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Effect of Diacetyl Tartaric Esters of Monoglycerides and Sodium Stearoyl Lactylate Emulsifiers on Dough and Bulk Bread Properties

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A B S T R A C T

To improve the quality, bioavailability of nutrients, texture, and shelf life of breads, it can be suggested to add emulsifiers to the formulation. To determine the optimal amount of emulsifier addition, bulk breads (McDonald's) were baked with 0.1, 0.3, and 0.5% Sodium Stearoyl Lactylate (SSL) and diacetyl tartaric esters of monoglycerides (DATEM) emulsifiers. Dough Farinograph and chemical tests, including moisture, ash, fiber, and protein content of bread samples, were performed according to standard methods. Finally, tests were conducted to determine the staleness and water activity of the samples at 24-hour intervals over a 3-day period. In the bread samples produced, the increase in the amount of emulsifiers did not significantly affect the fat and protein content; however, their effect was significant on the fiber, ash, and moisture content of the samples, resulting in a significant increase in each of these parameters with the addition of emulsifiers. In general, it can be claimed that the rise of SSL and DATEM emulsifiers has caused an increase in energy, water absorption, formation time, dough expansion, stability, and loosening, ultimately affecting the quality of the Farinograph. In addition, the hardness of the breads decreased as the emulsifier rates increased, and the resulting breads with higher emulsifiers had less texture hardness compared to the control sample ($P < 0.05$). Increasing the emulsifier rate increased the water activity of the samples significantly. Samples containing 0.5% DATEM and 0.5% SSL yielded the best results among treatments.

Keywords: Bread, Emulsifier, Staleness, Water activity, SSL, DATEM

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1. Introduction

Designing functional foods fortified with nutraceuticals is a key focus of modern food science, aiming to enhance human health and well-being. However, many nutraceuticals have low water solubility and poor physicochemical stability, which makes it challenging to incorporate them into food matrices. Moreover, nutraceuticals may also have a low bioavailability after oral administration because they can either precipitate or chemically degrade, and/or might not be absorbed in the gastrointestinal tract. Numerous strategies have been developed and applied to encapsulate and deliver nutraceuticals. Emulsions are a kind of colloid delivery system where one phase is dispersed into another immiscible phase in the form of small droplets. These droplets have been widely used as carriers to improve the dispersibility, stability, and absorption of nutraceuticals. Many factors affect the formation and stability of emulsions, with the interfacial coating formed around the droplets by emulsifiers and other stabilizers being one of the most important. Hence, interfacial engineering principles are needed for the design and development of emulsions (Zhang et al., 2023; Valsalan et al., 2025).

As mentioned, nowadays, emulsifiers are one of the additives that are abundantly used in the production of bread and baked products (Karimi et al., 2023). Emulsifiers are used in the bread-baking industry as a dough conditioner and softener of bread crumbs. However, addition of emulsifiers to the bread formula, can be controlled the size of the gas bubbles, strengthening of the dough, increasing the gas storage capacity of the dough, increasing the softness of the bread texture, and improving the structure of the bread

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crumb, meanwhile emulsifiers are effective in delaying bread staleness speed due to their ability to form an insoluble spiral complex with starch amylose (Huang et al., 2018). Given the numerous practical characteristics of emulsifiers, including their natural varieties (such as proteins, eggs, and milk phospholipids) and the use of their artificial varieties, such as diacetyl tartaric esters of monoglycerides (DATEM), the food industry has seen significant growth (Irshad et al., 2023). The DATEM emulsifier is a type of diacetyl tartaric esters of mono- and diglycerides of fatty acids, and is essentially an oil-in-water anionic emulsifier. It improves dough elasticity, increases dough stability, and enhances bread volume, typically used at a concentration of 0.3% of the flour weight (Ibadullah et al., 2021). DATEM significantly contributes to reducing the size of gas bubbles produced in the dough, while also softening the bread texture and delaying the staling process. The anti-stiffness characteristics of the bread in DATEM can be due to changes in cell wall thickness and tension. The amount of emulsifier is also important, as a very low emulsifier rate cannot perform its duty, and an excessive amount of emulsifier can reduce the product quality (Karimi et al., 2023).

