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EFFECT OF IRON ENRICHMENT OF FLOUR ON THE DOUGH CHARACTERISTICS AND ORGANOLEPTIC QUALITIES OF ARABIC BREAD*

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Abstract. Effect of iron enrichment of flour on the dough characteristics and baking qualities has been studied. Salts used for iron enrichment were: reduced iron, ferric ammonium citrate, ferrous sulphate, ferric chloride and ferrous gluconate. It was found that up to enrichment level of 50 mg Fe/1b flour, there was no adverse effect on the physical characteristics of the dough as measured by Brabender farinograph and on the colour, texture, taste, off-flavour and general acceptability of the baked bread, irrespective of the salt used. Higher levels of enrichment in case of ferric chloride, ferrous sulphate and ferrous gluconate affect the dough and bread qualities adversely. Reduced iron and ferric ammonium citrate have minimum effects and hence seem to be good choices for flour enrichment.

The fundamental concept of research in nutrition is that a food, fit for consumption may be composed of many different nutrients in proper amounts and right proportions. At present about fifty different substances are known to be needed for proper nutrition. These include essential amino acids, vitamins and minerals. It is, therefore, a challenge to nutritionists and food technologists to devise a satisfactory combination of food nutrients that will satisfy the necessary nutritional requirements of the individual.

Iron is one of the important minerals required by man. Biochemical importance of iron is now established through its involvement in the process of cellular respiration. The action of enzymes such as cytochromes, catalases and peroxidases is dependent on iron.[1,2]

Deficiency of iron leads to anaemia of microcytic and hypochromic type. Despite the fact that various studies showed that iron intake in the Middle East is adequate,[3,4] nutritional surveys carried out by Inter Departmental Committee on Nutrition for National Defence (ICNND) showed that iron deficiency anaemia are common in this region.[5,6] As a result of these surveys it was recommended by ICNND that iron should be added to flour to prevent anaemia. In fact, Government of Jordan started enrichment of flour with iron and some vitamins in 1964 on experimental basis.[7]

Iron enrichment of flour is the only practical possibility to increase the iron intake of the population in the Middle East. This is so because the Arabic bread is main dietary staple in this region. Contribution of Arabic bread to total caloric intake reaches up to 85% and in extreme cases it is sole staple food in villages in Egypt.[8,9] However, before any programme of this type is recommended, studies are needed to investigate the effects of iron enrichment on the acceptability of resulting bread. The objectives of this study were (1) to investigate the effect of iron enrichment of flour on (a) dough characteristics and (b) organoleptic qualities of bread; and (2) to select a suitable iron compound(s) and optimum level which will not have deleterious effect on the bread.

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Materials and Methods

Iron Salts and Flour. The iron salts used in this study and their iron content are shown in Table 1. All salts were ground to pass 100-mesh sieve before use. Iron content was determined according to A.O.A.C.[10]

In farinographic studies 65% extraction flour, prepared experimentally at the Lebanese Industrial Institute (Beirut), was used. 'Balady'—the flour used in the local bakeries for the production of Arabic bread—was used in baking tests.

Preparation of Premixes. Calculated amounts of iron salts (Table 1) were weighed on a wax-paper and added to flour so that premix of each salt contained 3.14% iron. The salt and flour were first mixed on a sheet of aluminium foil, then in a mortar and pestle and finally passed through a 48-mesh sieve. This process was repeated five times. After mixing 'premixes' were stored in amber-coloured bottles at room temperature (23°C).

Preparation of Iron-Enriched Flour Samples. Calculated amounts of premixes (Table 2) were added to flour in order to get iron-enriched flour samples. Enrichment levels used were 10, 20, 30, 50, 100 and 500 mg iron per pound of flour. The 100 and 500 mg levels were used out of academic interest only, otherwise they are too high to be used for bread enrichment. The premix and flour were mixed in Crypto electric mixer (model EB 12 Crypto Ltd., London) for 30 min using speed 1. The flour sample without any addition of premix was considered as control (zero enrichment).

Testing Physical Characteristics of Dough. Brabender farinograph (OHG Duisburg, Germany), with a senior mixer was used to study dough charac-

TABLE 1. IRON SALTS* USED: THEIR IRON CONTENT AND AMOUNTS REQUIRED TO PREPARE 100 g 'PREMIX' (Each premix contains 3.14% iron).

