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PREPARATION OF MICROENCAPSULATED FERROUS SULPHATE AND ITS USE FOR IRON FORTIFICATION OF YOGHURT

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ABSTRACT

A method was developed to prepare two forms of microencapsulated mixture of ferrous sulphate and ascorbic acid. In the first form, the mix was coated with sodium alginate (MFS), and in the second the mix was coated by two layers of lecithin and sodium alginate (MLFS). The stability of these two forms of microencapsulated iron was examined under different processing conditions and in artificial gastric juice and bile solution. Yoghurt milk was fortified with different iron sources namely; ferrous sulphate (FS), MFS and MLFS to give 0, 4, 7 and 10 mg iron/100 g of yoghurt. The activity of yoghurt starter as will as lipid oxidation and sensory characteristics of the resultant yoghurt were followed during cold storage.

Results showed that MLFS was stable to salt, sugars, heat treatment (80 or 90°C/10 min) and acidity (up to pH 4 for 7 days) as compared with MFS. The oxidative stability of butter oil containing encapsulated iron especially MLFS was higher than that containing FS. Microencapsulated iron decomposed with bile salt and exhibited lower stability at pH 1.5 than at pH 3 during exposure to artificial gastric juice. The activity of yoghurt starter was not affected by the concentration or the source of iron. No significant increases in P.V and TBA were found in yoghurt containing microencapsulated iron as compared with FS fortification. Microencapsulated iron had no significant effect on sensory properties of yoghurt, while non-encapsulated iron (FS) caused significant increase in oxidized and metallic flavour of yoghurt.

INTRODUCTION

Iron is an integral component of hemoglobin, myoglobin, the cytochromes, catalase, peroxidase, and several enzyme systems. As a part of these heme complexes and metalloenzymes, iron serves important functions in oxygen transport, cellular respiration and protects against oxidant stress (Bender and Bender, 1997).

Iron deficiency anemia is still the most prevalent nutritional problem, which affects 30% of the world's population. Infants and children, adolescents, pregnant women, women at child bearing age, and the elderly are the population groups most vulnerable to iron deficiency. This deficiency causes more than half the maternal deaths in the world and retardation of physical growth and depresses academic achievement in language and reading skills of young students, as well as reduced work capacity, and exacts a high economic burden on society (Juneja *et al.*, 2004).

It is estimated that up to half of all anemia is caused by dietary iron deficiency. Oral iron supplementation, fortification, diet modification and health services are the most important approaches to combat iron deficiency anemia as recommended by international organizations (Stephenson, 1995). Fortification of daily foods to obtain the recommended daily dietary allowances for iron (15 mg) is one of the most effective solutions.

Fortification with iron is technically more difficult than with other nutrients because iron reacts chemically with several food ingredients. The most common iron fortification compounds can be classified into three groups according to solubility, namely; water-soluble (group 1), poorly water-soluble (group 2) and insoluble form (group 3). The freely water-soluble iron (e.g. ferrous sulphate, ferrous gluconate, ferrous lactate) have high bioavailability. However, it has a catalytic action on the oxidative reactions of the fatty acids, vitamins and amino acids. Consequently, it enhances lipid rancidity, which may alter the sensoryl properties and decrease the nutritive value of food. Poorly water-soluble iron but soluble in diluted acids (e.g. ferrous fumarate, ferrous succinate) has good bioavailability, but they can be used only in solid dehydrated food. The free fraction of iron in this group interacts with some constituents of food to decrease its nutritional value and alter its sensory characteristics. The water-insoluble iron or poorly soluble in diluted acids (e.g. ferric orthophosphate, ferric pyrophosphate) has very low bioavailability, but they do not change the sensory properties or nutritional value of the food (Boccio *et al.*, 1996).

Therefore, the ideal iron compound for food fortification should be one that supplies highly bioavailable iron, and in the mean time does not affect the nutritional value or sensory properties of the food, and should be stable during food processing, and of low cost, in order to be accessible for the whole population (Boccio *et al.*, 1996).

