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Production and Evaluation of Sheep's Milk Cheese Analogues Fortified with Milk Protein Concentrate and Native or Modified Starch with Guar Gum

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SHEEP's milk cheese analogues were made from sheep's milk with the addition of 3% milk protein concentrate (MPC) and corn starch (CS) or maltodextrin (MD) at rates of 1, 2, and 3%, along with 0.03% guar gum (GG). The chemical, rheological, sensory properties and yield of cheese analogues were studied. The addition of MPC, CS, MD, and GG increased the moisture and carbohydrate contents of cheese analogues, while protein and ash content increased with the addition of MPC and decreased with increasing levels of added CS and MD. The fat contents decreased with the addition of MPC and with increasing levels of added CS or MD. The results also indicated a significant increase in the yield of cheese analogues with the addition of MPC and with increasing levels of CS and MD added along with GG. Texture profile analysis showed that hardness, gumminess and chewiness values increased with the addition of MPC and CS, while the values tended to decrease with the addition of MD. The cohesiveness and springiness values increased with the addition of MPC while they decreased with addition of both types of starch. Cheese analogues with the addition of 3% MPC and 2% CS or 3% MD with 0.03% GG received the highest scores for sensory properties. From these results, it could be concluded that partial replacement of casein and fat by adding MPC and CS or MD achieved good sensory properties with a significant increase in yield and reduced the cost of producing sheep milk cheese analogues.

Keywords: Sheep's milk, Cheese analogues, Milk protein concentrate

Introduction

Sheep milk has high nutritional value and high levels of proteins, fats, vitamins and minerals especially calcium, compared to milk of other animal species. This makes it particularly ideal for cheese production (Jooyandeh and Aberoumand, 2010). In addition, sheep milk fat has a distinct flavour, which reflected in sheep milk products, such as cheese (Balthazar et al., 2017). World-famous classic cheeses such as Roquefort, Feta, and Halloumi are among the delicious and broad category of cheeses made from sheep's milk. However, the high price and scarcity of sheep's milk causes the cost of cheese made from it to rise, prompting customers to look for less expensive products. One of the most effective methods that can help expand the sheep milk cheese market is the availability of functional, healthy and affordable alternative products such as sheep milk cheese analogues. Cheese analogues are products that mimic or substitute traditional cheese; in such products, the milk fat, milk protein, or both may be partially or completely replaced by non-dairy ingredients, usually of plant origin (Chavan and Jana, 2007).

Casein is one of the main components of cheese analogues. Over the past few years, the price of casein has risen dramatically. Accordingly, there was an urgent need to find a suitable and functionally compatible replacement ingredient for casein (Mohd Shukri et al., 2022). Incorporating MPC into food formulations can provide a range of benefits including water

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binding, viscosity, gelling, emulsification and stabilization. In addition, MPC can provide opacity and a pleasant milky flavour profile. These excellent functional properties make MPC a versatile functional ingredient for various food applications. MPC is increasingly used as an ingredient at the expense of casein and caseinates. MPC is currently widely used as a protein source in the manufacture of a range of products including analogue cheese, processed cheese and cream cheese (Ikeda, 2015 and Ng et al., 2017). The two main expensive components of imitation cheese are casein and fat, therefore replacing these components with starch is being widely studied to reduce the cost of analogue cheese. Many native and modified starches are used to replace casein and fat in analogue cheese (Kamath et al., 2022). The primary function of starches is to provide additional viscosity, water-binding ability, and enhance the meltability of the final product (Fu and Nakamura, 2018). Milk fat is often replaced due to its higher price and also to reduce the cholesterol content of the diet. Milk fat is replaced not only with vegetable fats but also with a mixture of proteins and carbohydrates (Aljewicz et al., 2011). Starch can also be used to reduce or eliminate the need for the more expensive casein, allowing casein to be used only as a preferred ingredient and not as a critical ingredient in making cheese analogues with the desired functionality (Brown et al., 2012). Starch can be native or modified. Modified starches, also called starch derivatives, are prepared by physical, chemical or enzymatic treatment of the native starch, thus changing the properties of the starch. Both native and modified starches can be considered effective replacers for fat.Maltodextrin is a modified starch derivative produced by enzymatic or chemical hydrolysis of native starch and loses the physical properties of starch granules (Chavan et al., 2016). However, maltodextrin has a strong water-holding capacity and is able to form hydrothermally reversible gels, creating a fat-like mouthfeel. The function of maltodextrin as a fat replacer is different from that of the native starch granules, which require water. However, maltodextrin is also considered a fat replacer (Mironescu and Mironescu, 2012).

On the other hand, guar gum has a unique structure consisting of linear chains of galactose and mannose with branching points at regular intervals; hence the synergistic effect of guar gum increases its functional properties when used with other ingredients such as other hydrocolloids, protein, salt, and sugars. The synergistic effect of guar gum has been studied in various studies, including the synergistic effect of guar with milk protein (Hege et al., 2020). It has also been shown that guar gum has a synergistic effect with starch and affects the gelatinization and retrogradation behavior of cornstarch (Funami et al., 2005). Therefore, the present study was undertaken to formulate and evaluate a soft sheep milk cheese analogues made using milk protein concentrate to partially replace casein, with native cornstarch or maltodextrin to partially and simultaneously replace both fat and casein, along with guar gum.

Materials and Methods

Materials

Raw sheep's milk used in this work (16.84% total solids, 6.05% fat, 5.54% protein, 4.37% lactose, 0.88% ash) was collected from the animal production farm of the Faculty of Agriculture, Sohag University, Egypt. Milk protein concentrate (70% protein) was supplied by Havero Hoogwegt B.V, Netherlands. Corn starch was supplied from the National Company for Maize Products in 10th of Ramadan City, Egypt.Maltodextrin powder was imported from Alpha Chemika, Andheri West, Mumbai, Maharashtra (India).Guar gum was supplied by Premcem Gums Pvt. Ltd, India.