Sodium Stearoyl Lactylate (SSL) is a salt generated due to the reaction between lactic acid and stearic acid. This matter is an ionic emulsifier with high hydrophilicity, enabling the creation of highly stable oil-in-water emulsions that can withstand freezing and thawing processes multiple times. SSL is a modifier and anti-staling agent that enhances the dough's gas storage capacity. In addition, it shortens the rise time of the dough, increases the volume of the bread loaf, and also increases the strength of the dough. The complex of the SSL surfactant with starch is used to delay the retrogradation of bread and, hence, delay the bread staleness. The surfactants slow down the starch crystallization process, preventing the stiffness and staleness of the bread. SSL forms a complex not only with amylose, but also with amylopectin, and this complex reduces the stiffness of bread (Esther et al., 2017)

Considering the importance of emulsifiers in quality, this study was conducted to provide a suitable formulation for bulk bread (McDonald's) production containing DATEM and SSL emulsifiers. Investigate the effect of DATEM and SSL emulsifiers separately and together at three different concentrations on the physicochemical properties, water activity, and rheological properties of dough to select the best type of emulsifier with desirable quality characteristics for bread production.

2. Material and Methods

2-1- Sample preparation

Treatments containing different levels of DATEM and SSL emulsifiers (Pars Behbood Asia, Iran) were separately prepared. In the first step, dry matters (8% sugar, 4% salt, various rates of DATEM emulsifier and SSL (0.1, 0.3, and 0.5%), and 2% yeast) were mixed with flour. In the next step, water was added to the mixture, and after complete mixing of the flour and water, 8% of oil was added. The initial rest of the sample was performed for 10 minutes. Then, pieces of dough with an approximate weight of 650 g were made into balls, and after 10 minutes of rest, middle fermentation was conducted. Finally, the dough balls were placed in the fermentation chamber until the final fermentation stage was carried out at a temperature of 30 °C and a relative humidity of 80% for 60 minutes, and then the bread balls were inserted into an oven at a temperature of 200 °C. The baking time of the bread samples was 30-35 minutes. Breads were cooled at room temperature for half an hour and packed in polyethylene bags and maintained at room temperature until the corresponding tests were accomplished.

Table1. Treatments applied in this study

Treatment	Description
1	0.1% SSL added relative to the total weight of flour
2	0.3% SSL added relative to the total weight of flour
3	0.5% SSL added relative to the total weight of flour
4	0.1% DATEM added relative to the total weight of flour
5	0.3% DATEM added relative to the total weight of flour
6	0.5% DATEM added relative to the total weight of flour
7	0.1% DATEM & 0.1% SSL added relative to the total weight of flour
8	0.1% DATEM & 0.3% SSL added relative to the total weight of flour
9	0.3% DATEM & 0.1% SSL added relative to the total weight of flour
10	Wheat flour bread without emulsifiers, control

SSL: Sodium Stearoyl Lactylate; DATEM: Diacetyl tartaric esters of monoglycerides.

2-2- Methods

The chemical experiments performed included determination of moisture and ash content (AACC No. 16-44, AACC No. 01-08). Protein, fat, and fiber percentage (AACC No. 12-46, AACC No. 10-30, National Iranian Standard Method No. 3105), and pH test (according to National Iranian Standard No. 37) with three replications.

A Farinograph test was performed according to the AACC 5421 standard using the Farinograph device (Brabander, FE022-NK, Germany). Then, parameters such as consistency, flour water absorption, dough evolution, dough resistance time, dough tolerance, and dough quality index were calculated based on the farinogram.

To determine the texture characteristics of the bread and, in particular, to determine the shell stiffness, the device (Instron, M 350-10CT, England) was exploited using a 36-mm diameter cylindrical probe according to AACC No. 09-74. The tests were carried out at 24-hour intervals over 3 days. Two important rheological characteristics were obtained from this test: maximum force or failure force and maximum deformation or failure deformation.

Determination of water activity was conducted using a water activity meter (Novasina MS1-AW, Axair Ltd., Switzerland) based on the Stekelenburg and Labots (2007) method at 25 °C..

2-2-1- Statistical Method

To analyze the data derived from the experiments, a completely randomized design was used with three replications, and comparison of the mean values was performed by Duncan's multiple range tests using SPSS software (p-value: 0.05).

