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Effect of sesame seed protein supplementation on the nutritional, physical, chemical and sensory properties of wheat flour bread

T. A. El-Adawy

Food Science and Technology Department, Faculty of Agriculture, Menofiya University, Shibin El-Kom, Egypt

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Sesame products (sesame meal, roasted and autoclaved sesame meals, sesame protein isolate and concentrate) were added to red wheat flour to produce blends at protein levels of 14, 16, 18 and 20%. Dough properties were studied using a Brabender Farinograph. Loaves were prepared from the various blends using the straight dough procedure and then evaluated for volume, crust and crumb colour, crumb texture, flavour and overall quality. The water absorption, development time and dough weakening were increased ($P < 0.05$) as the protein level increased in all blends; however, dough stability decreased. Sesame products could be added to wheat flour up to 18% protein level (sesame protein isolate) and up to 16% protein level (for other sesame products) without any observed detrimental effects on bread sensory properties. No significant differences ($P > 0.05$) were recorded in loaf volume between control and breads containing sesame protein isolate (up to 18% protein level) and either autoclaved sesame meal or sesame protein concentrate (up to 14% protein level). Also, addition of these products increased the contents of protein, minerals, total essential amino acids, especially lysine, and also improved the *in vitro* protein digestibility and computed biological value. © 1997 Published by Elsevier Science Ltd. All rights reserved

INTRODUCTION

The major nutritional problem in most of the developing world is protein–calorie malnutrition. This acute problem is, of course, due to factors such as high birth rates, increased population, insufficient agricultural products and limited supply of high quality proteins. Therefore, looking for inexpensive high protein materials is considered an important task for nutritionists in these countries. Such materials will improve and enhance the nutritional quality of the diets and the health of the people thereafter.

In Egypt, wheat flour bread represents the main staple food for many people. Addition of high protein from good quality oil seed flour to wheat flour will give a marked improvement in its nutritional value with a slight increase in its production cost (Burns *et al.*, 1972; Fogg & Tinkling, 1972; Roony *et al.*, 1972; Salama *et al.*, 1992). Soybean meal is one of the suggested materials to complement the amino acid profile of wheat flour by increasing its lysine content, whereas sesame meal is high in sulphur-containing amino acids. On the other hand, Roony *et al.* (1972) compared the baking qualities of several oilseed–wheat flour mixtures (cottonseed, peanut, sunflower and sesame) and found that oilseeds had different effects on dough mixing and loaf volume characteristics. Heating enhanced the bread-making characteristics of cottonseed and sunflower proteins but it was detrimental to peanuts and sesame proteins.

The objectives of this research were to study the effects of sesame products such as sesame meal, roasted and autoclaved sesame meal, sesame protein isolate and concentrate additions on the rheological, physical, sensory, chemical and nutritional properties of the produced breads.

MATERIALS AND METHODS

Preparation of sesame products

Dehulled sesame seeds (*Sesumum indicum*) were obtained from the local market (Shibin El-Kom, Egypt) during the winter season of 1994. The seeds were hand-sorted to remove wrinkled, mouldy and foreign materials.

The sesame products (sesame meal, roasted and autoclaved sesame meals, protein isolate and concentrate) were prepared as shown in Fig. 1. After preparation, sesame products were reground and screened to pass through an 80-μm mesh sieve (British Standard Screen) and backed in air-tight kilner jars then kept in a refrigerator at 4°C until used.

Preparation of sesame product–wheat flour blends

The flour used was derived from American Soft Red (ASR) wheat obtained from the Middle and West Delta Milling Company, Shibin El-Kom, Egypt. The extraction ratio of the wheat flour was 72%.

Sesame products replaced wheat flour to produce blends with 14, 16, 18 and 20% protein levels.