In recent years, a new procedure was developed that allows the production of iron compounds that characterized by the desirable properties mentioned above. These compounds such as iron-milk protein complexes; iron-bis glycine chelate; microencapsulated iron by use of phospholipids or fatty acid ester; and super-dispersed ferric pyrophosphate (SDFe) (Zhang & Mahoney, 1989; Layrisse *et al.*, 2000; Lysionek *et al.*, 2000; Kwak & Yang, 2002; Juneja *et al.*,2004 and Zlotkin, 2004).

Milk and dairy products are poor in iron content. Therefore, they are attractive food vehicles for iron fortification, since; they are popular food preferred by population and especially by children for their good palatability. Some studies have been carried out on iron fortification of different dairy products such as Cheddar cheese (Zhang and Mahoney,1989), processed cheese (El-Sayed *et al.*, 1997), yoghurt (Hekmat & McMahon, 1997 and Mehanna *et al.*, 2000), and milk for school children (Virtanen *et al.*, 2001). Two major off-flavour have been associated with iron fortification of dairy products namely; oxidized and metallic flavour.

Therefore, the aim of the present paper was to prepare highly-bioavailable ferrous sulphate-containing microcapsule by use of lecithin and/or sodium alginate to avoid the interaction and the undesirable changes that happen when non-encapsulated ferrous sulphate is added.

MATERIALS AND METHODS

Materials:

Fresh buffalo's milk was obtained from Cairo University herd. Ferrous sulphate, soy lecithin and sodium alginate were obtained from Loba Chemie - India, Degussa-Turkia and MIFAD-Egypt, respectively. Yoghurt starter

YC-380 consisting of *Streptococcus thermophilus* and *Lactobacillus delbrueckii subsp. bulgaricus* (1:1) was obtained from Chr. Hansen's, Copenhagen, Denmark. Kit for determining the iron was obtained from Bio-diagenostic Co., Egypt.

Methods:

Preparation of microencapsulated ferrous sulphate:

The methods of Kwak & Yang (2002), Zlotkin (2004) and Sheu & Marshall (1993) were adopted for encapsulating the ferrous sulphate. Microencapsulation was performed by mixing 6.6 g ferrous sulphate and 2.0 g ascorbic acid without or with 12 g lecithin at 50°C and stirred at 200 rpm for 5 min, then one part of each mix was mixed with four parts of sodium alginate solution (3%). One part of the mixture (10 ml) was then added drop-wise to 5 parts of corn oil (50 ml in an 250 ml beaker) containing tween-80 (0.1%), and stirred at 200 rpm by magnetic stirrer. Within 10 min, a turbid emulsion was obtained. Calcium chloride (0.05 M) was added quickly to the beaker until the water/oil emulsion was broken. Calcium-alginate encapsulated beads containing ferrous sulphate were formed within 10 min. The microcapsules were collected by gentle centrifugation (350 xg for 10 min) and washed with distilled water using the same centrifugation conditions, and stored at 4°C until used.

The iron content of MFS was 9 mg of Fe/g, while that of MLFS was 19 mg of Fe/g as determined by the bio-diagnostic kit.

Determination of iron content in prepared microcapsules:

The entrapped ferrous sulphate was released completely from the microcapsules by gentle shaking in 0.1 M phosphate buffer (pH 7.5) for 10 min (Sheu and Marshall, 1993). Free-iron concentration was determined colorimetrically by Bio-diagenostic kit (Varley, 1975).

Stability of microencapsulated ferrous sulfate:

1. Heat stability:

Five milligrams of iron in the form of microencapsulated ferrous sulphate in sodium alginate (MFS) or in lecithin and sodium alginate (MLFS) were mixed with 100 ml distilled water, and heat treated at 80 and 90°C for 10 min. After cooling, each sample was centrifuged at 3000xg for 10 min and the free-iron concentration was determined colorimetrically in the supernatant by Bio-diagenostic kit.

2. The stability with salt and sugars:

Ferrous sulphate (FS), MFS and MLFS (5 mg iron) were mixed with 100 ml distilled water, 5% salt solution, and 10% sucrose or lactose solution, respectively. After 0,1 and 7 days of storage at room temperature, each sample was centrifuged at 3000xg for 10 min and absorbance of the supernatant was measured at 535 nm with Jenway 6300 spectrophotometer (U.K).