Salt	Iron (%)	Salt equivalent to 3·14 g iron (g)	Flour to make 100 g premix (g)
Ferrous sulphate ($FeSO_4 \cdot 7H_2O$)	20·20	15·54	84·46
Ferric ammonium citrate (green)	14·60	21·50	78·50
Ferric chloride ($FeCl_3 \cdot 6H_2O$)	19·52	10·08	83·92
Reduced iron (100 mesh)	97·05	3·22	96·78
Ferrous gluconate ($C_{12}H_{22}FeO_{14} \cdot 2H_2O$)	11·20	28·03	71·97

*Salts were obtained from E. Merck.

TABLE 2. AMOUNTS OF PREMIXES REQUIRED FOR VARIOUS LEVELS OF ENRICHMENT.

Level of enrichment (mg/lb flour)	Premix required (g/lb flour)
10	0.318
20	0.636
30	0.955
50	1.592
100	3.182
500	15.923

teristics. Following specifications were used: (1) 300 g flour; (2) 62 rev/min; (3) 500 B.U. line as reference line; (4) 30°C constant temperature of the bowl.

Titration and normal curves were obtained as described by Kent-Jones and Amos.[11] Duplicate curves were obtained for each treatment.

The normal curve in each case, taken as a whole, represents the characteristic quality picture of the treated sample. The individual factors that were measured from the farinograms were; per cent water absorption, dough stability and valorimeter.

Preparation of Arabic Bread. White bread was prepared by a microbaking technique. The dough was prepared in the farinograph mixing bowl. The following formula was used: 300 g flour; 9 g compressed yeast, 4.5 g sodium chloride and 50–52% water. Exact amount of water was determined by the farinograph. This equals the amount of water required to bring the 800 B.U. line in the centre of the curve at the peak time. The dough of 800 B.U. consistency gives the best results in the preparation of bread.[12]

The ingredients were mixed in the farinographic blow fon12 min. The resulting dough was then worked and fermented at room temperature as follows: (1) first fermentation period, 8–10 min; (2) scaling the dough into round balls; (3) second fermentation period, 10 mins; (4) rolling to circular, flat loaves (sheets of 8 cm dia; 4 mm thick) and (5) third fermentation period, 30 min. Uniform humid conditions were maintained during fermentation. At the end of third fermentation breads were baked in an oven at 500°C for 60 sec. They were then cooled and stored in polyethylene bags before presenting for evaluation.

Organoleptic Studies. In preliminary tests it was observed that enrichment level of 30 mg/lb or below had no effect on organoleptic qualities of bread. Therefore, only 30, 50, 100 and 500 mg levels of iron enrichment were used in these studies. Baked breads from enriched flour were allowed to cool to room temperature before being presented to a panel of six trained judges for evaluation. A scoring sheet based on hedonic scale was provided to each judge. Scoring was to be done as follows: 1–2 unacceptable; 3–4 poor; 5–6 fair; 7–8 good; and 9–10 excellent. In case of off-flavour scores were: 1–2 none; 3–4 slight; 5–7 moderate; 8–10 intense. Characteristics of bread that were to be scored included colour, taste, off-flavour, texture (chewability) and overall acceptability. Not more than three samples were presented at one time. A control sample was always used for comparison. Samples to be tested were chosen randomly. Average scores were calculated to represent the quality of the bread.

Staling of Bread. To study the effect of iron enrichment on staling, the 30 mg level sample was used. The baked breads scored as follows:

Acceptable as fresh, 1; stale but acceptable, 2; and very stale, unacceptable, 3. panel tests were carried out after a lapse of 6, 30 and 54 hr–baking. One treated and one control sample was presented at one time.

Statistical Analysis. The data obtained was analysed for variance according to Snedecor and Cochran[13] and Amerine *et al.*[14]

Results and Discussion

Effect on Physical Characteristics. Table 3 shows the effect of iron enrichment on water absorption, stability and valorimeter value of flour at various levels of enrichment. Ferrous sulphate, reduced iron and ferrous gluconate did not affect the water absorption at all even when used to supply iron at the level of 500 mg/lb flour. In case of ferric ammonium citrate and ferric chloride water absorption was reduced significantly but only at higher levels of enrichment, i.e. 100 or 500 mg level. It can be concluded, therefore, that water absorption is not affected up to 50 mg level of enrichment irrespective of the salt used.

The stability of the flour was affected in most of the salts. Table 3 shows a gradual increase in stability of the dough as the iron enrichment level rises in case of ferric ammonium citrate. There was small but significant increase in stability in case of reduced iron at 20 mg level, but it was not affected further with the increase in enrichment level. Ferric chloride and ferrous sulphate caused decrease in stability only at 100 or 500 mg level. In case of ferrous gluconate there was first increase in stability but there was significant decrease when iron level was raised to 100 and 500 mg/lb flour.