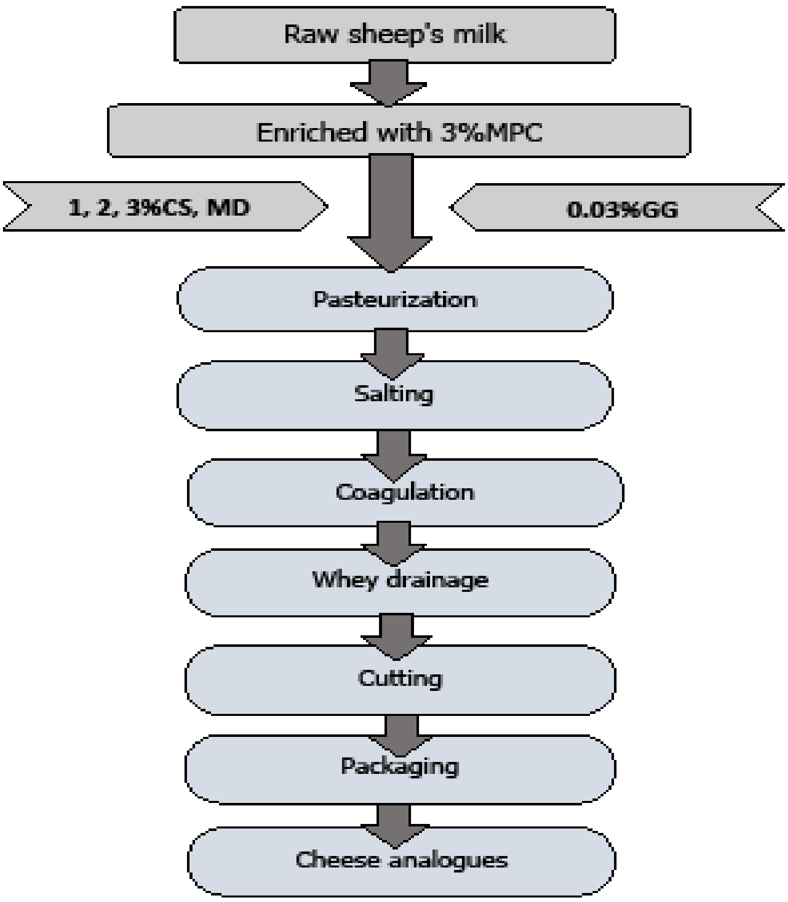
Methods

Manufacture of soft sheep's milk cheese analogues

Whole sheep's milkwas divided into eight equal batches. The first batch was left without any additives to serve as a control. Each of the other seven batches was heated to 55°C, enriched with 3% MPC, and mixed well with a high-speed mixer for approximately 30–40 min until the MPC was completely dispersed, as previously recommended by Patel &Patel (2014)to improve MPC solubility. CS and MD were then added separately at levels of 1, 2, and 3% along with 0.03% GG.Control and its mix formulations are presented in Table 1. Each batch was stirred continuously while adding these ingredients and then mixed well for an additional 10 minutes or until a homogeneous mixture was obtained. All batches were pasteurized at 63°C for 30 min, then rapidly cooled to 5°C and kept at this temperature overnight to ensure sufficient hydration of all additives. The next morning, all batches were heated to 40°C, 2% NaCl and 0.02% CaCl were added to each batch, then fresh liquid rennet was added, after which all batches were incubated at 40°C for 1.5–2 h. After complete coagulation the curds were cut and filled into stainless steel moulds lined with cheese cloth and consolidated by a slight pressure and left overnight to drain the whey. The next morning, the resulting cheese was cut and packed into plastic containers containing 5% brine solution, and stored under refrigerated temperature (5 ± 1°C). A schematic representation of the steps for making analogue cheese is shown in Fig 1. Throughout a 60-day storage period, samples were examined every 15 days for sensory assessment as well as for chemical composition, texture, and yield while still fresh. Every analysis was carried out in triplicate.

TABLE 1. Formulation of milk bases and control used for sheep›s milk cheese analogues manufacture, expressed in (g/100g).

Formulations	Dried ingredients			
	Milk protein concentrate	Corn starch	Maltodextrin	Guar gum
Control	0.0	0.0	0.0	0.00
MPC3	3.0	0.0	0.0	0.00
MPC-CS1	3.0	1.0	0.0	0.03
MPC-CS2	3.0	2.0	0.0	0.03
MPC- CS3	3.0	3.0	0.0	0.03
MPC-MD1	3.0	0.0	1.0	0.03
MPC-MD2	3.0	0.0	2.0	0.03
MPC-MD3	3.0	0.0	3.0	0.03



Chemical analysis

Chemical analyses of sheep'smilk and sheep'scheese analogues including moisture, total solids, protein, fat, ash,and salt, were determined according to AOAC (2012). Carbohydrate content was calculated by difference using the formula: % Carbohydrates = 100 – (% moisture + % protein + % fat + % ash).

Determination of cheese yield

According to Fox et al. (2000), the mass ratio between the curd obtained after the pressing stage and the weight of the milk was used to calculate the cheese yield. Every measurement was done three times.

Texture Profile Analysis (TPA)

Three days after manufacture, cheese analogues underwent texture profile analysis using the Mecmesin MultiTest 1-d Texture Analyzer (Slinfold, West Sussex, UK), and Specific Expression PC Software was used to compute the results. A compression test was used in the experiments to create a plot of force (N) versus time (sec). Samples were compressed twice at a rate of two centimeters per minute. Three evaluations of each texture parameter were conducted according to IDF (1992).

Sensory evaluation

Nine staff members of Dairy Science Department, Faculty of Agriculture, Sohag University/ Egypt, evaluated the cheese analogue samples based on their sensory evaluation according to the scheme described by Nelson and Trout (1956). Flavour received 50 points, body and texture received 35 points, and appearance received 15 points. The overall acceptability score was 100.

Statistical examination:

The data obtained from the current study was analyzed by ANOVA. In all analyses, the data means test was utilized to assess the variation between the samples when a significant difference ($p < 0.05$) was found in a particular variable. The Statistical Analysis System for Windows software was utilized to analyze the data (SAS, 2008).