Determination of the dough physical properties

Water absorption, development and stability times, and dough weakening of the blends were determined in a Brabender Farinograph according to the Constant

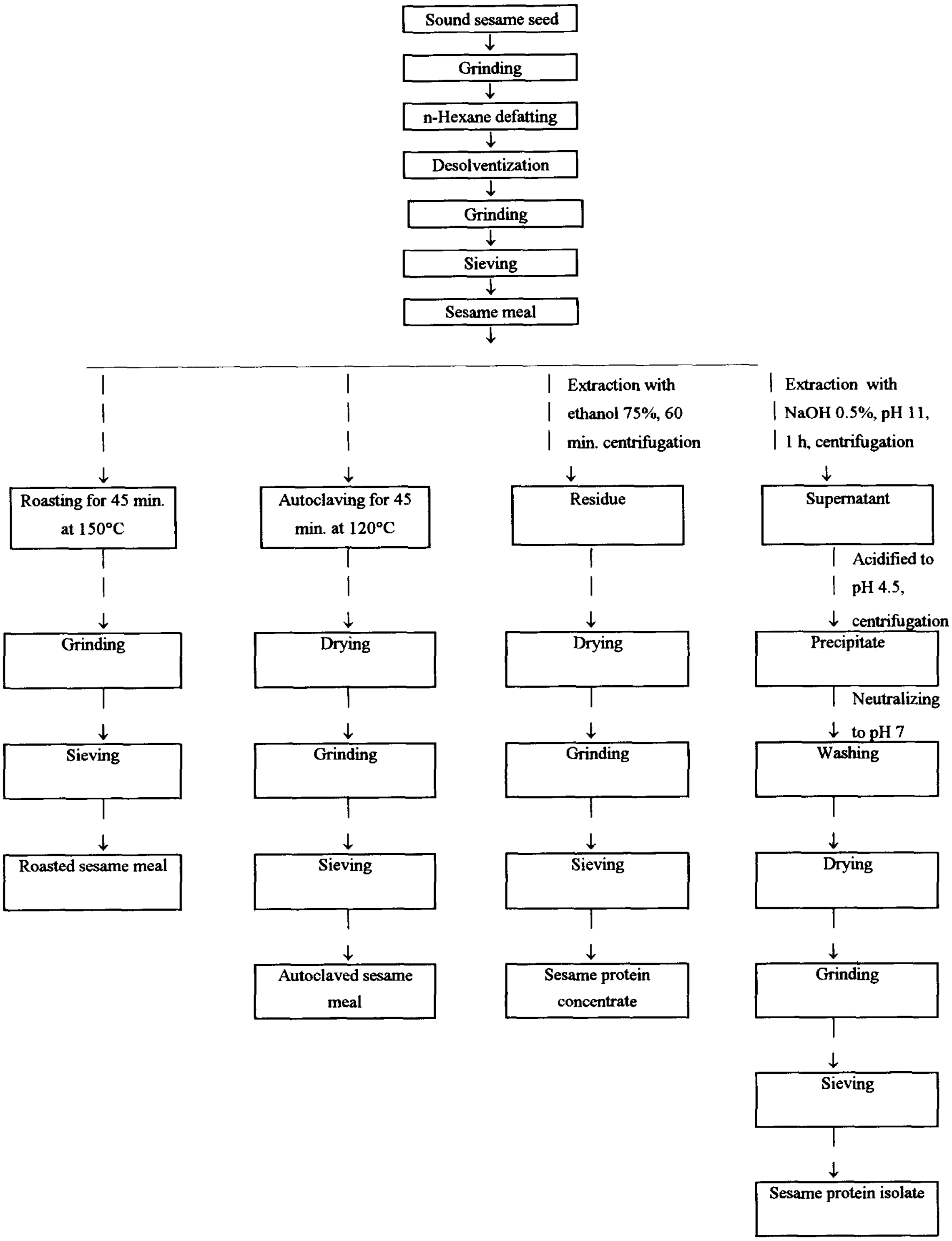

Fig. 1. Preparation of sesame seed products.

Flour Method 54-21 of AACC (1983). Ten grammes of flour were mixed at the optimum water absorption and the farinograph curve was centred on the 500 BU line.

Preparation of pan bread

A straight dough procedure, with a 3 h fermentation, 55 min proofing at 30°C, and 25 min baking at 220°C, was used. The baking formula, based on flour weight, was as follows: 50 g flour, 0.5 g sugar, 0.75 g salt, 0.5 g active dry yeast, 0.5 g shortening and water as determined from a farinograph absorption test (Faheid, 1992).

Loaf volume and sensory evaluation of baked bread

Loaf volume was measured immediately after baking by a rapeseed displacement method. Each treatment was measured in triplicate and the average was recorded.

