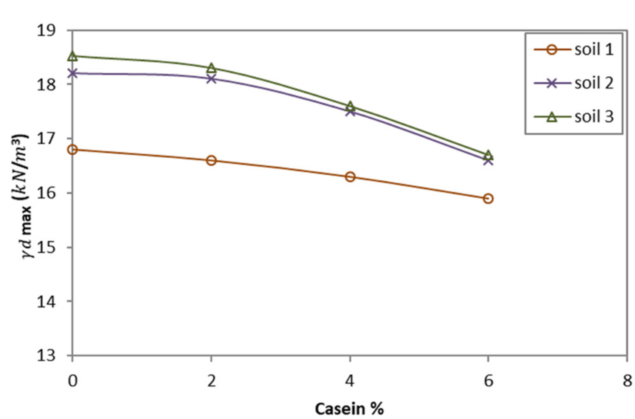

Figure 3: Maximum dry density of casein-treated soils.

4.2 Direct shear tests

The shear strength of treated soils for both dry and soaked conditions increases with increased casein content. In the presence of casein solution, soil particles are surrounded by the casein solution, which produces a continuous casein coating over the soil particles. This interparticle bonding leads to enhancing the shear strength of treated soil [7,26].

The results of casein-treated soils show that the shear strength under the dry conditions is significantly greater than that of the soaked conditions and progressively increase with higher casein content. In comparison, the soaked conditions become significantly less sensitive to changes in casein content. The significant reduction in strength in the soaked condition appears to be due to a combination of gypsum dissolution and hydration of the casein biopolymer due to the presence of water, resulting in weaker interaction bonds between soil particles and a decrease in the viscosity (or stiffness) of casein with the particles [26].

According to the results of direct shear tests, all untreated gypseous soils have a cohesion value; this may be due to the gypsum's cementing bonding. Moreover, the cohesion and angle of internal friction also increase with increased casein concentration, as found by Fatehi *et al.* [27]. For dry conditions, the strength of casein-treated soils decreases as the gypsum content increases.

Figure 5 presents the effect of casein concentration on cohesion for three gypseous soils under both dried and soaked conditions. The cohesion of soil 1 increased from 21.22 to 162.93 kPa with the addition of 2% casein concentration at a rate that was increased up to seven times, whereas the rise in cohesion was approximately 12 times and 14 times with 4 and 6% casein concentrations, respectively. For casein-treated soil 2, the cohesion raised from 37.89 to 259.25 kPa with the addition of 2% casein concentration with the rate increased up to seven times, while the increase in cohesion increased by approximately eight times with 4 and 6% casein concentrations, respectively.

The soil with the least gypsum percentage exhibits the greatest increase in cohesion, with an increase of around 26 times with a 6% casein concentration. Soil 2 is taken from a different area containing different mineral structures; therefore, it shows varied behavior than the other soils.

In treated soils, the cohesion of dry conditions is noticeably greater than that of soaked conditions. When compared to the dry state, the soil with water decreased the cohesion of 6% casein-treated soil by 64, 77, and 72% for soil 1, soil 2, and soil 3, respectively.

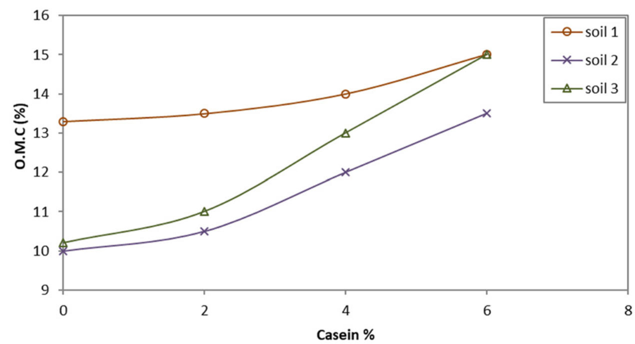

Figure 4: OMC of casein-treated soils.

In a comparison between the effects of a 6% casein concentration and previously attempted [35] xanthan biopolymer on cohesion in soaked conditions of gypseous soil, the cohesion increases up to ten times more than in xanthan-treated soils.

Figure 6 illustrates the effect of casein concentration on the angle of internal friction in three gypseous soils under both dry and wet conditions. For dry condition, the angle of internal friction after curing varied from 40.3° to 48.9° while it was between 28.36° and 37.23° before treatment.

The friction angle in dry conditions is noticeably greater than that in soaked casein-treated soils. After soaking, the friction angle ranged from 26.8° to 39.5°, whereas it was between 40.3° and 48.9° before soaking. The soil with the least gypsum concentration exhibits the greatest increase in friction angle in both dried and wet conditions.

4.3 Collapse tests

The gypseous soil collapse potential is associated with the dissolution of gypsum, the breakdown of the bonding between soil particles, and the reorientation of the soil particles [36].

The soil containing the highest gypsum content recorded the highest value of collapse potential, which was 6.6%. This value is located in the range of collapsible soil with trouble degree [34]. The collapse potential for soil 2 and soil 3 were 4.1 and 3.7%. These were located in the range of collapsible soil with a moderate trouble degree.