3. Results and discussion

3-1- Chemical properties of bread

The levels of fat and protein in treatments with varying percentages of DATEM and SSL emulsifiers did not show statistically significant differences. But these two emulsifiers showed statistically significant differences in fiber and ash content. According to Figure 1, the lowest ash amount was found in the control sample. Increasing the DATEM level in the samples caused a significant rise in ash content, and increasing the SSL level from 0.3 to 0.5 also significantly increased ash ($P < 0.05$). In samples containing both DATEM and SSL, the ash content increased significantly with higher levels of each ($P < 0.05$).

The results of this study agree with those of Demirkesen et al. (2010), who reported that breads with emulsifiers had higher ash content compared to the control, due to the special structure of the emulsifiers. Similarly, Hallen et al. (2004) found that as the level of emulsifiers increased in breads containing rice flour, the ash content also increased.

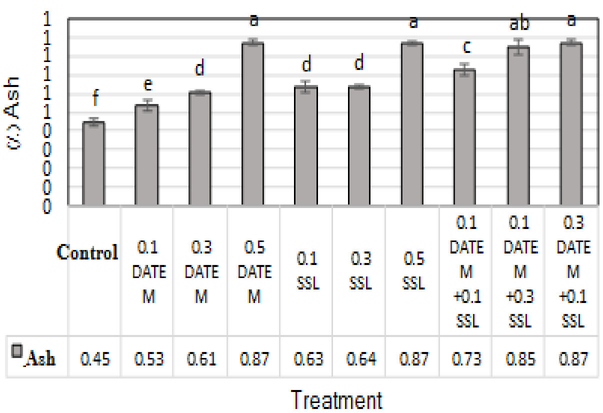

Figure1. Ash content of bread samples containing DATEM and SSL emulsifiers (Different letters indicate statistically significant differences (P<0.05)

According to the results of Figure 2, the highest fiber content was associated with the sample containing 0.5% SSL and the sample containing 0.5% DATEM, and the lowest fiber content was for the control sample. Increasing the level of DATEM and SSL each alone increased the fiber content significantly ($P < 0.05$), and the fiber content of samples containing both additives did not differ significantly ($P < 0.05$).

Moreover, increasing the usage of fiber increased the fiber content of the bread samples due to bonding with fiber and thereby preventing the fiber from dissolving in water and keeping it in the dough, and preventing it from exiting during preparation (Gomez et al., 2013).

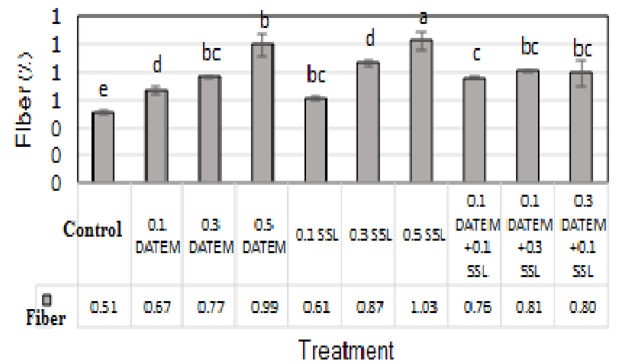

Figure2. Fiber content of bread samples containing DATEM and SSL emulsifiers (Different letters indicate statistically significant differences (P<0.05)

According to Figure 3, the lowest moisture content in treatments is related to the samples with an emulsifier rate of less than 0.3% ($P >$ 0.05). Emulsifiers allow continuous mixing of dough and also increase water absorption. Increasing the emulsifier prevents water from leaving the bread through forming a hydrogen bond with starch and absorbing on its surface, and hence increases the moisture content of the bread produced (Demirkesen et al., 2010; Alavi et al., 2023).

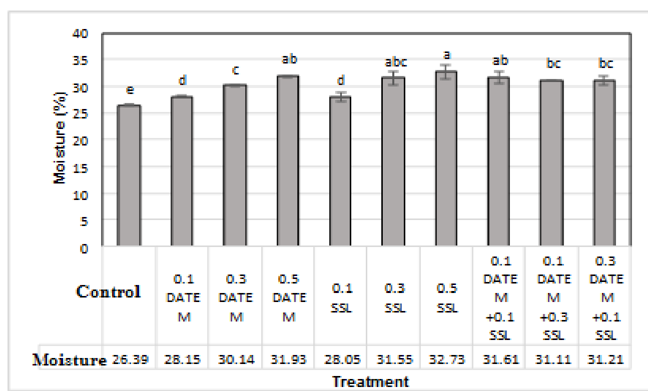

Figure3. Moisture content of bread samples containing DATEM and SSL emulsifiers (Different letters indicate statistically significant differences (P<0.05)