3. Acid stability:

MFS and MLFS (5 mg iron) were added to sterile distilled water adjusted to pH 6.8, 6, 5 and 4 using lactic acid, followed by storage for 7 days

at 4°C. Samples were taken at 0, 1 and 7 days; each sample was centrifuged at 3000xg for 10 min and the free-iron concentration was determined colorimetrically in the supernatant by Bio-diagenostic kit.

4. Oxidation degree:

FS, MFS and MLFS (5 mg iron) were mixed each with 100 g butter oil, then incubated at 63±1°C for 14 days to determine their effect on the oxidative stability of butter oil (Thamson, 1960). The peroxide (AOAC, 1990) and thiobarbituric acid (Keeny, 1971) values were determined at regular intervals.

5. Sensory evaluation:

Sensory evaluation tests for unpleasant flavours were conducted by 10 panelists on 5% glucose solution containing 5 mg iron in the form of FS, MFS and MLFS (Juneja *et al.*,2004).

6. The stability in artificial gastric juice and bile solution:

The artificial gastric juice was prepared by suspending pepsin (3 gl^{-1}) in saline (0.5 %) and adjusting the pH to 1.5 and 3 with 12 N HCl. To prepare bile solution, oxgall (Oxoid, U.K) was used to prepare 0.3% concentration of bile. All solutions were mixed with MFS or MLFS as 5 mg iron/100 ml. While such solutions are kept at 37°C for 90 min, the amount of the released iron was measured (Kwak and Yong, 2000).

Yoghurt manufacture and analysis:

Yoghurt milk samples were supplemented with FS, MFS and MLFS to give 0, 4, 7, and 10 mg iron/100 ml. All milk samples were heated at 90°C/10 min, cooled to 42°C, inoculated with yoghurt starter and incubated at the same temperature until complete coagulation. The activity of yoghurt culture was followed during fermentation period of 180 min. The resultant yoghurt was analyzed when fresh and after storage for 7days in refrigerator (4±1°C). This included determination of acidity, fat and total solids (Ling, 1963), pH using pH meter (Inolab pH 720, Germany), total volatile fatty acids (TVFA) (Kosikowski, 1978), and organoleptic evaluation as given by El-Shibiny *et al.* (1979).

Yoghurt samples were stirred and centrifuged at 10000 xg for 15min to separate fat layer, then melted at 55°C and the clear butter oil layer was carefully decanted. Separated fat was immediately analyzed for their P.V and A.V (AOAC, 1990) and TBA (Keeney, 1971).

RESULTS AND DISCUSSION

Stability of microencapsulated ferrous sulfate:

1. Heat stability:

Table (1) shows that the 13.4 and 17.8% iron were released at 90°C/10 min from MLSF and MSF, respectively; which was more than the amount released at 80°C/10 min. Therefore, the two forms of microencapsulated iron can be considered heat-stable especially MLFS. These results are partly in agreement with Juneja *et al.* (2004), who found that super-dispersed ferric pyrophosphate with lecithin (SDFe) was heat-stable which released no free iron.

Table (1): Heat stability of microencapsulated iron

Iron sources	Amount of iron released from capsules (mg)			
	80°C/10 min		90°C/10 min	
	mg	%	mg	%
MFS	0.56	11.2	0.89	17.8
MLFS	0.45	9.0	0.67	13.4

sources were added as 5 mg Fe/100 ml water.

2. The stability with salt and sugars:

Data presented in Table (2) indicate that the iron was reactive with NaCl or sugars but the rate of reaction was slower with sugars than NaCl. MFS was quite stable while MLFS was stable with salt and sugars compared with FS.

Table (2): Stability of microencapsulated iron with salt and sugars

Iron sources	Storage period (days)	O.D. at 535 nm			
		Water	Salt (5%)	Sucrose (10%)	Lactose (10%)
FS	0	0.013	0.015	0.014	0.016
	1	0.036	0.064	0.052	0.044
	7	0.177	0.291	0.259	0.231
MFS	0	0.010	0.010	0.009	0.010
	1	0.018	0.032	0.027	0.023
	7	0.052	0.097	0.083	0.063
MLFS	0	0.010	0.009	0.009	0.009
	1	0.012	0.019	0.017	0.017
	7	0.025	0.048	0.033	0.030

Iron sources were added as 5 mg Fe/100 ml solution.

