

# GROWTH AND ACTIVITY OF YOGHURT CULTURE IN THE MICROENCAPSULATED IRON FORTIFIED YOGHURT

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## ABSTRACT

Food fortification is one of the most important processes for improvement of the nutrients quality and quantity in food. Using dairy foods as a vehicle for supplementing iron seems to be advantage as iron-fortified dairy foods have a relatively high iron bioavailability. The aim of this investigation is to formulate microencapsulated whey protein-chelated iron (Fe-wp) using ferrous sulphate to fortify yoghurt and to determine the TBA values and some important sensorial attributes of the developed yoghurt. During the course of the study, the influence of iron on survival of yoghurt culture, TBA values of yoghurt and sensory properties of yoghurt were studied in control, free iron and encapsulated iron fortified yoghurt. It is noticed that there was no significant ( $P>0.05$ ) difference noticed statistically in count of *Lactobacillus delbrueckii*ssp. *bulgaricus* and *Streptococcus salivarius*ssp. *thermophilus* among control and different iron fortified yoghurt treatments on a storage period of 0, 7, 14 and 21 days. Further, during storage period, the count of *Lactobacillus delbrueckii*ssp. *bulgaricus* and *Streptococcus salivarius*ssp. *thermophilus* had significantly ( $P<0.05$ ) decreased both in control and as well as in iron fortified yoghurt and thus the fortified iron did not affect the viability of yoghurt bacteria. Furthermore, the TBA values of unencapsulated iron fortified yoghurt was significantly ( $P<0.05$ ) higher when compared to control and encapsulated iron fortified yoghurt. Significant ( $P<0.05$ ) difference was observed in astringent and oxidized flavour at 0, 7, 14 and 21<sup>st</sup> day of storage between control and different treatments of yoghurt. In addition, significant ( $P<0.05$ ) difference was observed in overall preference at 0, 7, 14 and 21<sup>st</sup> day of storage between control and different treatments of yoghurt and between different storage periods. It is concluded that microencapsulated whey protein chelated iron can be added up to a level of 80 mg per litre of yoghurt without altering the sensorial attributes and aesthetic appearance.

**Keywords:** Yoghurt, Iron Fortification, Microencapsulation, Culture Survival, TBA Values, Sensorial Attributes

## I INTRODUCTION

Anemia, of which globally about half is due to iron-deficiency [1], affects women of reproductive age and young children who are particularly vulnerable due to their high physiological requirements and for young

children, given their limited ability to consume sufficient amounts of high-iron foods. Iron deficiency leads to anemia, altered mental development, decreased immunity, impaired cognitive scores. Iron deficiency anaemia is still the most prevalent nutritional problem, which affects 30 % of the world's population. In India, 79% of children between 6 and 35 months and women between 15 and 49 years of age are anaemic; inadequate intake of iron and consumption of foods low in bioavailable iron are identified as the major cause of iron deficiency anaemia [2]. This causes more than half the maternal deaths in the world [3]. Iron deficiency adversely affects the cognitive performance, behaviour, and physical growth of children, immune status, physical capacity and work performance of all age groups and increases perinatal risks for mothers and neonates [4]. Fortification of daily foods to obtain the recommended daily dietary allowances for iron (10- 15 mg for adults) is one of the most effective solutions [5]. Dairy products are widely consumed, providing high quality proteins, vitamins and minerals except iron. Lack of iron in dairy products decreases the iron density of diets when the proportion of dairy products in the diets increases, so it is logical that fortifying dairy products with iron may increase dietary iron density of the people who consume large amounts of dairy products. Of late, among the dairy products, yoghurt has been gaining widespread consumer acceptance owing to its health giving attributes. It is an excellent source of calcium and protein but as is typical of all dairy products, contains very little iron. Therefore, dairy products are logical vehicles for iron fortification because they have high nutritive values, reach target population and are widely consumed. However, iron fortification is difficult in food processing due to potential oxidized off-flavors, color changes, and metallic flavors, probably as a result of lipid prooxidation of milk fat. Hence, the ideal iron compound for food fortification should be one that supplies highly bio-available iron, does not affect the nutritional value or sensory properties of the food, should be stable during food processing, and of low cost, in order to be accessible for the whole population [6]. The bioavailability of ferrous iron, especially ferrous sulfate, is high because the solubility of ferrous iron is higher than that of ferric iron. Ferrous iron is not very stable in solution and is easily oxidised to the insoluble ferric form and hitherto several methods of stabilizing ferrous iron in solution have been investigated and Iron-protein complexes have shown high iron bioavailability similar to  $\text{FeSO}_4$ .