Results and Discussion

Chemical composition of cheese analogues

Table 2 shows that the moisture content of cheese analogues was significantly increased ($P \leq 0.05$) by the addition of MPC, which can be attributed to the presence of whey proteins in the MPC composition and the high water-binding ability of MPC. These results are consistent with those of Caro et al. (2011). On the other hand, the moisture content of cheese analogues was also significantly increased ($P \leq 0.05$) by the addition of cornstarch or maltodextrin. This may be due to the ability of starches to increase moisture content, which leads to water retention as a result of the gelatinization process. This explains the high water absorption and water holding capacity of both cornstarch and maltodextrin. Bhaskaracharya and Shah (2001) studied inclusion of two types of maltodextrins and a modified potato starch in low-fat Mozzarella cheese. They reported that potato starch increased hardness and decreased the moisture content. Potato starch particles were distributed in the protein matrix. These particles apparently swelled and removed moisture from the surrounding proteins. They attributed the different properties of cheeses made from different starches to the sizes of starch particles, the degrees of fine microparticulation, and their interactions with casein. The larger starch particles are more effective at allowing more moisture to be incorporated into the cheese. Iakovchenko &Arseneva (2016) found that the use of tapioca maltodextrin in the production of soft unripened cheese increased the moisture-binding capacity and moisture content of the cheese. These results are also consistent with the findings of Nazari et al. (2020) on the effect of maltodextrin as a fat replacer in ultra-filtered low-fat feta cheese.Furthermore, the addition of guar gum in our study may also have contributed to the increased moisture content of the resulting cheese analogues. Oberg et al. (2015) observed an increase in moisture content in low-fat mozzarella cheese using several polysaccharides including waxy cornstarch and guar gum as fat mimetics.

Data in the same table show that adding MPC to cheese milk resulted in a significant ($P \leq 0.05$) increase in the protein content of the cheese analogues compared to the control cheese. The same results were obtained by Rashidi (2016). Conversely, the protein content of cheese analogues decreased significantly ($P \leq 0.05$) with the addition of cornstarch or maltodextrin and this decrease was proportional to the level of addition. This may be primarily due to the water-retaining properties of both types of starch (Table 2). Similar results were reported by Sipahioglu et al.(1999). The fat content of cheese analogues was significantly decreased ($P \leq 0.05$) with the addition of MPC (Table 2). This was probably due to the higher moisture content and higher yield compared to the control cheese. Caro et al. (2011) found that the use of MPC caused a significant reduction in cheese fat and fat-in-dry matter in Oaxaca cheese. The fat content of the cheese analogues also decreased significantly (P ≤ 0.05) with the addition of cornstarch and maltodextrin (Table 2). This is probably due to their hygroscopic properties and the absence of fat in the starches. Similar results were reported by Nazari et al. (2020). The carbohydrate content of cheese analogues increased significantly (P ≤ 0.05) with the addition of cornstarch or maltodextrin, and this increase was proportional to the increase in the level of cornstarch and maltodextrin added (Table 2). Similar results were observed by Mehanna et al. (2021).

The ash content of cheese analogues increased significantly (P ≤ 0.05) with the addition of MPC (Table 2). Similar results were reported by Guinee et al. (2006) on cheddar cheese produced from milk standardized with MPC. In contrast, the ash content of cheese analogues decreased significantly (P ≤ 0.05) with the addition of cornstarch or maltodextrin (Table 2). Similar results were observed by Basiony and Hassabo (2022) in low-fat halloumi cheese made using modified corn starch. The salt content of the cheese analogues increased significantly (P ≤ 0.05) with the addition of MPC (Rashidi, 2016), but there was no clear correlation between the salt content of the cheese analogues and the added levels of cornstarch and maltodextrin (Table 2). The results showed that as the storage period progressed, the content of protein, fat, ash and salt were significantly increased (P ≤ 0.05) in all cheese analogues, possibly due to moisture loss, leading to an increase in the total solids content of the product, while the carbohydrate content gradually significantly decreased(P ≤ 0.05) during the storage period (Table 2). The present results agree with El – Hawary et al. (2009) and Basiony and Hassabo (2022)

TABLE 2. Chemical composition of sheep's milk cheese analoguesfortified with milk protein concentrate and different levels of carbohydrates along with guar gum during refrigerated storage.