3. Acid stability:

As for acid stability of microencapsulated iron, data in Table (3) show that the pH had a slight effect on the release of iron from the capsules after one day of storage at 4°C (less than 18% at pH 4.0). A 7-days storage at 4°C resulted in release of more iron, being 49 and 37.8% at pH 4.0 from MFS and MLFS, respectively. Also, Table (3) shows that the amount of iron released at pH 4.0 was more than that released at pH 6.8 of both iron forms (MSF and MLSF).

Table (3): Effect of acid on release of entrapped iron from encapsulated beads

Iron sources	Storage period (days)	pH							
		6.8		6.0		5.0		4.0	
		Released iron amount							
		mg	%	mg	%	mg	%	mg	%
MFS	0	0.0	0.0	0.0	0.0	0.05	1.0	0.1	2.0
	1	0.56	11.2	0.67	13.4	0.78	15.6	0.89	17.8
	7	1.67	33.4	1.78	35.6	1.89	37.8	2.45	49.0
MLFS	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1	0.34	6.8	0.34	6.8	0.45	9.0	0.56	11.2
	7	1.22	24.4	1.34	26.8	1.67	33.4	1.89	37.8

Iron sources were added as 5 mg Fe/100 ml solution.

These results can be attributed to the addition of an acidulant which accelerated the solubility of calcium salts being released from calcium alginate beads (Onsqyen, 1997).

4. Oxidation degree:

Table (4) records the oxidation degree of butter oil as affected by microencapsulated iron. Peroxides and TBA values increased during the 14 days in all tested samples. On day 14 of incubation of butter oil, P.V and TBA values of control, FS, MFS and MLFS containing samples were 18.66 & 0.088; 30.97 & 0.132; 24.74 & 0.115; and 21.57 & 0.096, respectively. From the test results, it is seen that the P.V and TBA values of butter oil containing encapsulated iron was lower than that of butter oil containing non-encapsulated iron. These results are partly in agreement with Kwak and Yang (2002), who found that the TBA values of non-encapsulated iron-containing milk was much higher than that of encapsulated iron-containing milk, encapsulated iron was prepared by using fatty acid ester.

Table (4): Peroxide and TBA values of butter oil containing microencapsulated iron during stability oven test at 63 ± 1°C

Incubation period (days)	Iron sources							
	Control[1]		FS		MFS		MLFS	
	P.V	TBA	P.V	TBA	P.V	TBA	P.V	TBA
0	2.93	0.004	2.93	0.005	2.93	0.004	2.93	0.004
2	2.96	0.005	3.12	0.011	3.00	0.009	3.00	0.007
4	3.15	0.012	3.72	0.019	3.51	0.016	3.32	0.013
6	3.62	0.022	4.05	0.031	3.94	0.026	3.71	0.024
8	4.05	0.029	5.15	0.041	4.81	0.035	4.43	0.032
10	6.77	0.038	11.81	0.062	8.93	0.049	7.31	0.043
12	11.03	0.054	19.11	0.091	16.13	0.070	13.98	0.061
14	18.66	0.088	30.97	0.132	24.74	0.115	21.57	0.096

(1) Without iron
Iron sources were added as 5 mg Fe/100 ml butter oil.

5. Sensory evaluation:

Results in Table (5) show that MLFS developed no off-flavour compared with other iron sources. This may be attributed to MLFS is a ferrous sulphate stabilized by vitamin C and protected by soy lecithin and calcium alginate.

Table (5): Sensory evaluation of different iron solutions [1]

Iron sources	Evaluation [2]
FS	3.6
MFS	2.4
MLFS	1.0

(1) 5 mg Fe/100 ml 5% glucose solution
(2) 1: no iron flavour and taste **2: iron flavour and taste**
3: strong iron flavour and taste **4: extremely strong iron flavour and taste**

6. The stability in artificial gastric juice and bile solution:

In order to investigate the stability of microencapsulated iron in stomach, microcapsules were exposed to artificial gastric juice at pH 1.5 and 3.0, which like the stomach pH when fasting and after eating; respectively. As

the results in Table (6), the amount of iron released at pH 1.5 was more than the amount released at pH 3.0 for both iron forms (MFS & MLFS). Also, the amount of released iron increased with the increase of time exposure being at a higher rate with MFS than that of MLFS at both pH 1.5 and 3.0. These results are partly in agreement with Kwak and Yang (2002). Commonly, microencapsulated iron is eaten, together with foods, so that iron release by acid is small.