The trained panel consisted of nine members (average age mid-40s) selected randomly from laboratory staff and lecturers of the Food Science and Technology Department. They were trained and instructed to rate the score of crust colour, crumb colour, crumb texture, flavour and overall quality of the breads. A rating scale of 1–7 points (1 = dislike very much; 7 = like very much) was used (Peryam & Pilgrim, 1957). Bread was evaluated, 3 h after baking, when loaves were sliced into 1-cm thick slices by a bread slicing machine. Panellists evaluated one slice of different bread systems which were offered at the same time in an open area without special lighting. Water was provided for rinsing purposes.

Chemical composition

The proximate composition of sesame products, wheat flour and bread was determined using the following AOAC (1984) methods: moisture (14.004), crude lipid (14.018), ash (14.006), crude fibre (14.020) and nitrogen (14.026). The conversion factors of nitrogen to protein were 5.7 and 6.25 for wheat flour, and bread and sesame products, respectively.

Amino acids

Amino acids were determined using a Mikrotechna AAA 881 automatic amino acid analyser according to the method of Moore and Stein (1963). Hydrolysis of the samples were performed in the presence of 6 M HCl at 110°C for 24 h under nitrogen atmosphere. Sulphur-containing amino acids were determined after performic acid oxidation. Tryptophan was chemically determined by the method of Miller (1967).

Minerals

Minerals were determined after wet-ashing by concentrated nitric acid and perchloric acid (1:1 v/v). Na, K and Ca were determined by flame photometer (Corning Model 410), while Mg, Mn, Zn, Fe and Cu were determined using an atomic absorption spectrophotometer (Perkin-Elmer Instrument Model 2380). Phosphorus was estimated photometrically via the phosphorus molybdate complex as described by Taussky and Shorr (1953).

In-vitro protein digestibility

In-vitro protein digestibility was determined as described by Salgo *et al.* (1984) by measuring the change in the sample solution pH after incubation at 37°C with a trypsin–pancreatin enzyme mixture for 10 min.

Biological values

Biological values of bread samples were determined on the basis of amino acid profiles. Chemical score (CS) of amino acids was calculated using the FAO/WHO (1973) reference pattern. Essential Amino Acid Index (EAAI) was calculated according to Oser (1959) using the amino acids composition of the whole egg protein published by Hidvégi and Békés (1984). Protein efficiency ratio (PER) was estimated according to the following regression equation proposed by Alsmeyer *et al.* (1974):

$$\mathrm{PER} = -0.684 + 0.456(\mathrm{Leu}) - 0.047(\mathrm{Pro}).$$

Statistical analysis

Physical properties, chemical composition, *in vitro* protein digestibility and sensory properties data of sesame products and bread treatments were statistically analysed according to the analysis of variance and least significant difference (Steel & Torrie, 1980). Significant differences were determined at the $P < 0.05$ level.

RESULTS AND DISCUSSION

Chemical composition of sesame products and wheat flour

The chemical analysis data of the used raw materials are presented in Table 1. It is clear that both heat treatments used (roasting and autoclaving) had no significant effects on ($P < 0.05$) the total protein, ether extract or total carbohydrates. The changes in proximate composition due to heat treatments were quite minor. Roony *et al.* (1972) studied the effect of autoclaving on the protein content of some oilseed flours and found that the heated and non-heated flour did not differ in protein content. Sesame protein isolate had a significantly higher ($P < 0.05$) protein content than wheat flour and other sesame products. Also, sesame protein concentrate had significantly higher ($P < 0.05$) levels of crude fibre and ash compared to wheat flour and other sesame products. Consequently, addition of sesame

Table 1. Chemical composition of wheat flour and sesame products (on dry weight basis)