Adding 2% casein content reduced the collapse potential of soil 1 from 6.6 to 3.1%, resulting in a 53% reduction in collapse potential. While increasing the efficiency to approximately 67 and 74% with 4 and 6% casein concentrations, respectively, which was recognized with a

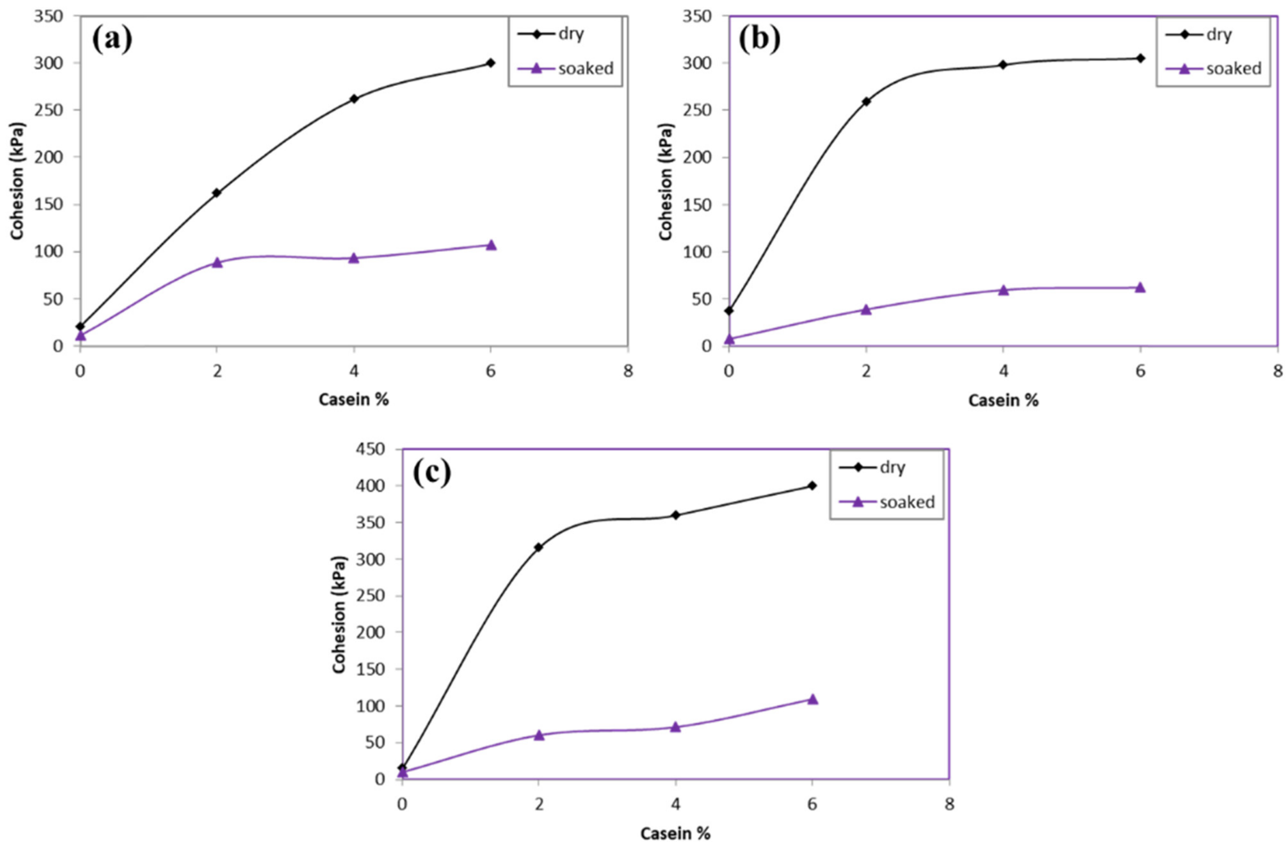

Figure 5: Effect of casein content on cohesion: (a) soil 1, (b) soil 2, and (c) soil 3.