Keeping in mind the aforementioned technical issues, this investigation of microencapsulation of whey protein chelated iron and incorporation in the development of fortified yoghurt has been designed in such a way that it, the consumer panel shall not detect any significant differences in the appearance, mouthfeel, flavor, or overall quality between fortified and unfortified flavored yogurts at the same time the prepared yoghurt will be shelf stable during storage and will be of low cost.

## II. MATERIALS AND METHODS

### 2.1 Experimental Design

Different treatments of yoghurt were designed as detailed below.

|              |   |   |
|--------------|---|---|
| <b>PY</b>    | - | Control-without addition of iron                  |
| <b>PFSY1</b> | - | 20 mg / litre of un-encapsulated ferrous sulphate |

|              |   |   |
|--------------|---|---|
| <b>PFSY2</b> | - | 40 mg / litre of un-encapsulated ferrous sulphate                     |
| <b>MFSY1</b> | - | 20 mg / litre of encapsulated whey protein chelated ferrous sulphate  |
| <b>MFSY2</b> | - | 40 mg / litre of encapsulated whey protein chelated ferrous sulphate  |
| <b>MFSY3</b> | - | 80 mg / litre of encapsulated whey protein chelated ferrous sulphate  |
| <b>MFSY4</b> | - | 100 mg / litre of encapsulated whey protein chelated ferrous sulphate |

## 2.2 Microencapsulation of Iron by Emulsion Method

Whey protein chelated iron (Fe-Wp) was prepared by adding 8 g of ferrous sulphate into 100 ml of 20 per cent whey protein solution and heating to precipitate the complex. The precipitate was centrifuged at 8000G for 5 min: washed once with 0.25 per cent lactic acid solution and twice with deionised water. Microencapsulated whey protein chelated iron (MFe-Wp) was prepared by method of Azzam[7]. One part of Fe-Wp mixed with four parts sodium alginate solution (3 per cent). To one part of the mixture 10 ml was then added drop wise to 5 parts of sunflower oil 50 ml containing 0.1w/v tween 80 and stirred at 200 rpm by magnetic stirrer. Within 10 minutes a turbid emulsion was obtained. Calcium chloride 0.05M was added quickly to the beaker until the water oil emulsion was broken. Calcium alginate encapsulated beads containing Fe-Wp were formed within 10 min. The microcapsules were collected by gentle centrifugation (350 g for 10 min) and washed with distilled water using the same centrifugation conditions, and stored at 4°C until used.

## 2.3 Preparation of Plain Yoghurt and Iron Fortified Yoghurt

The control yoghurt (Plain yoghurt) was formulated using fresh milk incorporated with skim milk powder at the rate of 4 per cent (w/v) and sugar at the rate of 6 per cent (w/v) which was subjected to homogenization at 2500 psi. The contents were mixed well and pasteurized at 85°C for 30 minutes, cooled to room temperature and inoculated with 2 per cent of yoghurt cultures containing *Lactobacillus delbrueckii* ssp. *bulgaricus*, and *Streptococcus salivarius* ssp. *thermophilus*. It was then mixed well and incubated at 42°C for 4 to 5 hours and finally stored at 5°C. In regard to the treatment yoghurt, the encapsulated iron beads / unencapsulated iron were added separately as given in the experimental design in the respective treatments to 1 litre of mix. It was then mixed well and incubated at 42°C for 4 to 5 hours and finally stored at 4 to 5°C.

## 2.4 Preparation of Iron Fortified Yoghurt

Different lots of iron fortified yoghurt were formulated using fresh milk incorporated with skim milk powder at the rate of 4 per cent (w/v) and sugar at the rate of 6 per cent (w/v) and subjected to homogenization at 2500 psi. The contents were mixed well and pasteurized at 85°C for 30 minutes, cooled to room temperature and inoculated with 2 per cent of yoghurt cultures containing *Lactobacillus delbrueckii* ssp. *bulgaricus*, and *Streptococcus salivarius* ssp. *thermophilus*. Then encapsulated iron beads and as well as unencapsulated iron were added separately as per the treatments to 1 litre of mix. It was then mixed well and incubated at 42°C for 4 to 5 hours and finally stored at 4 to 5°C.