Based on the results obtained from Figure 4, among the bread samples containing different levels of DATEM and SSL emulsifiers, the highest texture hardness was related to the control sample, followed by the sample containing 0.1% DATEM and the sample containing 0.1% SSL, and no significant difference was observed between them ($P < 0.05$). In addition, the lowest texture hardness was associated with the sample containing 0.5% DATEM, the sample containing 0.5% SSL, and the combined sample containing 0.1% SSL and 0.3% DATEM, and vice versa. Increasing the level of DATEM and SSL alone significantly decreased the texture stiffness ($P < 0.05$).

The introduction of the emulsifier into the spiral section of the amylose chain and preventing the formation of hydrogen bonds among the various amylose chains were key factors in preventing stiffness of the product, as one of the important roles of emulsifiers is their capability to react with starch and hence prevent the occurrence of the retrogradation phenomenon and finally hardness and adhesion of the product. In a study regarding adding rice bran to Barbari bread, it was shown that high water absorption of fiber compounds prevented water loss, and, on the other hand, the reaction between fiber compounds and starch molecules retarded the retrogradation process in bread texture during the storage period (Milani et al, 2009). Moreover, in another study on the examination of the effect of isolates of soy protein and gum on the properties of muffin cake, a decrease was observed in the stiffness of the final product (Bazrafshan et al., 2015).

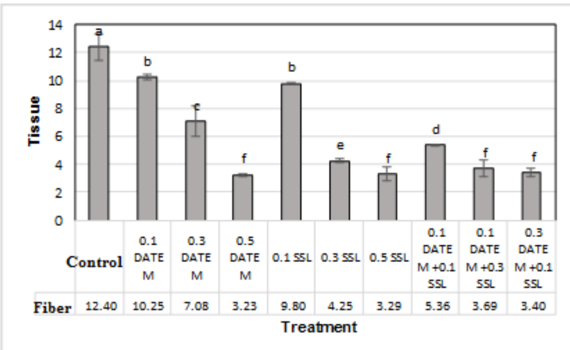

Figure4. Texture stiffness of bread samples containing DATEM and SSL emulsifiers (Different letters indicate statistically significant differences (P<0.05)

3-2- Physicochemical properties of dough

According to farinograms, the water absorption rate was also increased by increasing the percentage of emulsifiers. Accordingly, the lowest water absorption rate was observed in the control sample, and the highest absorption rates were associated with the samples containing 0.5% DATEM, the sample containing 0.5% SSL, and the combined sample containing 0.1% SSL and 0.3% DATEM, and vice versa. The dough formation time for the samples containing the DATEM and SSL emulsifiers increased with increasing emulsifier rate, and the formation time was higher in comparison to the control sample. The presence of emulsifiers and the competition of these compounds with gluten over water absorption could cause a delay in the dough reaching its highest consistency (Parsa and Mohebbi, 2023; Karimi et al., 2023). This delay also increased with an increase in the emulsifier percentage. Given the results, the samples containing DATEM and SSL emulsifiers, due to the ability to high capacity for maintaining water, increase the dough stability. Therefore, the lowest stability was for the control sample, and the highest stability was associated with the dough related to the treatments containing 0.5% DATEM emulsifier, 0.5% SSL emulsifier, and 0.1% DATEM emulsifier and 0.3% SSL emulsifier, and vice versa. The dough loosening time is related to the ability of the dough to maintain water; hence, the dough loosening time increased with increasing the amount of emulsifiers, so a longer time is required for the dough to start loosening due to mixing. In other words, the highest loosening time of the dough was for samples containing 0.5% DATEM emulsifier and 0.5% SSL emulsifier, and the samples containing 0.3% DATEM and 0.1% SSL and vice versa, in addition, the lowest loosening time was related to control samples; this could be due to increased fiber percentages, water retention capacity, and increased strength of gluten network of the dough (Majzoobi et al., 2007; Irshad et al., 2023; Parsa and Mohebbi, 2023). The Farinograph quality index, measured in newer models of Farinograph, is almost equal to the baking or volumetric value of flour and is the sum of the results of the mixing time of the dough, the stability time, and the loosening time of the dough. Taking into account the results, the initial flour had a good quality index. By adding different amounts of SSL and DATEM, the Farinograph quality was enhanced. According to the results of this study, the valoremetry number indicating the overall quality of dough was increased, and the highest degree of the farinograph quality was related to treatments containing higher SSL and DATEM levels.