Products	Moisture (%)	Crude protein (%)	Ether extract (%)	Crude fibre (%)	Ash (%)	Total carbo-hydrates* (%)
Sesame meal	9.20[b]	55.7[c]	1.64[ab]	3.41[c]	9.83[b]	29.4[b]
Roasted sesame meal	8.76[b]	57.1[c]	1.73[a]	4.01[b]	9.02[c]	28.1[b]
Autoclaved sesame meal	9.31[b]	54.8[c]	1.80[a]	4.21[ab]	10.16[b]	29.0[b]
Sesame protein isolate	6.61[d]	87.0[a]	1.10[b]	0.91[e]	4.68[d]	6.30[d]
Sesame protein concentrate	7.21[d]	62.3[b]	1.20[b]	4.36[a]	10.97[a]	21.2[c]
Wheat flour	12.68[a]	12.3[d]	1.42[ab]	1.30[d]	1.18[e]	83.8[a]

*Calculated by differences. Means in the same column with different letters as superscripts are significantly different ($P < 0.05$).

products to wheat flour should increase both protein and ash content of the produced bread. Crude fibre and ether extract content of the sesame protein isolate were quite low (0.91 and 1.10%, respectively).

Physical properties of dough

Farinograph data of wheat flour (control) and of those supplemented with sesame products at protein levels of 14, 16, 18 and 20% are shown in Table 2. The water absorption was increased significantly ($P < 0.05$) due to the addition of sesame products at all protein levels. Generally, wheat flours blended with sesame protein isolate, concentrate and autoclaved sesame meal had greater water absorption than those blended with sesame meal and roasted sesame meal. Wheat flour–sesame protein isolate blends appeared to have the highest water absorption compared with the other blends over all the ratios of blending. The observed higher water absorption of wheat flour blends may be due to the increased hydration capacity of sesame products, especially protein isolate. Generally, these results agree well with those reported by Rasco *et al.* (1990), Gonzalez-Galan *et al.* (1991) and Yue *et al.* (1991). They found that water absorption increased substantially by addition of (5–15%) native sunflower protein concentrate and isolate to wheat flour.

Dough development time was also higher for all wheat flour–sesame products than control. Wheat flour–sesame protein concentrate blends had a significantly higher ($P < 0.05$) dough development time. Generally, the increase in dough development time may be due to the differences in the physico-chemical properties of sesame products and that of wheat flour as previously detected and reported by Morad *et al.* (1980) for different protein sources.

Table 2. Farinograph properties of sesame product–wheat flour blends

Products	Blend composition (%)		Protein level (%)	Water absorption (%)	Development time (min)	Stability time (min)	Weakening (BU)
	Sesame products (%)	Wheat flour (%)					
Wheat flour (control)	0.00	100	12.3	58.9[h]	1.5[e]	4.5[a]	80[f]
Sesame meal	3.91	96.09	14	59.7[gh]	3.5[b]	2.5[e]	110[de]
	8.53	91.47	16	60.3[fgh]	3.5[b]	2.5[e]	130[bcd]
	13.15	86.85	18	61.5[def]	3.0[c]	2.0[f]	140[ab]
	17.77	82.23	20	61.9[cdef]	3.0[c]	2.0[f]	160[a]
Roasted sesame meal	3.78	96.22	14	61.5[def]	3.5[b]	3.0[d]	120[cd]
	8.25	91.75	16	62.2[cde]	3.5[b]	2.5[e]	120[cd]
	12.73	87.27	18	62.9[bcd]	3.0[c]	2.0[f]	140[ab]
	17.20	82.80	20	62.9[bcd]	3.0[c]	2.0[f]	150[ab]
Autoclaved sesame meal	3.97	96.03	14	60.6[efg]	3.5[b]	3.0[d]	110[de]
	8.68	91.32	16	61.5[def]	3.5[b]	3.0[d]	120[cd]
	13.38	86.62	18	62.7[bcd]	3.0[c]	2.5[e]	150[ab]
	18.09	81.91	20	63.5[abc]	2.5[d]	2.5[e]	150[ab]
Sesame protein isolate	2.26	97.74	14	62.7[bcd]	3.5[b]	3.5[c]	130[bcd]
	4.94	95.06	16	63.5[abc]	3.0[c]	3.5[c]	130[bcd]
	7.62	92.38	18	64.1[ab]	3.0[c]	3.5[c]	150[ab]
	10.29	89.71	20	64.9[a]	3.0[c]	3.0[d]	160[a]
Sesame protein concentrate	3.38	96.62	14	61.9[cdef]	4.0[a]	4.0[b]	90[ef]
	7.38	92.62	16	62.5[bcd]	3.5[b]	4.0[b]	120[cd]
	11.38	88.62	18	63.1[bcd]	3.5[b]	3.5[c]	130[bcd]
	15.38	84.62	20	63.9[ab]	3.0[c]	3.5[c]	140[ab]

Means in the same column with different letters as superscripts are significantly different ($P < 0.05$).