The formulated iron fortified yoghurt was subjected to organoleptic evaluation, TBA value and enumeration of count of yoghurt bacteria employing the procedure given by Kim *et al.*[8] and the data obtained in all the experiments were analyzed statistically by applying one way and two way ANOVA [9]

### III .RESULTS AND DISCUSSION

#### 3.1 Thiobarbituric Acid Values of Microencapsulated Iron Fortified Yoghurt

##### (Absorbance At 532 Nm)

Significantly higher values TBA were observed in unencapsulated iron fortified yoghurt (PFSY2), when compared to control and capsulated iron fortified yoghurt (IFY) treatments (Table 1).

The mean ( $\pm$  SE) TBA of control and iron fortified yoghurt at 0, 7, 14 and 21 days of storage period are shown in Table 14. The TBA values of control and iron fortified yoghurt ranged from  $0.0132 \pm 0.02$  to  $0.0989 \pm 0.02$ . Statistically significant ( $P < 0.05$ ) difference was noticed in TBA values between control and iron fortified yoghurts. During storage of yoghurt there was significant ( $P < 0.05$ ) increase in TBA was also observed between control and iron fortified yoghurt.

**Table 1**

##### Thiobarbituric acid values of microencapsulated iron fortified yoghurt (Absorbance at 532 nm)

| Treatment | Duration               |                        |                        |                        |
|-----------|------------------------|------------------------|------------------------|------------------------|
|           | 0 day                  | 7 days                 | 14 days                | 21 days                |
| PY        | $0.0132^{Aa} \pm 0.02$ | $0.0164^{Ba} \pm 0.03$ | $0.0227^{Ca} \pm 0.09$ | $0.0346^{Da} \pm 0.03$ |
| PFSY1     | $0.0133^{Aa} \pm 0.02$ | $0.0167^{Ba} \pm 0.03$ | $0.0242^{Ca} \pm 0.03$ | $0.0350^{Da} \pm 0.01$ |
| PFSY2     | $0.0135^{Aa} \pm 0.01$ | $0.0392^{Bb} \pm 0.02$ | $0.0743^{Cc} \pm 0.09$ | $0.0989^{Dc} \pm 0.02$ |
| MFSY1     | $0.0132^{Aa} \pm 0.02$ | $0.0165^{Ba} \pm 0.03$ | $0.0227^{Ca} \pm 0.09$ | $0.0345^{Da} \pm 0.04$ |
| MFSY2     | $0.0132^{Aa} \pm 0.02$ | $0.0166^{Ba} \pm 0.04$ | $0.0231^{Ca} \pm 0.09$ | $0.0347^{Da} \pm 0.03$ |
| MFSY3     | $0.0133^{Aa} \pm 0.05$ | $0.0167^{Ba} \pm 0.03$ | $0.0235^{Ca} \pm 0.08$ | $0.0348^{Da} \pm 0.04$ |
| MFSY4     | $0.0135^{Aa} \pm 0.03$ | $0.0167^{Ba} \pm 0.06$ | $0.0241^{Ca} \pm 0.01$ | $0.0348^{Da} \pm 0.04$ |

The data indicated that oxidation process may be quicker in yoghurt samples containing unencapsulated iron than in those containing iron in encapsulated form. These findings were in accordance with the findings of Kim *et al.*[8], who reported that TBA absorbance was significantly lower in encapsulated iron fortified yoghurts than the unencapsulated iron fortified yoghurts. Similarly, Jayalalitha *et al.* [10] also observed that oxidation process was quicker in yoghurt samples containing unencapsulated iron than in those containing encapsulated iron. This increase in TBA values of unencapsulated iron fortified yoghurt may be due to interaction of added iron with casein resulting in iron– casein complexes and the presence of O<sub>2</sub>, acts as a pro-oxidant, resulting in accelerated lipid oxidation in yoghurt. It can be opined that microencapsulation of iron lead to reduced rate of fat oxidation and increased fat stability, which facilitated a decreased TBA value as observed in encapsulated iron fortified yoghurt.