Constituents (%)	Storage period (days)	Control*	Treatments						
			MPC3	MPC-CS1	MPC-CS2	MPC-CS3	MPC-MD1	MPC-MD2	MPC-MD3
Moisture	1	60.29^{Da}	61.54^{Ca}	62.32^{BCa}	63.78^{Aa}	64.35^{Aa}	62.09^{Ca}	62.46^{BCa}	63.17^{Ba}
	15	59.42^{Ca}	60.83^{Ba}	61.55^{Bab}	62.46^{Ab}	62.90^{Ab}	61.47^{Bab}	61.02^{Bb}	62.49^{Aa}
	30	58.16^{Db}	59.69^{Cb}	60.72^{ABb}	61.20^{ABc}	61.43^{Ac}	60.93^{Abc}	60.35^{Bbc}	61.06^{ABb}
	45	57.91^{Dc}	59.25^{Cb}	60.37^{ABb}	60.93^{Ac}	61.06^{Ac}	60.27^{ABc}	59.44^{BCc}	60.87^{Ab}
	60	57.74^{Dc}	59.00^{Cb}	60.25^{ABb}	60.87^{Ac}	60.84^{Ac}	59.63^{BCc}	59.20^{Cc}	60.56^{Ab}
Protein	1	15.34^{Eb}	17.08^{Ab}	16.29^{Cb}	15.42^{Ec}	14.61^{Gc}	16.65^{Bc}	15.97^{Dc}	15.02^{Fc}
	15	15.59^{Eb}	17.41^{Ab}	16.62^{BCb}	15.92^{Db}	15.06^{Fb}	16.92^{Bbc}	16.49^{Cb}	15.35^{EFbc}
	30	15.97^{DEa}	17.83^{Aa}	16.90^{Bab}	16.17^{Db}	15.54^{Fa}	17.24^{Bb}	16.80^{Cb}	15.68^{EFb}
	45	16.12^{DEa}	17.95^{Aa}	17.03^{Ca}	16.40^{Da}	15.68^{Fa}	17.47^{Ba}	16.87^{Ca}	15.84^{EFa}
	60	16.26^{DEa}	18.19^{Aa}	17.15^{Ca}	16.56^{Da}	15.90^{Fa}	17.72^{Ba}	17.24^{Ca}	16.15^{EFa}
Fat	1	18.50^{Ad}	15.00^{Bd}	13.92^{Cd}	12.75^{Dd}	12.00^{Ed}	14.08^{Cc}	13.50^{Cc}	12.33^{DEd}
	15	19.33^{Ac}	15.67^{Bc}	14.75^{Cc}	13.83^{Dc}	13.25^{DEc}	14.83^{Cbc}	14.50^{Cb}	13.00^{Ec}
	30	20.00^{Ab}	16.50^{Bb}	15.50^{Cb}	14.75^{Db}	14.08^{Eb}	15.50^{Cb}	15.00^{CDb}	13.92^{Eb}
	45	20.50^{Aab}	16.83^{Bab}	15.92^{Cab}	15.25^{Db}	14.67^{Eab}	16.00^{Cb}	15.50^{CDab}	14.67^{Ea}
	60	20.67^{Aa}	17.25^{Ba}	16.17^{CDa}	15.50^{Ea}	15.08^{EFa}	16.67^{Ca}	15.83^{DEa}	14.83^{Fa}
Carbohydrate	1	2.72^{Ca}	2.95^{Ca}	4.07^{Ca}	4.68^{Ba}	5.82^{Aa}	3.76^{Ba}	4.73^{Ba}	6.18^{Aa}
	15	2.45^{Da}	2.52^{Db}	3.60^{Cb}	4.24^{Bb}	5.37^{Ab}	3.24^{Cb}	4.39^{Bab}	5.67^{Ab}
	30	2.29^{DEb}	2.24^{Eb}	3.01^{Cc}	4.16^{Bb}	5.14^{Ab}	2.65^{CDc}	4.03^{Bbc}	5.43^{Ab}
	45	1.67^{Ec}	1.86^{Ec}	2.52^{Dd}	3.47^{Cc}	4.52^{Ac}	2.35^{Dc}	3.92^{Bc}	4.50^{Ac}
	60	1.20^{Gd}	1.21^{Gd}	2.17^{Ed}	2.86^{Dd}	3.75^{Bd}	1.83^{Fd}	3.32^{Cd}	4.18^{Ac}
Ash	1	3.15^{Cd}	3.43^{Ad}	3.40^{Ac}	3.37^{ABe}	3.22^{BCe}	3.42^{Ad}	3.34^{ABe}	3.30^{Bd}
	15	3.21^{Cd}	3.57^{ABd}	3.48^{Bc}	3.55^{ABd}	3.42^{Bd}	3.54^{ABd}	3.60^{Ad}	3.49^{ABd}
	30	3.58^{Cc}	3.74^{Bc}	3.87^{Ab}	3.72^{Bc}	3.81^{ABc}	3.68^{BCc}	3.82^{Ac}	3.91^{Ac}
	45	3.80^{Db}	4.11^{Bb}	4.16^{Aa}	3.95^{Cb}	4.07^{BCb}	3.91^{Cb}	4.27^{Ab}	4.12^{Bb}
	60	4.13^{Ca}	4.35^{ABa}	4.26^{Ba}	4.21^{BCa}	4.43^{Aa}	4.15^{Ca}	4.41^{Aa}	4.28^{Ba}
Salt	1	1.65^{ABd}	1.76^{Ae}	1.76^{Ad}	1.70^{Ae}	1.56^{Be}	1.69^{Ad}	1.75^{Ad}	1.72^{Ae}
	15	1.80^{Bd}	2.05^{Ad}	2.03^{ABc}	1.97^{ABd}	1.91^{Bd}	2.03^{ABc}	2.11^{Ac}	1.97^{ABd}
	30	1.97^{Bc}	2.30^{Ac}	2.12^{ABc}	2.18^{ABc}	2.24^{Ac}	2.18^{ABc}	2.28^{Ac}	2.23^{ABc}
	45	2.24^{Bb}	2.52^{Ab}	2.41^{ABb}	2.47^{ABb}	2.52^{Ab}	2.34^{ABb}	2.56^{Ab}	2.47^{ABb}
	60	2.61^{Ca}	3.04^{Aa}	2.70^{BCa}	2.63^{Ca}	2.86^{BCa}	2.52^{Ea}	2.95^{Aa}	2.79^{BCa}

The means (n = 3) with similar capital letters in the same row (between treatments) and similar small letters in the same column .(during storage) are not significantly different at P ≤ 0.05; Control*, Cheese made from sheep's milk without additives