Dough stability time (in min) as a major index for dough strength indicated that addition of sesame products reduced the stability periods for all blends compared to controls. These results agree well with those reported by Anjum *et al.* (1991) and Yue *et al.* (1991); they found that the high level of substitution of sunflower protein concentrate and isolate may have been responsible for decreasing the dough stability time.

Dough weakening data showed that sesame substitution increased the dough weakening significantly ($P <$ 0.05) over the control, except for the sesame protein concentrate–wheat flour blend at 14% protein level which was non-significant ($P > 0.05$) regarding dough weakening. This observed weakening of dough, resulting from the addition of sesame products, could be due to: (a) the presence of sulphyhydryl groups in sesame products which cause the dough softening (El-Farra *et al.*, 1981); (b) an effective decrease in wheat gluten content (dilution effect); and (c) competition between proteins of sesame products and wheat flour for water (Deshpande *et al.*, 1983). However, Fleming and Sosulski (1978) ascribed the weakening of dough with supplemented proteins to the well-defined protein–starch complex in wheat flour bread.

Bread baking properties

Loaf volume and sensory properties data of bread prepared from sesame product–wheat flour blends are presented in Table 3. The loaf volume was decreased with increasing levels of the different sesame product proteins. Loaf volume of control was significantly higher ($P < 0.05$) than volumes of those baked with sesame meal or roasted sesame meal (at all protein levels), autoclaved sesame meal (16–20% protein levels), sesame protein isolate (20% protein level) and sesame protein concentrate (16–20% protein levels). However, this difference was not significant ($P > 0.05$) for loaf volumes of wheat flour bread and breads containing sesame protein isolate up to 18% protein level; also the same trend was observed for breads prepared from autoclaved sesame meal and sesame protein concentrate at 14% protein level. These results are in good agreement with those reported by Talley *et al.* (1972) who found that 17% and 30% substitution of sunflower meal in wheat flour produced dense, compact loaves; however, 3% enrichment gave an attractive loaf. There was no significant difference ($P > 0.05$) in crust colour among all breads up to 18% protein level of sesame products. Also, the differences were not significant ($P > 0.05$) in crumb colour, crumb texture, flavour and overall quality between control and breads prepared with sesame meal, roasted and autoclaved sesame meal, sesame protein concentrate (up to 16% protein level) and sesame protein isolate (up to 18% protein level). Matthews *et al.* (1970) mentioned that substituting high levels of sunflower flour resulted in deterioration of crumb colour and grain and texture of the bread.

Therefore, the rest of this study was conducted only on breads containing sesame meal, roasted and autoclaved sesame meal, and sesame protein concentrate at 16% protein level. Sesame protein isolate was used at 18% protein level.

Chemical composition of breads

Table 4 shows the changes in proximate composition of breads as a result of added sesame products at 16%

Table 3. Loaf volume and sensory evaluation of bread fortified with sesame products