### 3.2 Effect of Iron Fortification on Viability of *Lactobacillus delbrueckii ssp. bulgaricus* in Yoghurt ( $\log_{10}$ cfu/ml)

The mean ( $\pm$  SE) values of count of *Lactobacillus delbrueckii ssp. bulgaricus* between control and iron fortified yoghurt treatments (Table 2.) ranged from  $9.29 \pm 0.01$  to  $7.41 \pm 0.01$  during storage period of 0, 7, 14 and 21 days at 5°C. Statistically no significant ( $P > 0.05$ ) difference was noticed in count of *Lactobacillus delbrueckii ssp. bulgaricus* between control and different iron fortified yoghurt (IFY) treatments on day 0. As the storage period advances to 21 days there was significant reduction in the count of *Lactobacillus delbrueckii ssp. bulgaricus*.

**Table 2**

**Effect of iron fortification on viability of *Lactobacillus delbrueckii ssp. bulgaricus* in yoghurt ( $\log_{10}$ cfu/ml)**

| Treatment | Duration             |                      |                      |                      |
|-----------|----------------------|----------------------|----------------------|----------------------|
|           | 0 day                | 7 days               | 14 days              | 21 days              |
| PY        | $9.15^{Aa} \pm 0.02$ | $8.83^{Ba} \pm 0.01$ | $8.19^{Ca} \pm 0.01$ | $7.66^{Da} \pm 0.01$ |
| PFSY1     | $9.13^{Aa} \pm 0.01$ | $8.68^{Ba} \pm 0.01$ | $8.10^{Ca} \pm 0.01$ | $7.47^{Da} \pm 0.01$ |
| PFSY2     | $9.07^{Aa} \pm 0.01$ | $8.62^{Ba} \pm 0.01$ | $8.16^{Ca} \pm 0.01$ | $7.41^{Da} \pm 0.01$ |
| MFSY1     | $9.19^{Aa} \pm 0.01$ | $8.56^{Ba} \pm 0.02$ | $8.19^{Ca} \pm 0.01$ | $7.55^{Da} \pm 0.01$ |
| MFSY2     | $9.29^{Aa} \pm 0.01$ | $8.63^{Ba} \pm 0.01$ | $8.20^{Ca} \pm 0.01$ | $7.57^{Da} \pm 0.02$ |
| MFSY3     | $9.20^{Aa} \pm 0.01$ | $8.95^{Ba} \pm 0.01$ | $8.29^{Ca} \pm 0.01$ | $7.71^{Da} \pm 0.01$ |
| MFSY4     | $9.19^{Aa} \pm 0.01$ | $8.63^{Ba} \pm 0.01$ | $8.19^{Ca} \pm 0.01$ | $7.55^{Da} \pm 0.01$ |

Statistically no significant ( $P > 0.05$ ) difference was noticed in count of *Lactobacillus delbrueckii ssp. bulgaricus* between control and IFY treatments on day 0 to 21. It is also observed that there was a significant ( $P < 0.05$ ) decrease in *Lactobacillus delbrueckii ssp. bulgaricus* counts as the storage period advances towards 21 days. These findings concurred with the findings of Kim *et al.* [8] who reported that the mean counts of *Lactobacillus delbrueckii ssp. bulgaricus* for control and other groups of yoghurt did not differ significantly at 0 day, and also the mean counts in all groups showed a decreasing trend during 20 days of storage at 4°C. Fortification of yoghurt with different iron salts had no effect on the total lactic acid bacteria in all treatments when fresh and during cold storage El-Kholy [11]. So iron fortification did not significantly ( $P > 0.05$ ) affect the growth and viability of *Lactobacillus delbrueckii ssp. bulgaricus* both in the fresh yoghurt and during storage. The metabolic enzymatic activity of the yoghurt starter culture could be the reason for increase in the acidity and decrease in the pH, which could be responsible for decreasing the viability of *Lactobacillus delbrueckii ssp. bulgaricus* as the storage period advances beyond a certain period.

### 3.3 Effect of Iron Fortification on *Streptococcus Salivarius*ssp. *thermophilus* Viability in Yoghurt ( $\log_{10}$ cfu/ml)

Table 3 shows the mean ( $\pm$  SE) values of count of *Streptococcus salivarius* ssp. *thermophilus* between control and different IFY treatments ranged from  $8.93 \pm 0.02$  to  $7.10 \pm 0.01$  during storage period of 0, 7, 14 and 21 days at  $5^{\circ}\text{C}$ . Statistically no significant ( $P > 0.05$ ) difference was noticed in count of *Streptococcus salivarius*ssp. *thermophilus* between control and IFY treatments.