Cheese yield

Figure 2 shows that the cheese analogues had a significantly higher yield ($P \leq 0.05$) than the control cheese made entirely from sheep's milk. The yield in sheep's cheese analogues ranged from 32.93 to 37.77% compared to 26.85% in the control cheese. Addition of MPC to cheese milk resulted in a significant ($P \leq 0.05$) increase in the yield of cheese analogues. This may be due to the increased moisture content of the cheese analogues, which was associated with increased protein content and total solids recovery. Several studies have reported that adding MPC to cheese milk increases cheese yield (Rashidi, 2016 and Khiabanian et al., 2022). Researchers found that standardizing cheese milk with MPC resulted in increased mozzarella cheese yield due to increased recovery of total solids and proteins in MPC cheese and due to slightly higher cheese moisture (Francolino et al., 2010). On the other hand, the yield of cheese analogues increased significantly ($P \leq 0.05$) with the addition of cornstarch or maltodextrin, and the increase in yield resulting from the addition of cornstarch was greater than that resulting from the addition of maltodextrin. However, the difference between the yield of cheese analogues with the addition of cornstarch or maltodextrin was not significant ($p \geq 0.05$) (Fig. 2). This can be attributed to the water-binding properties of both types of starch and thus the increased moisture content in the cheese analogues. Diamantino et al. (2014) found that the use of modified waxy corn starch as a fat replacer in fresh reduced-fat Minas cheese increased the moisture content and attributed this to the polar nature of starch, which increased water-holding capacity. However, the loss of starch in the whey and the amount of starch used (0.5%) may not have been sufficient to significantly improve the yield and texture of fresh cheese. They also reported that the higher WHC of waxy starches could be enhanced by higher amylopectin content in the starch, thus increasing the number of hydrophilic groups available in its branches. Several studies have reported that adding different types of starch to cheese milk increases cheese yield (Brown et al., 2012 and Bi et al., 2016). Furthermore, the addition of guar gum to cheese milk in our study may also have contributed to the increased yield of cheese analogues. This is mainly due to the fact that hydrocolloidal gum has the ability to control the rheology of water-based systems and inhibit whey expulsion, which ultimately leads to increased cheese yield. Several authors reported that adding guar gum to cheese milk resulted in increased cheese yield compared to control cheese (Sattar et al., 2015 and Murtaza et al., 2017).

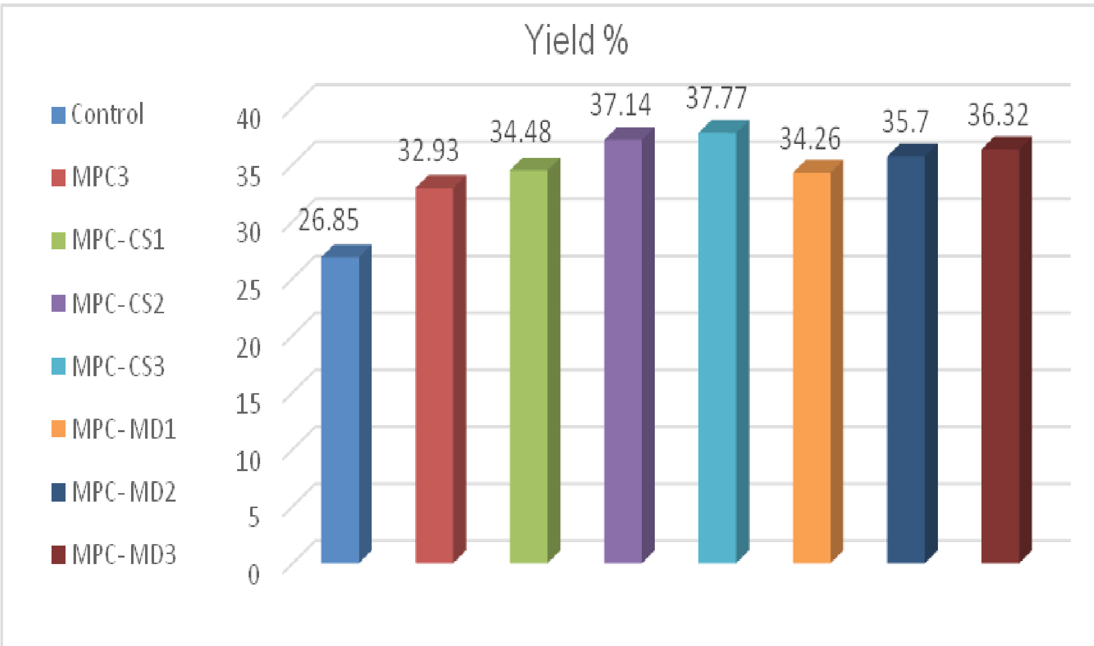


Fig. 2. Yield of sheep's milk cheese analogues fortified with milk protein concentrate and different levels of carbohydrates along with guar gum

Textural characteristics of cheese analogues

The values of the texture profile analysis (TPA) parameters for the cheese analogues are given in Table 3. The results showed that the hardness, cohesiveness, springiness, gumminess and chewiness of the cheese analogues increased significantly ($P \leq 0.05$) with the addition of MPC compared to the control cheese. This may be due to the increased protein content with a slight decrease in fat content in the cheese analogues. Gholamhosseinpour et al. (2018) reported that the hardness of UF-Feta cheese analogue increased significantly with increasing levels of MPC and WPC due to increased dry solids content. In addition, severalstudies have evaluated the effect of totally or partially reducing fat and/or replacing it with different types of ingredients on the microstructure and textural properties of cheese.Most of these studies showed that partial reduction in milk fat resulted in modification of microstructure and textural properties, because the protein matrix becomes more compact and has a more elastic, firm and chewy texture in reduced-fat cheese compared to full-fat cheese (lobato-calleros et al., 2007). Giha et al. (2021) reviewed how total or partial replacement of milk fat can affect the microstructure, rheology, and texture profile of cheese analogues.