After passage of the capsules through the acidic stomach conditions, it is important that, they are stable to the bile salt in the intestine, the normal level of which is around 0.3%. Therefore, the microcapsules were exposed to bile salt for 90 min. The results (Table 6) show that large amount of iron were released upon exposure to bile salt. At the longer exposure time, more iron was released. Absorption of iron is mostly conducted within the duodenum in the small intestine, so that encapsulated iron can be favorably released.

Table (6): Amount of iron released from capsules after 90 min exposure at 37°C to artificial gastric juice and bile salt

Iron Sources	Time exposure (min)	Released Iron amount (mg)					
		Gastric juice				Bile salt	
		pH 3.0		pH 1.5			
		mg	%	mg	%	mg	%
MFS	30	0.34	6.8	0.78	15.6	1.86	37.2
	60	0.78	15.6	1.23	24.6	2.61	52.2
	90	1.23	24.6	1.76	35.2	3.91	78.2
MLFS	30	0.22	4.4	0.56	11.2	1.68	33.6
	60	0.56	11.2	0.89	17.8	2.39	47.8
	90	0.89	17.8	1.23	24.6	3.54	70.8

Iron sources were added as 5 mg Fe/100 ml solution.

Quality of iron fortified yoghurt

1. Yoghurt starter activity

Table (7) shows the activity of yoghurt starter in yoghurt milk as affected by using microencapsulated iron with different concentrations. Iron fortification had no effect on the incubation time. All treatments reached pH 4.56 ± 0.05 after 3.0 h. In milk fortified with FS, the pH values was the highest at the end of incubation period, while the milk fortified with MLFS had the lowest pH values. Statistical analysis revealed that activity of yoghurt starter was not affected by different iron sources and different concentrations ($p < 0.05$). These results are in agreement with Hekmat and McMahon (1997) and Mehanna *et al.* (2000), who found that the activity of yoghurt starter was not affected by milk fortification with different iron sources at levels of 10 to 40 mg/kg or 20 to 60 ppm.

Further acid production at the end of storage period (Table 8) was also similar in all treatments with non-significant differences. The acidity and pH values of control and fortified samples reached 0.93 ± 0.03 and 4.28 ± 0.06, respectively after 10 days of storage.

Table (7): Effect of milk fortification with microencapsulated iron on activity of yoghurt starter during the fermentation period

Iron sources	Iron conc.[1]	pH values				
		Fermentation period (min)				
		0	60	120	150	180
Control [2]	0	6.51	6.25	5.52	5.02	4.58
	4	6.52	6.29	5.65	5.09	4.61
FS	7	6.51	6.29	5.64	5.05	4.60
	10	6.51	6.27	5.61	5.06	4.60
	4	6.50	6.25	5.63	5.09	4.54
MFS	7	6.51	6.23	5.63	5.10	4.55
	10	6.51	6.22	5.61	5.08	4.56
	4	6.52	6.19	5.53	5.00	4.52
MLFS	7	6.50	6.22	5.52	4.98	4.53
	10	6.50	6.21	5.54	4.98	4.51

(1) mg/100 ml (2) Without iron LSD = 0.137

2. Lipolysis and oxidative stability

As shown in Table (8), the TVFA, P.V and TBA values in fresh unfortified and fortified yoghurt with different sources and concentrations of iron were similar with non-significant differences between all treatments. After 10-days of storage, their values increased as increase of iron concentration of any source. The effect of MLFS fortification on lipolysis and fat oxidation of yoghurt was non-significant as compared with the control. There were also no significant differences between fortification with MLFS or MFS at different concentrations. On the other hand, the yoghurt fortified with FS had higher values of TVFA, P.V and TBA, which suggested significant effect on lipolysis and fat oxidation compared with control and yoghurt fortified with MLFS at different concentrations. This may be explained on the base that MLFS may reduce the ability of iron to participate in iron-catalyzed hydroxyl radical formation by several reasons. First, because of ascorbic acid and lecithin-containing MLFS have a great antioxidant activity.