Bread products	Protein level (%)	Loaf volume (ml)	Crust colour	Crumb colour	Crumb texture	Flavour	Overall quality
Control	12.3	250^{a}	6.3^{a}	5.9^{a}	5.7^{a}	5.4^{a}	5.8^{a}
Sesame meal	14	220^{cd}	6.0^{a}	5.7^{a}	5.6^{a}	5.2^{a}	5.6^{a}
	16	210^{de}	5.7^{a}	5.6^{a}	5.5^{a}	5.1^{a}	5.5^{a}
	18	190^{h}	5.7^{a}	4.9^{b}	4.9^{b}	4.8^{b}	5.0^{b}
	20	190^{h}	4.7^{b}	4.6^{c}	4.5^{b}	4.5^{b}	4.5^{b}
Roasted sesame meal	14	230^{bc}	5.9^{a}	5.7^{a}	5.5^{a}	5.1^{a}	5.6^{a}
	16	211^{ef}	5.8^{a}	5.6^{a}	5.5^{a}	5.0^{a}	5.5^{a}
	18	202^{fg}	5.7^{a}	4.7^{b}	4.6^{b}	4.2^{b}	4.6^{b}
	20	190^{h}	4.7^{b}	4.3^{c}	4.0^{c}	3.8^{c}	4.1^{c}
Autoclaved sesame meal	14	240^{ab}	6.1^{a}	5.6^{a}	5.6^{a}	5.2^{a}	5.6^{a}
	16	225^{bc}	5.9^{a}	5.5^{a}	5.4^{a}	5.1^{a}	5.5^{a}
	18	206^{ef}	5.7^{a}	5.0^{b}	5.0^{b}	4.8^{b}	4.9^{b}
	20	195^{gh}	5.0^{b}	5.0^{b}	4.6^{b}	4.8^{b}	4.9^{b}
Sesame protein isolate	14	249^{a}	6.2^{a}	5.8^{a}	5.8^{a}	5.4^{a}	5.8^{a}
	16	240^{ab}	6.2^{a}	5.6^{a}	5.6^{a}	5.2^{a}	5.7^{a}
	18	233^{ab}	5.9^{a}	5.5^{a}	5.4^{a}	5.1^{a}	5.5^{a}
	20	225^{bc}	5.2^{b}	4.8^{b}	4.7^{b}	4.5^{b}	4.8^{b}
Sesame protein concentrate	14	240^{ab}	5.9^{a}	5.7^{a}	5.5^{a}	5.1^{a}	5.6^{a}
	16	232^{bc}	5.7^{a}	5.5^{a}	5.4^{a}	5.0^{a}	5.4^{a}
	18	221^{cd}	5.7^{a}	4.7^{b}	4.5^{b}	4.2^{b}	4.7^{b}
	20	210^{ef}	4.8^{b}	4.3^{c}	4.0^{c}	4.0^{b}	4.3^{c}

Means in the same column with different letters as superscripts are significantly different ($P < 0.05$).

Table 4. Chemical composition of bread fortified with sesame products (on dry weight basis)

Bread sample	Crude protein (%)	Ether extract (%)	Crude fibre (%)	Ash (%)	Total carbohydrates* (%)
Control	12.6[c]	1.38[ab]	1.26[b]	1.25[d]	83.5[a]
Sesame meal[a]	16.2[b]	1.52[a]	1.73[a]	2.43[b]	78.1[b]
Roasted sesame meal[a]	16.3[b]	1.59[a]	1.80[a]	2.20[b]	78.2[b]
Autoclaved sesame meal[a]	16.2[b]	1.63[a]	1.86[a]	2.83[a]	77.5[b]
Sesame protein isolate[b]	18.4[a]	0.94[b]	1.02[b]	1.84[c]	77.8[b]
Sesame protein concentrate[a]	16.2[b]	1.11[ab]	1.92[a]	2.90[a]	77.8[b]

*Calculated by differences.Means in the same column with different letters as superscripts are significantly different ($P<0.05$).
[a]16% protein level.
[b]18% protein level.

protein level, except sesame protein isolate which was added at 18% protein. Addition of sesame products to wheat flour increased the protein content significantly ($P<0.05$) from 12.63% for control to 18.42% for bread containing sesame protein isolate. No significant differences ($P>0.05$) in fat content were observed between wheat flour breads and sesame products breads, except for sesame protein isolate bread which had the lowest fat content. The crude fibre of sesame products breads was significantly different ($P<0.05$) from control except that of sesame protein isolate bread, which was not significant ($P>0.05$) and comparable to controls. Also, the addition of sesame products to wheat flour showed an increase in the ash content, while total carbohydrate content was reduced due to sesame products addition. These results are in full agreement with those reported by Khan *et al.* (1975), Hansmeyer *et al.* (1976), Rasco *et al.* (1989) and Salama *et al.* (1992).

Mineral content of breads

Table 5 shows the mineral contents of different sesame product bread. The results show that there was a marked increase in all mineral contents of the final bread product due to substitution with sesame products (compared to the control bread). These results are mainly related to sesame products which are a good source of minerals. Breads baked with sesame protein concentrate had higher contents of micro- and macro-elements than those of other sesame products bread. Generally, the same trend was reported by Salama *et al.* (1992).