On the other hand, the hardness of the cheese analogues increased significantly ($P \leq 0.05$) with the addition of cornstarch and tended to decrease with the addition of maltodextrin compared to cheese made with the addition of MPC only, and the increase and decrease in hardness was proportional to the level of starch added (Table 3). Montesinos-Herrero et al. (2006) found that the hardness of imitation cheeses increased linearly with increasing starch content and to a greater extent for retrograded resistant starch than for native resistant starch. They attributed this to the combined effect of a large amount of water entrapped in the tapioca starch gel. Mounsey and O'Riordan (2001;2008a,b) investigated native and modified starches from different plant origins and reported that the physical properties of imitation cheese were affected by amylose content, swelling ability, and the shape and size of starch granules, and starch concentration. High amylose starch increased the hardness of imitation cheese more than low amylose starch, because high amylose starch undergoes retrogradation more readily than low amylose starch. Shah et al. (2010) reported that for the production of mozzarella cheese analogues, the use of maltodextrin contributes to reducing the hardness, improving chewiness and stabilizing the melting property of the product. By using maltodextrin, the moisture content of the formulation increases and the sliceable properties improve. Nazari et al. (2020) studied the effect of maltodextrin as a fat replacer in low-fat, UF-feta cheese. They reported that because maltodextrin caused an increase in the distance between protein aggregates through water absorption, the number of voids decreased and their volume increased which likely explains the decreased hardness of the maltodextrin treatments. Recently, Murtaza et al. (2023) reported that by increasing the level of inulin and resistant starch in low-fat cheddar cheese, the cheese became harder. Cohesiveness of cheese analogues increased significantly ($P \leq 0.05$) with the addition of MPCtheir internal structure would not disintegrate easily (Table 3). This may be due to the increased protein content, which strengthened the structure and cohesiveness of the casein network. Caro et al. (2011) found that cohesiveness was similar for all treatments with the addition of skim milk or MPC on Oaxaca cheese. However, Gholamhosseinpour et al. (2018) showed that the cohesiveness of the recombined UF-Feta cheese analogue increased significantly with increasing MPC and attributed this to the increased amount of protein, which enhanced the gel structure and cohesiveness. However, the cohesiveness values of the cheese analogues tended to decrease significantly (P □ 0.05) with the addition of both types of starch, especially maltodextrin, compared to cheese made with the addition of MPC only, and the rate of decrease in cohesiveness values was proportional to the level of added starch (Table 3). This may be due to changes in the protein matrix due to the addition of starch and decreased fat content. Some research has indicated that the effect of starch on the cheese cohesiveness is affected by the type of starch used and the shape of the starch granules. Mounsey &O'Riordan (2001) observed that replacing protein with starch caused a decrease in the cohesiveness of imitation cheese, and they stated that the role of starch in reducing cohesiveness could be due to structural failure in deformation due to stress localization at the starch-protein matrix interface. Montesinos-Herrero et al. (2006) showed that the cohesiveness of imitation cheese increased linearly with increasing native resistant starch content but was unaffected by retrograded resistant starch. The cohesiveness results obtained in the study probably reflect the combined effect of decreased fat and increased starch content. In a recent study by Butt et al. (2020), pre-gelatinized starches (native and modified) were used to partially replace protein and fat in the production of imitation mozzarella cheese and were compared with conventional cheese (0% starch). The resultant imitation cheeses were softer, more cohesive, and had improved melting properties compared to the control.Springiness values of the cheese analogues increased significantly (P ≤ 0.05) with the addition of MPC (Table 3). Guinee and Kilcawley (2004) reported that by increasing the concentration of casein in the cheese matrix, the number of intra- and interstrand linkages is increased and finally the matrix becomes more elastic. Whereas springiness values decreased significantly (P ≤ 0.05) when both types of starches were added and maltodextrin caused the greater decrease in springiness values. However, the differences in springiness values between different levels of maltodextrin added to each other were not statistically significant (P 0.05) (Table 3). The gumminess and chewiness values of the cheese analogues increased significantly (P ≤ 0.05) with the addition of MPC compared to the control cheese. On the other hand, the gumminess and chewiness values of the cheese analogues increased significantly (P ≤ 0.05) with the addition of cornstarch but tended to decrease with the addition of maltodextrin compared to the control cheese (Table 3). Veiskarami et al. (2020) studied the textural properties of cheese analogues made from sweet corn containing MPC and WPC. The results showed that as levels of MPC and WPC increased, the hardness, gumminess, and cohesiveness values of the cheese analogues increased, and as the level of corn extract increased, the hardness and chewiness values decreased.On the other hand, the addition of guar gum to cheese milk may have contributed to improving the textural properties of the cheese analogues. It has been repeatedly reported that the use of different types of gum reduces the hardness of cheese. Lashkari et al. (2014) showed that the addition of guar gum reduced the hardness of low-fat Iranian white cheese due to the increased moisture-to-protein ratio, and at high concentrations of guar gum the cheese texture became very soft and its protein matrix decomposed. Shendi (2017) reported that increasing guar gum concentration in low-fat Iranian white cheese decreasing the hardness but high concentrations made cheese hard texture; it was because of viscosity increase due to this gum's performance in high concentration and increase of structural bonds. Similar results were obtained by Hesarinejad et al. (2021).

TABLE 3. Texture parameters values of sheep's milk cheese analoguesfortified with milk protein concentrate and different levels of carbohydrates along with guar gum.

Treatments	Texture parameters				
	Hardness N	Cohesiveness (B/A area)	Springiness Mm	Gumminess N	Chewiness N/m
Control*	3.69^{g}	0.485^{bc}	0.648^{b}	1.790^{de}	1.160^{e}
MPC 3.0%	5.68^{c}	0.585^{a}	0.683^{a}	3.323^{b}	2.269^{a}
MPC 3.0% + CS 1%+ 0.03% GG	6.86^{b}	0.530^{ab}	0.592^{c}	3.636^{a}	2.152^{b}
MPC 3.0% + CS 2%+ 0.03% GG	6.95^{a}	0.524^{b}	0.582^{c}	3.642^{a}	2.120^{b}
MPC 3.0% + CS 3%+ 0.03% GG	7.00^{a}	0.499^{b}	0.554^{d}	3.493^{ab}	1.935^{c}
MPC 3.0% + MD 1%+ 0.03% GG	5.17^{d}	0.531^{ab}	0.525^{e}	2.745^{c}	1.441^{d}
MPC 3.0% + MD 2%+ 0.03% GG	4.32^{e}	0.441^{cd}	0.520^{e}	1.905^{d}	0.991^{f}
MPC 3.0% + MD 3%+ 0.03% GG	4.11^{f}	0.401^{d}	0.516^{e}	1.648^{e}	0.850^{g}

Control*: Cheese made from sheep's milk without any additives

The values with different superscript letters within the same column are significantly different (p ≤ 0.05).