Table (8): Chemical composition and fat stability of yoghurt [1] made from milk fortified with microencapsulated iron

Iron sources	Iron conc.[2]	pH		T.A		TVFA		P.V		TBA	
		Storage period (days)									
		Fresh	10	Fresh	10	Fresh	10	Fresh	10	Fresh	10
Control [3]	0	4.58	4.30	0.81	0.93	11.15	12.59	2.79	4.07	0.015	0.037
	4	4.61	4.33	0.82	0.90	10.75	13.35	2.87	5.79	0.015	0.053
FS	7	4.60	4.34	0.82	0.90	11.17	13.92	2.76	6.25	0.019	0.068
	10	4.60	4.34	0.81	0.91	11.24	14.73	2.80	8.04	0.019	0.074
	4	4.54	4.27	0.84	0.94	11.15	12.98	2.63	4.62	0.017	0.043
MFS	7	4.55	4.28	0.84	0.92	11.33	13.10	2.76	5.31	0.019	0.045
	10	4.56	4.29	0.83	0.92	11.33	13.20	2.80	5.71	0.017	0.046
	4	4.52	4.22	0.85	0.93	11.24	12.70	2.79	4.31	0.015	0.039
MLFS	7	4.53	4.23	0.86	0.95	11.15	12.81	2.76	4.60	0.015	0.042
	10	4.51	4.23	0.86	0.96	10.87	12.98	2.63	4.78	0.019	0.041
LSD values		0.124		0.081		0.593		1.421		0.0094	

(1) Fat = 6.8% , T.S = 15.9% (2) mg/100 ml (3) Without iron

Second, lecithin acted as chelating agent for the iron and inhibits its involvement in such redox reactions. Third, the protective role of calcium alginate. Furthermore, the high acidity of yoghurt may also reduce the formation and oxidation potency of iron hydroxides as mentioned by Hekmat and McMahon (1997).

3. Sensory characteristics

Table (9) shows the mean scores for the organoleptic properties of the unfortified and iron fortified yoghurt when fresh and during 10 days of storage. It appears from the presented data that there is no significant differences between unfortified and iron fortified yoghurt for general appearance, firmness and smoothness. There were also no significant differences based on the source of iron used or the level of iron fortification. As for wheying-off, there were no significant differences between all yoghurt samples when fresh and after 10 days of storage except yoghurt fortified with FS at level of 10 mg iron at the end of storage, which had the highest amount of wheying-off as compared with the control samples. The source of iron used for fortification had a significant effect on oxidized and metallic flavours. The panelists did not detect significant differences in the flavour among yoghurts fortified with MLFS or MFS and control when fresh and during storage. Yoghurt fortified with FS at different levels had significant increase in oxidized and metallic flavour, therefore, it gained the lowest flavour score. Our results are in agreement-in part with those given by Abd-Rabou (1994) and Mehanna *et al.* (2000), who reported that yoghurt was rejected organoleptically when ferrous sulfate (FS) was added to give 80 ppm iron.

Table (9): Sensory evaluation of yoghurt made from milk fortified with microencapsulated iron

Iron sources	Iron conc.[1]	General Appearance (10)		Firmnes (10)		Smooth-ness (10)		Wheying-off (10)		Flavour (60)	
		Fresh	10	Fresh	10	Fresh	10	Fresh	10	Fresh	10
Control [2]	0	9.2	8.8	9.0	8.7	9.3	8.0	9.5	9.1	58	56
FS	4	8.9	8.3	8.7	8.3	9.1	8.6	9.3	8.7	53	48
	7	8.9	8.1	8.7	8.3	9.0	8.5	9.3	8.5	49	44
	10	8.9	8.0	8.6	8.1	9.0	8.3	9.1	8.3	45	40
MFS	4	9.0	8.6	9.0	8.6	9.3	8.8	9.4	8.9	56	53
	7	9.0	8.6	9.0	8.5	9.3	8.8	9.4	8.9	54	52
	10	9.0	8.4	9.0	8.5	9.3	8.6	9.3	8.7	52	50
MLFS	4	9.2	8.7	9.0	8.7	9.3	8.9	9.5	9.0	58	55
	7	9.2	8.7	9.0	8.6	9.3	8.9	9.4	8.8	57	54
	10	9.2	8.6	9.0	8.5	9.3	8.7	9.4	8.7	56	53
LSD values		0.861		0.733		0.804		0.652		6.03	