Table 2. Farinograph results for bread samples containing DATEM and SSL emulsifiers

Treatment/Feature	Consistency	Water absorption (%)	Dough evolution time (min)	Resistance time	Dough loosening	Quality index
C (control)	473.00 ± 4.58^{e}	57.92 ± 2. 95^{e}	5.57 ± 0. 15^{f}	9.62 ± 0. 33^{f}	77.67 ± 1. 53^{f}	95.67 ± 1. 53^{f}
T1 (0.1 DATEM)	501.33 ± 1. 53^{d}	64.68 ± 2. 35^{d}	6.40 ± 0. 10^{e}	12.39 ± 0. 44^{e}	0.86 ± 2. 65^{ed}	112.33 ± 2. 52^{e}
T2 (0.3 DATEM)	541.00 ± 2^{b}	74.78 ± 3. 02^{b}	8.37 ± 0. 15^{c}	15.47 ± 0. 28^{c}	96.33 ± 2. 08^{c}	135.67 ± 1. 53^{c}
T3 (0.5 DATEM)	554.33 ± 1.53^{a}	83.96 ± 3. 02^{c}	10.30 ± 0. 1^{a}	18.18 ± 0. 23^{a}	132.33 ± 4. 16^{a}	165.67 ± 2. 18^{a}
T4 (0.1 SSL)	502.67 ± 3. 79^{d}	64.01 ± 1. 4^{d}	6.62 ± 0. 2^{e}	12.72 ± 0. 66^{e}	81.33 ± 1. 59^{fe}	114.33 ± 2. 08^{e}
T5 (0.3 SSL)	542.67 ± 1. 53^{b}	75.78 ± 0. 69^{b}	8.03 ± 0. 57^{c}	15.81 ± 0.86^{cb}	97.00 ± 1^{c}	137.00 ± 1^{c}
T6 (0.5 SSL)	552.67 ± 1. 53^{a}	83.33 ± 0. 77^{a}	10.63 ± 0.59^{a}	17.84 ± 0. 46^{a}	130.33 ± 3. 06^{a}	167.33 ± 2. 08^{a}
T7 (0.1 SSL+0.1 DATEM)	524.33 ± 3. 21^{c}	68.55 ± 0. 62^{c}	7.29 ± 0. 33^{d}	14.36 ± 0. 48^{d}	93.00 ± 2^{dc}	122.67 ± 3.79^{d}
T8 (0.3 SSL + 0.1 DATEM)	521.00 ± 1^{a}	80.58 ± 0.9^{d}	9.28 ± 0. 13^{b}	16.56 ± 0. 22^{b}	111.33 ± 1. 15^{b}	153.33 ± 3.06^{b}
T9 (0.1 SSL + 0.3 DATEM)	552.67 ± 2. 52^{a}	80.84 ± 0.58^{a}	9.61 ± 0. 19^{b}	17.63 ± 0. 68^{a}	112.33 ± 1. 453^{b}	152.00 ± 1^{b}

(Different letters indicate statistically significant differences (P < 0.05))

3-3- Physicochemical properties of bread during storage

As presented in Figure 5, the water activity has increased with the increase in the DATEM and SSL levels alone. The highest rates of water activity were observed for the sample containing 0.5% DATEM, the sample containing 0.5% SSL, and combined samples containing 0.3% DATEM and 0.1% SSL, and vice versa. In addition, the lowest levels of water activity were associated with the control sample as well as the sample containing 0.1% SSL. Figure 5 indicates the water activity of the samples over time. According to the figure, it is clear that with the passage of time, the water activity has decreased significantly in all treatments ($P < 0.05$). The highest level of activity was observed for the sample containing 0.5% DATEM and the sample containing 0.5% SSL in the first 24 hours. This is because emulsifiers improve wettability and help maintain moisture during storage, and show this ability well, for example, in products like bulk breads, and this moisture preservation is also very effective in softening the bread crumb, and this property of emulsifiers can be associated with their high ability to bond with water molecules. In 2021, Mohamed stated that the rate of loss of cake moisture during the baking process depended on the nature of the active surface materials used in the product; hence, using these compounds, the final product, such as cake, benefited from a higher moisture and water activity, and maintaining such an amount of moisture would be higher during the storage period.