Sensory properties of cheese analogues

The data in Table 4 showed that scores of all sensory attributes of cheese analogues decreased significantly ($P \leq 0.05$) with the addition of MPC, possibly due to higher protein-to-fat ratios and lower fat content. Fat is responsible for many of the desirable functional, textural and sensory properties in cheese, and its reduction alters the flavour and physical properties, reducing cheese quality (Nateghi et al., 2012). The flavor scores of the cheese analogues improved slightly with the addition of 1 and 2% cornstarch but decreased as the addition increased to 3% (Table 4). This is probably due to the slightly starchy taste of cornstarch. Basiony and Hassabo (2022) reported that when modified corn starch was used as a fat replacer in low-fat halloumi cheese, flavor scores decreased as the starch level increased. Meanwhile, the flavor scores of the cheese analogues increased as the maltodextrin addition level increased to 3% (Table 4). According to the panelists' evaluation, cheese analogues produced with the addition of maltodextrin had a better flavor than those made with the addition of cornstarch. This may be because maltodextrin has a bland, slightly sweet taste.

However, the addition of cornstarch and maltodextrin, especially at higher levels, significantly ($P \leq 0.05$) improved body and texture scores for the cheese analogues (Table4). There is some evidence that casein–starch interactions prevent retrogradation of starch and improve processability in reduced-fat cheese. Starch acts as a filler compound in the protein matrix and leads to an increase in gel strength, which is consistent with the results of the texture analysis Diamantino et al. (2019). Iakovchenko and Arseneva (2016) reported that the addition of tapioca maltodextrin in natural low-fat cheese improved texture and acceptability compared to low-fat cheese without maltodextrin. Similar results were also reported by Nazari et al. (2020) who used maltodextrin as a fat replacer in low-fat UF-feta cheese. The color and appearance scores of the cheese decreased significantly ($P \leq 0.05$) with the addition of MPC, but the color of cheese analogues improved significantly ($P \leq 0.05$) with the addition of both types of starch, especially at higher levels (Table 4). This may be because MPC is grayish-white, while both types of starch are white (Suthar et al., 2017). The overall acceptability scores for the cheese analogues increased significantly ($P \leq 0.05$) with increasing levels of addition of both types of starch, up to 2% with the addition of cornstarch and to 3% with the addition of maltodextrin, compared to cheese made only with the addition of MPC (Table 4).

The functionality of maltodextrin is slightly different from that of native starch because maltodextrin is a hydrolyzed product and therefore does not have a globular structure. However, maltodextrin's strong ability to retain water gives it the ability to form hydrogels in food systems. The characteristic of maltodextrins to reproduce fat-like mouthfeel presumably originates from three-dimensional network built by maltodextrin when gelled. The irregular maltodextrin microgel aggregates are 1-3 μm in diamete (Peng and Yao, 2017). Interestingly, they closely resemble sheep milk fat globules in diameter, making them well dispersed, which contribute to their fat-like behaviors and homogeneous properties. On the other hand, guar gum added in our study likely has a role in improving different sensory attributes of cheese analogues. Rashidi et al. (2015) reported that a mixture of guar and xanthan gum, generally improved the texture, appearance and total acceptance score of low-fat UF feta cheese, but the effect on taste score was not significant. As the storage period progressed, the flavor, texture, appearance, and color scores of all cheese samples increased significantly (P 0.05), mainly due to the development of sensory attributes of cheese through various biochemical changes with the progression of the storage period. These results are consistent with those of Basiony and Hassabo (2022)

Conclusion

This study concluded that simultaneous partial replacement of casein and fat in cheese analogues by adding MPC and CS or MD with GG achieved substantially the same sensory properties as the control cheese with a significant increase in yield. Therefore, using both types of starch would not only be a healthier option as a replacer for protein and fat, but would also reduce the cost of producing sheep milk cheese analogues and meet the demands of consumers.

TABLE 4. Sensory properties of sheep's milk cheese analogues fortified with milk protein concentrate and different levels of carbohydrates along with guar gum during refrigerated storage