**Table 3**  
Effect of iron fortification on *Streptococcus salivarius*ssp. *thermophilus* viability in yoghurt ( $\log_{10}$ cfu/ml)

| Treatment | Duration             |                      |                       |                      |
|-----------|----------------------|----------------------|-----------------------|----------------------|
|           | 0 day                | 7 days               | 14 days               | 21 days              |
| PY        | $8.93^{Aa} \pm 0.02$ | $8.43^{Ba} \pm 0.01$ | $7.82^{Ca} \pm 0.01$  | $7.26^{Da} \pm 0.01$ |
| PFSY1     | $8.73^{Aa} \pm 0.01$ | $8.11^{Ba} \pm 0.01$ | $7.680^{Ca} \pm 0.01$ | $7.17^{Da} \pm 0.01$ |
| PFSY2     | $8.72^{Aa} \pm 0.01$ | $8.18^{Ba} \pm 0.01$ | $7.56^{Ca} \pm 0.01$  | $7.10^{Da} \pm 0.01$ |
| MFSY1     | $8.79^{Aa} \pm 0.01$ | $8.26^{Ba} \pm 0.02$ | $7.79^{Ca} \pm 0.01$  | $7.15^{Da} \pm 0.01$ |
| MFSY2     | $8.83^{Aa} \pm 0.01$ | $8.13^{Ba} \pm 0.01$ | $7.60^{Ca} \pm 0.01$  | $7.22^{Da} \pm 0.02$ |
| MFSY3     | $8.85^{Aa} \pm 0.01$ | $8.35^{Ba} \pm 0.01$ | $7.78^{Ca} \pm 0.01$  | $7.24^{Da} \pm 0.01$ |
| MFSY4     | $8.81^{Aa} \pm 0.01$ | $8.33^{Ba} \pm 0.01$ | $7.79^{Ca} \pm 0.01$  | $7.23^{Da} \pm 0.01$ |

Statistically no significant ( $P > 0.05$ ) difference was noticed in count of *Streptococcus salivarius*ssp. *thermophilus* between control and IFY treatments. *Streptococcus salivarius*ssp. *thermophilus* counts were decreased significantly ( $P < 0.05$ ) as the storage period increased among control and IFY. These findings were in consistent with the findings of Kim *et al.* [8] who reported that mean counts of *Streptococcus salivarius*ssp. *thermophilus* for control and other groups of yoghurt were not significantly different. Similarly, Cavallini and Rossi [12] reported that viability of mixed starter culture containing *Streptococcus salivarius*ssp. *thermophilus* and *Lactobacillus delbrueckii*ssp. *bulgaricus* decreased as the storage time increased in iron and calcium fortified soy yoghurt. The reduction of *Streptococcus salivarius*ssp. *thermophilus* counts on storage may be due to low pH and high acidic condition prevailing in the yoghurt beyond a certain period during storage.

### 3.4 Effect of Iron Fortification on Bitterness, Metallic Flavour and Astringent Flavour in Yoghurt

Table 4 shows the mean ( $\pm$  SE) values of bitterness between control and IFY treatments during storage period of 0, 7, 14 and 21 days at  $5^{\circ}\text{C}$ . The bitterness scores ranged from  $1.05 \pm 0.17$  to  $7.40 \pm 0.12$  between control and different IFY up to 21 days of storage at  $5^{\circ}\text{C}$ . No significant ( $P > 0.05$ ) difference was noticed between control and IFY treatments at 0 day, whereas significant ( $P < 0.05$ ) difference was observed at 7, 14 and 21<sup>st</sup> day of storage. Results indicate no significant ( $P > 0.05$ ) difference between storage periods.