The increase in stability is desirable.[15] It is then concluded from Table 3 that only higher levels of iron enrichment of flour using ferrous sulphate, ferric chloride and ferrous gluconate as sources have some

TABLE 3. EFFECT OF IRON ENRICHMENT OF FLOUR ON PHYSICAL CHARACTERISTICS OF DOUGH AS DETERMINED BY BRABENDER FARINOGRAPH (values are mean of two farinograms per treatment)*.

Salt	Enrichment level (mg iron/lb)	H_2O absorption (%)	Stability (min)	Valorimeter value
Ferrous sulphate	0	66·55	3·75	44·0
	10	66·80	4·00	44·0
	20	66·70	3·60	43·5
	30	66·50	4·00	43·0
	50	66·50	3·85	43·5
	100	66·50	3·75	43·0
	500	66·20	3·00++	43·5
Ferric ammonium citrate	0	66·55	3·75	43·5
	10	66·50	4·20+	44·0
	20	66·45	4·20+	43·5
	30	66·40	4·50++	43·5
	50	66·00	4·50++	44·5
	100	65·20++	5·75++	45·5+
	500	64·50++	7·50++	49·5++
Ferric chloride	0	66·60	3·75	44·0
	10	66·35	4·00	43·0
	20	66·40	3·70	41·5++
	30	66·30	3·75	40·0++
	50	66·00	3·70	40·0++
	100	65·50++	3·25+	38·5++
	500	65·00++	3·00++	33·5++
Reduced iron	0	66·55	3·75	43·5
	10	66·50	3·70	43·5
	20	66·50	4·35++	44·5
	30	66·70	4·35++	44·5
	50	66·70	4·35++	44·5
	100	66·80	4·35++	44·0
	500	66·80	4·35++	44·0
Ferrous gluconate	0	66·55	3·75	43·5
	10	66·70	4·25+	46·0++
	20	66·60	4·20+	46·0++
	30	66·50	4·35+	45·5++
	50	66·80	4·35+	46·0++
	100	66·75	3·00++	44·0
	500	66·75	2·50++	41·0++
LSD 1%		1·10	0·60	1·64
LSD 5%		0·80	0·45	1·22

*In each column comparison has been made between control (zero level) and treatment values for the same salt. (+), significant ($P<0·05$); (++) highly significant ($P<0·01$).

adverse affect on the stability of the dough. It is clear that up to 50 mg level none of the salts used showed effect on the stability of the dough. Similarly it is evident from Table 3 that valorimeter value of dough was not affected up to 50 mg level except in case of ferric chloride.

The effect of ferric ammonium citrate and ferrous gluconate can be explained according to the hypothesis put forward by Bennet and Etwart.[16] It is postulated that anions which can cross-link by means of secondary forces affect the dough behaviour. It seems that citrate and gluconate ions form a network with gluten molecules because of their cross-linking capacity. This network then shows more stability to dough mixing.

From farinographic studies it is concluded that up to 50 mg level of enrichment there is no adverse effect on the physcial characteristics of dough irrespective of the salt used. From the results it might be predicted that bread qualities will not be affected by iron enrichment up to 50 mg/lb flour. The final judge, however, as Shuey has pointed out, is the actual baking test.[15]

Organoleptic Qualities. Table 4 shows the effect of iron enrichment of flour on the organoleptic qualities of bread. The addition of iron up to 30 mg/lb flour caused no change in organoleptic qualities so far as colour, off-flavour, taste and overall acceptability were concerned.

Statistical analysis of bread score values showed that there was no significant difference in bread quality up to 50 mg level of enrichment (Table 4). At 100 mg level, significant changes took place in certain characteristics but bread quality was still unaffected in case of ferric ammonium citrate and reduced iron. Bread characteristics were adversely affected at 500 mg level.

It appears from Table 4 that texture of the bread was not sensitive to iron addition. It was affected only at 500 mg level in case of ferrous sulphate and ferrous gluconate. Off-flavour was slight at 100 mg level in case of all salts but intense at 500 mg level in case of ferric chloride and ferrous gluconate. Reduced iron and ferric ammonium citrate caused slight off-flavour even at 500 mg level. Overall reaction scores showed that bread was unacceptable at 500 mg level of iron enrichment in case of ferric chloride and ferrous gluconate but it was still liked at this level in case of reduced iron and ferric ammonium citrate.

Staling. Average scores for staleness study are shown in Table 5. Comparison between treated and control samples showed no significant changes in staling after 6, 30 or 54 hr of storage. The results revealed that addition of iron at 30 mg did not enhance or retard the process of staling in the bread.