(1) mg/100 ml (2) Without iron

In conclusion, the microencapsulated iron (MLFS) prepared according to the present study developed no oxidation of lipids and was stable under different processing conditions and decomposed only with bile

salt, thus increasing absorption efficiency of iron in the human body. Additionally, the microcapsules can be uniformly dispersed when added to yoghurt milk without changing yoghurt properties. Furthermore, a cup of yoghurt (120 g) fortified with 4 to 10 mg of iron/ 100 g of yoghurt would provide approximately 28 to 70% of the Food and Nutrition Board recommended daily allowance of iron.

REFERENCES

Abd-Rabou, N.M.S. (1994). "Production of Some Dietetic Dairy Products." Ph.D. Thesis, Fac. of Agric., Ain Shams Univ., Cairo, Egypt.

AOAC (1990). "Official Methods of Analysis." 15th ed. Association of Official Analytical Chemists Inc., USA.

Bender, D.A. and A.E. Bender (1997). "Nutrition a Reference Handbook." Oxford Univ. Press, pp.394.

Boccio, J.R.; M.B. Zubillaga; R.A.Caro; C.A. Gotelli; M.J. Gotelli and R. Weill (1997). "A new procedure to fortify fluid milk and dairy products with high-bioavailable ferrous sulfate." Nutrition Reviews, 55: 240.

Boccio, J.R.; M.B. Zubillaga; R.A.Caro; C.A. Gotelli; M.J. Gotelli and R. Weill (1996). "Bioavailability and stability of microencapsulated ferrous sulfate in fluid milk: Studies in mice." J. Nutr. Sci. Vitaminol., 42: 233.

El-Sayed, M.M.; N.S. Abd-Raou; A.F. Sayed and Y.A. El-Samragy (1997). "Iron fortification of processed Ras cheese." Egypt. J. Dairy Sci., 25: 289.

El-Shibiny, S.; H.F. El-Dien and A.A. Hofi (1979). "Effect of storage on the chemical composition of zabady." Egypt. J. Dairy Sci., 7: 1.

Hekmat, S. and D. J. McMahon (1997). " Manufacture and quality of iron-fortified yoghurt." J. Dairy Sci., 80: 3114.

Juneja, L.R.; N.Sakaguchi; R. Yamaguchi and H.Nanbu (2004). "Iron fortification of dairy products: A novel approach. In Handbook of Funcitional Dairy Products." Ed. C. Shortt and J. O'Brien, CRC Press, London.

Kenney, P.G. (1971). "A guide to controlling oxidation in butter and creams." Candy and Snack Industry, 136: 68.

Kosikowski, F. (1982). "Cheese and Fermented Milk Foods." 2nd printing with revisions (1978). F.V. Kosikowski and Associates, P.O. 139, Brooktondal, Ithaca, N.Y., USA.

Kwak,H. and K. Yang (2002). "Method for preparing microcapsule containing soluble iron using fatty acid ester." US Patent 6,402,997B1.

Layrisse, M.; M.N.Garcia-Casal; L.Solano; M.A.Baron; F.Arguello; D.Llovera; J.Ramirez; I.Leets and E.Tropper (2000). "Iron bioavailability in humans from breakfast enriched with iron bis-glycine chelate, phytates and polyphenols." J. Nutr., 130: 2195.

Ling, E.R. (1963). "Text Book of Dairy Chemistry." Vol. II. 3rd ed. Practical Chapman ands Hall, L.T.D., London.

Lysionek, A.E.; M.B.Zubiliaga; M.J.Salgveiro; M.I.Sarabia; R.A.Caro, R.Weill and J.R.Boccio (2000). "Study of industrial microencapsulated ferrous sulfate by means of the prophylactic-preventive method to determine its bioavailability." J. Nutr. Sci. Vitaminol., 46: 125.