**Table 4**

**Effect of iron fortification on bitterness in yoghurt**

| Treatment | Duration                 |                          |                          |                          |
|-----------|--------------------------|--------------------------|--------------------------|--------------------------|
|           | 0 day                    | 7 days                   | 14 days                  | 21 days                  |
| PY        | 1.05 <sup>Aa</sup> ±0.17 | 1.10 <sup>Aa</sup> ±0.09 | 1.15 <sup>Aa</sup> ±0.09 | 1.17 <sup>Aa</sup> ±0.10 |
| PFSY1     | 1.23 <sup>Aa</sup> ±0.11 | 1.46 <sup>Aa</sup> ±0.15 | 1.50 <sup>Aa</sup> ±0.12 | 1.63 <sup>Aa</sup> ±0.09 |
| PFSY2     | 1.60 <sup>Aa</sup> ±0.13 | 3.80 <sup>Bb</sup> ±0.14 | 5.20 <sup>Cb</sup> ±0.11 | 7.40 <sup>Db</sup> ±0.12 |
| MFSY1     | 1.11 <sup>Aa</sup> ±0.20 | 1.20 <sup>Aa</sup> ±0.15 | 1.33 <sup>Aa</sup> ±0.17 | 1.38 <sup>Aa</sup> ±0.18 |
| MFSY2     | 1.12 <sup>Aa</sup> ±0.19 | 1.21 <sup>Aa</sup> ±0.15 | 1.33 <sup>Aa</sup> ±0.17 | 1.39 <sup>Aa</sup> ±0.18 |
| MFSY3     | 1.13 <sup>Aa</sup> ±0.20 | 1.22 <sup>Aa</sup> ±0.15 | 1.33 <sup>Aa</sup> ±0.17 | 1.39 <sup>Aa</sup> ±0.19 |
| MFSY4     | 1.11 <sup>Aa</sup> ±1.19 | 1.19 <sup>Aa</sup> ±0.14 | 1.31 <sup>Aa</sup> ±0.16 | 1.37 <sup>Aa</sup> ±0.18 |

The bitterness values and metallic flavour values of encapsulated iron fortified yoghurt were similar to control, and the bitterness values and metallic flavour values were not significantly ( $P>0.05$ ) increased during storage periods between control and encapsulated iron fortified yoghurt. These results were partly in accordance with the findings of Kwak *et al.* [13]. The astringent flavour values of encapsulated iron fortified yoghurt treatment MFSY3 and unencapsulated iron fortified yoghurt treatment MFSY1 were also similar to control. These astringent flavour values were significantly ( $P<0.05$ ) increased during storage periods. These results were partly in agreement with the findings of Kwak *et al.*[13].

Table 5 shows the mean ( $\pm$  SE) values of metallic flavour of control and different IFY treatments during storage period of 0, 7, 14 and 21 days at 5°C. The metallic flavour scores ranged from 1.04  $\pm$  0.17 to 7.49  $\pm$  0.12 between control and IFY treatments during 21 days of storage period at 5°C. No significant ( $P>0.05$ ) difference was noticed between control and IFY treatments at 0 day, whereas significant ( $P<0.05$ ) difference was observed at 7, 14 and 21<sup>st</sup> day of storage between control and IFY treatments. Results also indicate that no significant ( $P>0.05$ ) difference in metallic flavour was observed between storage periods.

**Table 5**

**Effect of iron fortification on metallic flavour in yoghurt**

| Treatment | Duration                 |                          |                          |                          |
|-----------|--------------------------|--------------------------|--------------------------|--------------------------|
|           | 0 day                    | 7 days                   | 14 days                  | 21 days                  |
| PY        | 1.04 <sup>Aa</sup> ±0.17 | 1.11 <sup>Aa</sup> ±0.09 | 1.14 <sup>Aa</sup> ±0.09 | 1.16 <sup>Aa</sup> ±0.10 |
| PFSY1     | 1.24 <sup>Aa</sup> ±0.11 | 1.45 <sup>Aa</sup> ±0.15 | 1.50 <sup>Aa</sup> ±0.12 | 1.62 <sup>Aa</sup> ±0.09 |

|       |                          |                          |                          |                          |
|-------|--------------------------|--------------------------|--------------------------|--------------------------|
| PFSY2 | 1.60 <sup>Aa</sup> ±0.13 | 3.82 <sup>Bb</sup> ±0.14 | 5.23 <sup>Cb</sup> ±0.11 | 7.49 <sup>Db</sup> ±0.12 |
| MFSY1 | 1.11 <sup>Aa</sup> ±0.20 | 1.20 <sup>Aa</sup> ±0.15 | 1.33 <sup>Aa</sup> ±0.17 | 1.38 <sup>Aa</sup> ±0.18 |
| MFSY2 | 1.12 <sup>Aa</sup> ±0.19 | 1.21 <sup>Aa</sup> ±0.15 | 1.32 <sup>Aa</sup> ±0.17 | 1.39 <sup>Aa</sup> ±0.18 |
| MFSY3 | 1.13 <sup>Aa</sup> ±0.20 | 1.22 <sup>Aa</sup> ±0.15 | 1.33 <sup>Aa</sup> ±0.17 | 1.39 <sup>Aa</sup> ±0.19 |
| MFSY4 | 1.11 <sup>Aa</sup> ±1.19 | 1.19 <sup>Aa</sup> ±0.14 | 1.31 <sup>Aa</sup> ±0.16 | 1.37 <sup>Aa</sup> ±0.18 |