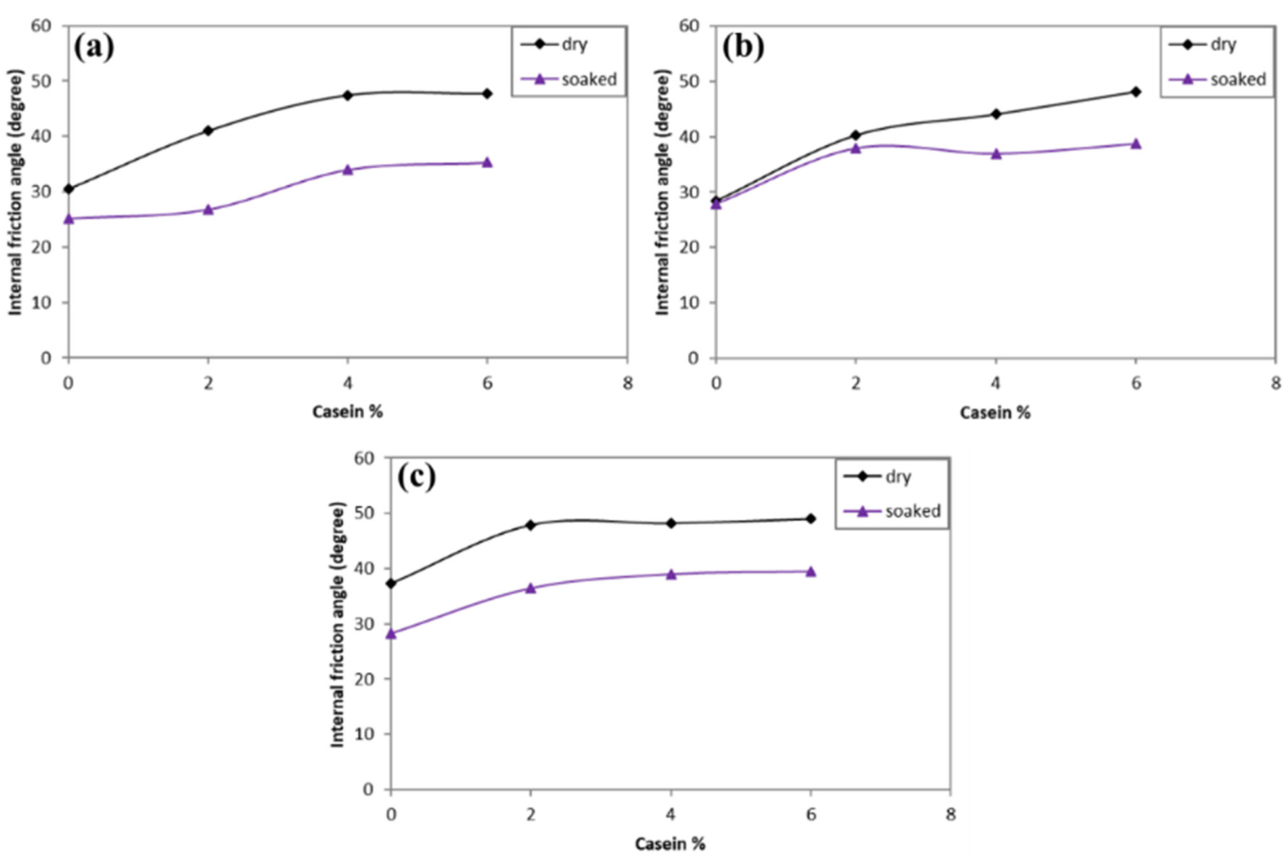

Figure 6: Effect of casein content on friction angle: (a) soil 1, (b) soil 2, and (c) soil 3.

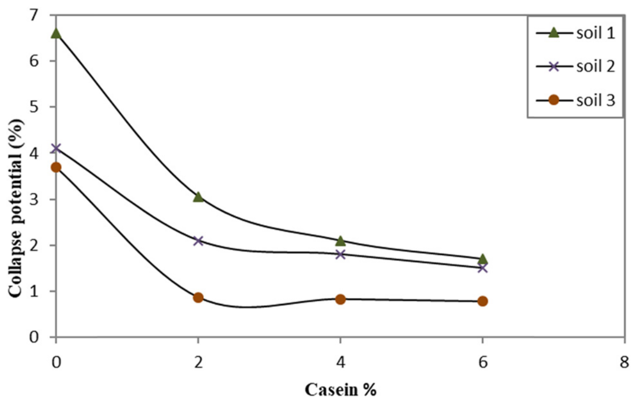

Figure 7: Effect of casein concentration on collapse potential.

moderate degree of collapse. The collapse potential decreases with the increase of casein content and decrease of gypsum content.

Figure 7 presents the effect of casein concentration on collapse potential. The collapse potential of soil 2 was decreased to 1.5% when treated with 6% casein; the efficiency percentage in lowering the collapse potential was 63%, while the collapse potential of soil 3 was less than 1% to reach a "No Problem" stage. The soil with the least gypsum content exhibits the greatest reduction in collapse potential after treatment with a 6% casein concentration.

5 Conclusion

This study shows that recycling casein can significantly improve the characteristics of gypseous soil. The recycling of casein can help decrease the amount of milk waste. The hydrophobic properties of casein binder contributed to increasing shear strength in soaked conditions and hence reducing collapsibility of gypseous soil. Despite the decrease in maximum dry density, the cohesion of casein-treated soil increased to 14 times for soaked conditions with 6% casein content than for untreated conditions. The collapse potential of treated gypseous soils showed a reduction by a range of about 65–80%. The percentage of casein to treat gypseous soil is indicated as 6% to achieve optimum shear strength and collapsibility performance. Future studies are recommended for a better knowledge of biopolymer gypseous soil improvement from a microscopic viewpoint and the use of other water-resistant biopolymers for more effective eco-friendly development.

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