It is clear that up to 50 mg level of iron enrichment dough characteristics and bread qualities are not adversely affected. Reduced iron and ferric ammonium citrate seem to be the best choice for flour enrichment as they did not affect the dough or the bread characteristics even up to 100 mg level of enrichment. Ferrous sulphate is the next choice but ferric chloride and ferrous gluconate are not recommended. Reduced iron and ferric ammonium citrate have also been shown to produce much less rancidity in flour and flour 'premixes' than other iron salts.

From our studies we can suggest only the maximum safe level of iron enrichment, i.e. 50 mg/lb flour but cannot point out the optimum level. In actual practice iron addition to flour ranges between 13–35 mg/kg flour in some of the countries.[18] As a matter of fact there is still considerable uncertainty as to the levels of iron fortification desirable.[19] Elwood *et al.*[20] plead for long term community studies as to the most valid way to generate a sound basis for national policy on iron fortification. Further studies are suggested on animals as well as humans to find out physiological availability of iron from the bread enriched with different iron salts.

Incidently it can be pointed out that Arabic bread resembles to Pakistani 'roti' or more closely to 'nan'. The results of these studies, therefore, could be applicable to 'roti' or 'nan'. In the light of these studies it is expected that up to 50 mg level of iron enrichment

TABLE 4. EFFECT OF IRON ENRICHMENT OF FLOUR ON ORGANOLEPTIC QUALITIES OF ARABIC BREAD (values are mean of six judgements).

Salt	Evaluated	Enrichment level (mg Fe/lb flour) 0	30	50	100	500	LSD 5%
Ferrous sulphate	Colour	8.6	8.8	8.9	6.8	2.0	1.9
	Taste	8.2	8.2	8.5	7.3	2.7	1.7
	Off-flavour	0.6	0.5	1.2	2.2	6.8	—
	Texture	8.0	7.5	7.5	7.2	3.5	2.0
	Overall	7.8	7.7	7.3	6.2	2.0	1.5
Ferric ammonium citrate	Colour	8.6	7.5	8.7	7.3	5.7	1.6
	Taste	8.2	7.8	8.0	7.5	6.8	NS
	Off-flavour	0.6	0.7	0.5	1.0	3.0	—
	Texture	8.0	8.0	8.5	7.5	5.0	1.0
	Overall	7.8	7.2	8.0	7.7	6.3	NS
Ferric chloride	Colour	8.6	9.2	7.7	4.5	0.3	1.5
	Taste	8.2	9.0	7.8	6.5	1.5	1.4
	Off-flavour	0.6	0.5	1.8	2.7	8.3	—
	Texture	8.0	8.2	7.2	6.7	6.8	NS
	Overall	7.8	8.3	7.2	5.7	2.0	1.4
Reduced iron	Colour	8.6	8.6	8.7	7.8	5.0	1.8
	Taste	8.2	8.2	8.0	8.0	7.2	NS
	Off-flavour	0.6	0.5	0.5	1.3	2.0	—
	Texture	8.0	8.2	8.5	8.0	7.7	NS
	Overall	7.8	8.0	8.0	7.8	5.8	1.3
Ferrous gluconate	Colour	8.6	8.5	7.2	5.5	1.2	1.6
	Taste	8.2	8.0	7.8	7.2	2.7	1.6
	Off-flavour	0.6	0.8	1.0	2.2	9.2	—
	Texture	8.0	7.7	7.5	8.2	4.5	1.7
	Overall	7.8	7.3	7.3	7.5	2.2	1.3

NS, Difference not significant.

TABLE 5. EFFECT OF IRON ENRICHMENT OF FLOUR ON STALENESS OF ARABIC BREAD (enrichment level, 30 m/lb flour).

Salt	Sample	Scores (mean of six judgements), Storage time (hr) 6		30		54	
Ferrous sulphate	Control	1·0	NS	1·8	NS	2·3	
	Enriched	1·1		2·0		2·3	
Ferric ammonium citrate	Control	1·0		1·8	NS	2·3	NS
	Enriched	1·0		2·0		2·1	
Ferric chloride	Control	1·1		2·0		2·1	NS
	Enriched	1·1		2·0		2·0	
Reduced iron	Control	1·1		1·3	NS	1·8	
	Enriched	1·1		1·5		1·8	
Ferrous gluconate	Control	1·0		1·5	NS	2·0	NS
	Enriched	1·0		1·8		2·1	

NS, difference not significant.

of flour in Pakistan, the dough characteristics or organoleptic qualities of resulting 'roti' or 'nan' will not be affected.

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