Attributes	Storage period (days)	Control*	Treatments						
			MPC3	MPC-CS1	MPC-CS2	MPC-CS3	MPC-MD1	MPC-MD2	MPC-MD3
Flavour (50)	1	34.7^{Ae}	31.4^{Be}	32.2^{ABd}	31.7^{Bd}	28.7^{Cd}	32.0^{Bd}	32.6^{ABe}	33.1^{ABc}
	15	38.0^{Ad}	35.6^{Bd}	34.7^{Bc}	35.8^{Bc}	33.0^{Cc}	34.4^{BCd}	36.1^{Ad}	37.7^{Ab}
	30	41.3^{Ac}	39.6^{BCc}	40.0^{ABab}	38.2^{Db}	37.3^{Eb}	37.2^{Ec}	39.7^{BCc}	39.3^{Cb}
	45	45.9^{Ab}	43.0^{Bb}	42.9^{Ba}	42.3^{BCa}	39.7^{Da}	42.0^{Cb}	43.0^{Bb}	42.5^{BCa}
	60	48.3^{Aa}	46.8^{Ba}	45.1^{Da}	43.5^{Ea}	40.3^{Fa}	45.6^{CDa}	46.4^{BCa}	42.8^{Ea}
Body & Texture (35)	1	29.3^{Ac}	26.6^{Cc}	26.8^{Cd}	28.3^{Bc}	29.0^{Ac}	27.9^{BCc}	28.1^{Bd}	29.5^{Ab}
	15	30.5^{Abc}	26.9^{Cc}	28.2^{BCcd}	29.4^{ABc}	30.6^{Abc}	28.7^{Bbc}	29.5^{ABcd}	30.0^{Ab}
	30	31.5^{Aab}	28.0^{Cb}	29.5^{Bbc}	30.6^{ABbc}	31.3^{Aab}	29.6^{Bbc}	30.7^{ABbc}	31.2^{Ab}
	45	32.7^{Aa}	30.1^{Ca}	31.3^{Bab}	32.2^{ABab}	31.9^{ABab}	32.0^{ABa}	31.4^{Bab}	32.7^{Aa}
	60	33.1^{Aa}	30.3^{Ba}	32.0^{ABa}	33.7^{Aa}	32.4^{ABa}	32.2^{ABa}	32.9^{ABa}	33.5^{Aa}
Color & Appearance (15)	1	11.0^{ABd}	10.1^{Dc}	10.5^{Cc}	10.9^{BCd}	11.7^{Ac}	10.4^{CDe}	11.0^{ABd}	11.2^{ABd}
	15	12.4^{Ac}	10.7^{Dc}	11.1^{CDb}	11.3^{BCc}	12.2^{Ac}	11.3^{BCd}	11.9^{ABc}	12.5^{Ac}
	30	12.9^{Abc}	12.4^{ABb}	12.6^{ABa}	11.4^{Cc}	13.0^{Ab}	12.0^{Bc}	12.3^{Bbc}	12.5^{ABc}
	45	13.6^{Aab}	13.0^{ABab}	12.6^{Ca}	12.5^{Cb}	13.6^{Ab}	12.8^{BCb}	13.5^{Aab}	13.3^{ABb}
	60	14.2^{Aa}	13.5^{Ba}	13.0^{Ba}	14.0^{ABa}	14.3^{Aa}	13.7^{Ba}	13.8^{ABa}	14.0^{ABa}
Overall acceptability (100)	1	75.0^{Ad}	68.1^{Cd}	69.5^{BCe}	70.9^{BCd}	69.4^{BCd}	70.3^{BCe}	71.7^{BCe}	73.8^{ABd}
	15	80.9^{Ac}	73.2^{Dc}	74.0^{CDd}	76.5^{BCc}	75.8^{Cc}	74.4^{CDd}	77.5^{BCd}	80.2^{ABc}
	30	85.7^{Ab}	80.0^{BCb}	82.1^{BCc}	80.2^{BCb}	81.6^{BCb}	78.8^{Cc}	82.7^{ABc}	83.0^{ABc}
	45	92.2^{Aa}	86.1^{Bb}	86.8^{Bb}	87.0^{Bb}	85.2^{Ba}	86.8^{Bb}	87.9^{Bb}	88.5^{Bb}
	60	95.6^{Aa}	90.6^{BCa}	90.1^{BCa}	91.2^{Ba}	87.0^{Ca}	91.5^{Ba}	93.1^{Aa}	90.3^{Ba}

The means (n = 3) with similar capital letters in the same row (between treatments) and similar small letters in the same column (during storage) are not significantly different at $P \leq 0.05$; Control*, Cheese made from sheep's milk without additives.

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إنتاج وتقييم مشابهات جبن لبن الغنم المدعم بمركز بروتين اللبن والنشا الأصلي أو المعدل مع صمغ الجوار

أجري هذا البحث بهدف دراسة إمكانية زيادة كميات الجبن المنتجة من لبن الغنم في محاولة للتغلب على مشكلة محدودية كميات لبن الغنم المنتجة عالمياً، وذلك من خلال إنتاج بعض مشابهات جبن لبن الغنم المدعمة بمركز بروتين اللبن، وإضافة نشا الذرة أو المالتوديكسترين كبدائل للدهن والبروتين مع إضافة صمغ الجوار، وتقييم أثر ذلك على جودة مشابهات الجبن المنتجة، حيث تم تصنيع مشابهات جبن لبن الغنم بإضافة مركز بروتين اللبن بنسبة ٣ ٪ الى لبن الغنم، ثم أضيف نشا الذرة والمالتوديكسترين بشكل منفصل بمعدلات ١ و ٢ و ٣٪ مع إضافة ٠,٠٣٪ صمغ الجوار إلى معاملات النشا والمالتوديكسترين. كما تم تصنيع عينة من جبن لبن الغنم بدون أي إضافات للمقارنة. تم أخذ عينات من المنتج الطازج لتقدير التركيب الكيميائي والخصائص الريولوجية ونسبة التصافي، وتم تخزين العينات لمدة شهرين على درجة حرارة الثلاجة لتقييم التركيب الكيميائي والخصائص الحسية بشكل دوري. وقد أشارت النتائج إلى أن إضافة مركز بروتين اللبن ونشا الذرة والمالتوديكسترين وصمغ الجوار أدى إلى ارتفاع نسبة الرطوبة والكربوهيدرات مع انخفاض نسبه الدهن فى المشابهات الناتجه، بينما لوحظ زيادة معنوية في نسبة البروتين والرماد مع إضافة مركز بروتين اللبن بينما انخفضت مع زياده النسب المضافه من نشا الذرة والمالتوديكسترين. كما لوحظ أن نسبة التصافي قد زادت معنويا باضافة مركز بروتين اللبن وبزيادة النسب المضافة من نشا الذرة والمالتوديكسترين واضافة صمغ الجوار. وأظهرت نتائج الخصائص الريولوجية زيادة في قيم الصلابة مع إضافة مركز بروتين اللبن والنشا ، في حين تميل القيم إلى الانخفاض مع إضافة المالتوديكسترين وصمغ الجوار. زادت قيم التماسك والمرونة مع إضافة مركز بروتين اللبن بينما انخفضت مع إضافة كلا النوعين من نشا الذرة وصمغ الجوار مقارنة بعينة مركز بروتين اللبن. كما أشارت نتائج التقييم الحسي إلى أن مشابهات الجبن الناتجة كانت لها درجات نكهة قريبة جدًا منعينة المقارنة. أما بالنسبة للقوام والتركيب، فبإضافة مركز بروتين اللبن، انخفضت الدرجات معنويا، ولكن بإضافة نشا الذرة أوالمالتوديكسترين وإضافة صمغ الجوار، تحسنت الدرجات. والخلاصة أنه من الممكن تصنيع مشابهات جبن لبن الغنم ذات خصائص حسية وانتاجية جيدة مع تكلفه اقل نسبيا عن طريق إستبدال الكازين والدهون بإضافة مركز بروتين اللبن، ونشا الذرة أوالمالتوديكسترين.