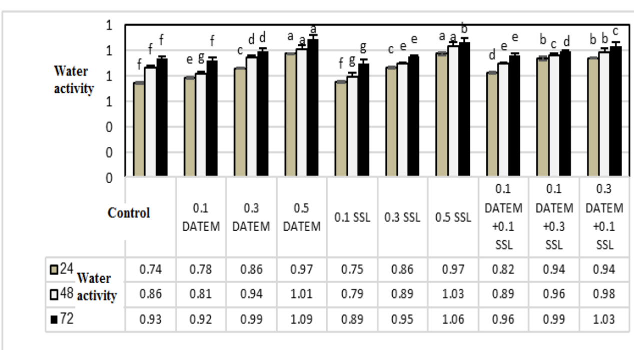

Figure5. Water activity of bread samples containing DATEM and SSL emulsifiers during storage by 24h intervals (Different letters indicate statistically significant differences (*P*<0.05))

Increasing the amount of DATEM and SSL alone, the staleness rate diminished. The lowest staleness rates were for the sample containing 0.5% of DATEM and the sample containing 0.5% SSL, as well as combined samples containing 0.3% of DATEM and 0.1% of SSL and vice versa. Similarly, the highest rate of staleness was observed for the control sample and which contained 0.1% DATEM, and the sample that contained 0.1% SSL. Figure 6 illustrates the staleness of samples with time. In 2018, Ai et al. reported that the anti-staling properties of emulsifiers were thanks to their ability to form an insoluble spiral complex with amylose and prevent it from leaking into the inter-granular space, and also their limited reaction with starch amylopectin; such complexes postpone starch retrogradation. The decrease in the staleness of bread samples containing emulsifiers was due to the presence of the DATEM and SSL emulsifiers, which were effective in increasing the elasticity of these breads compared to the control samples (Yesil and Levent, 2022; Gomez-Ruffi et al., 2012). Moreover, the performance of the DATEM and SSL emulsifiers as a softening agent of the bread crumb was completely dependent on their reaction with starch, especially amylose and amylopectin molecules. Therefore, the crumb of the bread containing emulsifiers is more softened compared to that of the control breads, which is consistent with the results of the study by Karimi et al. (2023) and Parsa and Mohebbi (2023), stating that the use of DATEM caused a decrease in the staling rate of bread samples produced.

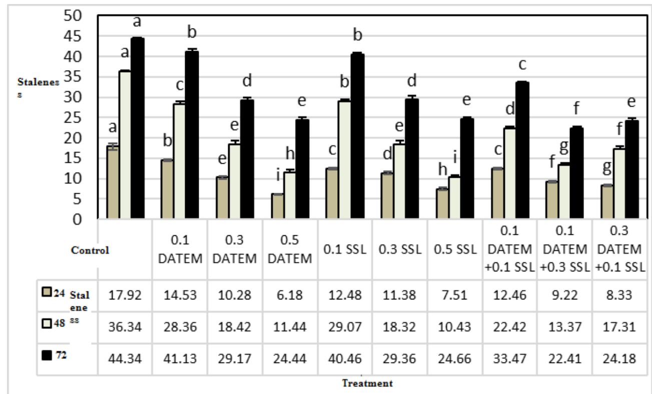

Figure6. Staleness rate of bread samples containing DATEM and SSL emulsifiers during storage at 24h intervals (Different letters indicate statistically significant differences (*P*<0.05)

4. Conclusion

To improve the quality, bioavailability of nutrients, texture, and shelf life of breads, the use of emulsifiers can be suggested. Among the emulsifiers used in this field are sodium stearoyl lactylate and diacetyl tartaric esters of monoglycerides, which were used separately and together in this study to improve the characteristics of McDonald's voluminous bread.

The best amount of emulsifiers SSL and DATEM, according to the results of dough and bread, especially the evaluation of texture and staleness, is 0.5% DATEM or 0.5% SSL and the combined sample contains 0.1% SSL and 0.3% DATEM, and vice versa.

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