Table 6 shows the mean ( $\pm$  SE) values of astringent flavour scores between control and IFY treatments during the storage period of 0, 7, 14 and 21 days at 5°C. The astringent flavour scores ranged from 1.30 $\pm$  0.06 to 7.30 $\pm$  0.15 between control and IFY treatments during 21 days of storage period at 5°C. Significant ( $P<0.05$ ) difference was observed in astringent flavour at 0, 7, 14 and 21<sup>st</sup> day of storage between control and IFY treatments.

**Table 6**  
**Effect of iron fortification on astringency in yoghurt**

| Treatment | Duration                 |                           |                           |                          |
|-----------|--------------------------|---------------------------|---------------------------|--------------------------|
|           | 0 day                    | 7 days                    | 14 days                   | 21 days                  |
| PY        | 1.30 <sup>Aa</sup> ±0.06 | 1.46 <sup>Aa</sup> ±0.07  | 1.66 <sup>ABa</sup> ±0.09 | 1.98 <sup>Ba</sup> ±0.07 |
| PFSY1     | 1.50 <sup>Aa</sup> ±0.09 | 1.76 <sup>Aa</sup> ±0.09  | 2.21 <sup>ABa</sup> ±0.06 | 2.50 <sup>Ba</sup> ±0.08 |
| PFSY2     | 2.60 <sup>Ab</sup> ±0.06 | 3.83 <sup>Bb</sup> ±0.16  | 5.50 <sup>Cc</sup> ±0.08  | 7.30 <sup>Dc</sup> ±0.14 |
| MFSY1     | 1.30 <sup>Aa</sup> ±0.12 | 1.50 <sup>ABa</sup> ±0.13 | 1.80 <sup>BCa</sup> ±0.06 | 2.20 <sup>Ca</sup> ±0.09 |
| MFSY2     | 1.41 <sup>Aa</sup> ±0.09 | 1.51 <sup>Aa</sup> ±0.14  | 1.82 <sup>Ba</sup> ±0.05  | 2.21 <sup>Ca</sup> ±0.09 |
| MFSY3     | 1.42 <sup>Aa</sup> ±0.09 | 1.52 <sup>Aa</sup> ±0.13  | 1.83 <sup>Ba</sup> ±0.06  | 2.28 <sup>Ca</sup> ±0.12 |
| MFSY4     | 1.30 <sup>Aa</sup> ±0.14 | 1.50 <sup>ABa</sup> ±0.12 | 1.80 <sup>Ba</sup> ±0.06  | 2.18 <sup>Ca</sup> ±0.09 |

The oxidized flavour values of encapsulated iron fortified yoghurt treatment MFSY3 and unencapsulated iron fortified yoghurt treatment MFSY1 were similar to control. These oxidized flavour values were significantly ( $P<0.05$ ) increased during storage between control and Iron Fortified Yoghurt treatments. Gaucheron [14] reported that microencapsulation techniques can be used to avoid oxidized, metallic flavours and colour changes during fortification with iron. This is supported by the findings of Jayalalitha *et al.*, [10], who concluded that encapsulation treatment for iron will give the good sensory quality by avoiding the oxidized flavour in iron fortified yoghurt.

### 3.5 Effect of Iron Fortification on Overall Preference of Yoghurt

All the panelists liked control yoghurt and MFSY3 over other treatments and in that order of preference. This indicated that iron can be fortified only up to 20mg per litre in unencapsulated form, while in the form of

microencapsulated iron it can be incorporated up to 80 mg per litre of yoghurt using ferrous sulfate without affecting the accepted appearance, sensorial and textural attributes of yoghurt.

#### IV CONCLUSION

The present work enabled the development of fortified yoghurt with microencapsulated whey protein chelated iron up to a level of 80 mg per litre of yoghurt without affecting the accepted appearance and taste and the viability of probiotic yoghurt bacteria, that could be used in the prevention and control of iron deficiency anaemia in general population

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