Mehanna, N.M.; T.M. Saleh; A.S. Mehanna and S.M.A. El-Asfory (2000). "Composition and some properties of Zabady made from iron-fortified buffalo's milk." Egypt. J. Dairy Sci., 28: 183.

Onsqyen, E. (1997). " Alginates" In: Thickening and Celling Agents for Food, Ed. A. Imeson, Blackie Academic & Professional, London.

SAS (1994). "SAS User's Guide: Statistics, version 6.0." SAS Institute, Gary, NC.

Sheu, T.Y. and R.T. Marshall (1993). "Microentrapment of lactobacilli in calcium alginate gels." J. Food Sci., 54: 557.

Stephenson, L.S. (1995). "Possible new developments in community control of iron deficiency anemia." Nutr. Rev., 53: 23.

Thampson, S.W. (1960). "Survey of accelerated test for determining the stability of oils and fats." In Laboratory Handbook for Oil and Fat Analysis, Ed. L.V. Cooks and C. Van Reds. Academic Press, London, New York.

Varley, H. (1975). "Practical Clinical Biochemistry." 4th ed. by Arnold-Heinemann, pp.473.

Virtanen, M.A.; C.J.E. Svahn; L.U. Viinikka; N.C.R. Raiha; M.A. Siimes and I.E.M. Axelsson (2001). "Iron-fortified and unfortified cow's milk: Effects on iron intakes and iron status in young children." Acta Paediatr, 90: 724.

Zhang, D. and A. W. Mahoney (1989). "Bioavailability of iron-milk protein complexes and fortified Cheddar cheese." J. Dairy Sci., 72: 2845.

Zlotkin, S.H. (2004). "Composition comprising microencapsulated iron." US Patent 6,830,761B1.

تحضير كبسولات من كبريتات الحديدوز وإستخدامها فى تدعيم الزبادى بالحديد

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تم تصميم هذه الدراسة لتحضير صورتين من كبسولات كبريتات الحديدوز مع حمض الأسكوربيك وذلك لتدعيم الزبادى بالحديد دون حدوث تفاعل مع مكوناته. فى الصورة الأولى تم كبسلة خليط كبريتات الحديدوز مع حمض الأسكوربيك بواسطة ألجينات الصوديوم (MSF) وفى الثانية تم كبسلة الخليط بواسطة طبقتين من الليسثين وألجينات الصوديوم (MLSF). وتم إختبار ثبات هذه الكبسولات تحت ظروف تصنيعيه مختلفه وكذلك فى العصير المعدى المحضر معمليا وفى وجود أملاح الصفراء. و إستخدمت هذه الكبسولات وكذلك كبريتات الحديدوز الغير مكبسلة (FS) فى تدعيم اللبن المعد لصناعة الزبادى بالكمية التى تعطى تركيزات صفر ، ٤ ، ٧ ، ١٠ ملجم حديد/١٠٠ جم زبادى. وتم تقدير نشاط البادىء ، أكسدة الدهن ، والخواص الحسية للزبادى الناتج.

وقد أظهرت النتائج أن كبسولات الـ MLSF أكثر ثباتا من كبسولات MSF فى وجود الملح ، السكر ، المعاملة الحرارية ٨٠ أو ٩٠ °م /١٠ ق . الحموضة حتى درجة pH ٤ لمدة ٧ أيام. أما درجة أكسدة دهن اللبن المحتوى على كبسولات الحديد خاصة الـMLSF فقد كانت منخفضة مقارنة بالدهن المحتوى على الحديد الغير مكبسل (FS). وتحت ظروف الأمعاء تحللت هذه الكبسولات فى وجود أملاح الصفراء وكانت أقل ثباتا عند تعرضها للعصير المعدى عند pH ١,٥ عنه عند pH ٣. وبالنسبة للزبادى المدعم بهذه الكبسولات من الحديد والحديد الغير مكبسل قلم يتأثر نشاط البادىء ولم يحدث زيادة معنوية فى الأكسدة عند إستخدام الحديد المكبسل مقارنة بالحديد الغير مكبسل. وحسيا لم يكن للحديد المكبسل تأثير معنوى على الخواص الحسية للزبادى بينما أدى إستخدام الحديد الغير مكبسل الى زيادة معنوية فى الطعم المؤكسد والمعدنى.