Amino acid profile of breads

Table 6 shows the amino acid composition of breads. The addition of sesame products to bread increased the concentration of total essential amino acids, valine, lysine, leucine (except sesame meal) and total sulphur amino acid (except sesame meal and autoclaved meal). The lysine content of sesame product-containing breads was increased by 80–125% compared to control. These results agree well with those reported by Hansmeyer *et al.* (1976) and Salama *et al.* (1992). In the comparison of the amino acid composition of sesame products breads to the FAO/WHO (1973) pattern, it could be seen that sesame products breads contained similar or higher essential amino acids than the standard except for a modest deficiency in some essential amino acids such as threonine and tryptophan. The deficiency of these amino acids was not the result of sesame products addition.

In-vitro digestibility and biological value of breads

In-vitro digestibility and biological values of breads are given in Table 7. Bread containing sesame products had a significant difference for ($P<0.05$) *in-vitro* protein digestibility with the exception of sesame meal bread. The digestibility of bread containing sesame protein

Table 5. Mineral content of bread fortified with sesame products (on dry weight basis)*

Bread sample	Micro-elements (mg/100 g)				Macro-elements (mg/100 g)				
	Cu	Zn	Fe	Mn	Mg	Na	Ca	K	P
Control	0.42	2.06	3.12	1.27	66.3	461	98.4	100	120
Sesame meal[a]	1.73	6.33	4.41	1.73	190	420	121	140	140
Roasted sesame meal[a]	1.52	6.51	4.53	1.62	210	440	118	150	137
Autoclaved sesame meal[a]	1.85	5.62	4.36	1.60	200	430	131	145	141
Sesame protein isolate[b]	0.93	2.43	3.91	1.31	120	561	90	80	109
Sesame protein concentrate[a]	2.10	9.82	4.92	1.80	220	480	142	150	165

*Average of two determinations.
[a]16% protein level.
[b]18% protein level.

Table 6. **Amino acid composition of bread fortified with sesame products (g amino acid/16 g nitrogen)**

Amino acid	Control	Sesame meal[a]	Roasted sesame meal[a]	Autoclaved sesame meal[a]	Sesame protein isolate[b]	Sesame protein concentrate[a]	FAO/WHO (1973)
Threonine	3.06	2.70	3.20	3.29	2.99	2.87	4.00
Cystine	1.75	1.86	2.33	1.52	1.45	1.44	—
Methionine	1.29	1.15	1.59	1.10	1.70	1.65	—
Total sulphur amino acid	3.04	3.01	3.92	2.62	3.15	3.09	3.50
Tyrosine	4.44	4.61	2.67	4.02	3.76	3.81	—
Phenyalanine	5.26	5.04	5.31	5.21	5.32	5.13	—
Total aromatic amino acid	9.70	9.65	7.98	9.23	9.08	8.94	6.00
Isoleucine	4.08	3.92	4.06	4.16	4.11	4.14	4.00
Leucine	7.46	7.37	7.68	7.46	7.71	7.86	7.00
Lysine	1.88	3.75	3.38	4.23	4.16	3.99	5.50
Valine	4.95	4.95	5.35	5.47	5.54	5.55	5.00
Tryptophan	0.98	0.70	0.60	0.70	0.80	0.92	1.00
Total essential amino acid	35.2	36.1	36.2	37.2	37.5	37.4	36.0
Aspartic acid	4.50	5.42	5.37	5.97	5.64	6.03	—
Glutamic acid	29.5	25.8	25.8	24.5	23.2	22.9	—
Proline	12.3	10.8	10.7	9.38	10.2	8.93	—
Serine	5.29	5.14	5.47	4.81	4.62	6.07	—
Glycine	4.11	4.63	4.49	4.95	4.88	5.12	—
Alanine	3.43	4.00	3.93	4.54	4.43	4.84	—
Arginine	3.83	5.20	5.61	5.47	6.63	5.93	—
Histidine	1.89	3.01	2.47	3.31	2.88	2.80	—
Total non-essential amino acid	64.9	64.0	63.8	62.8	62.5	62.64	—

[a]16% protein level.
[b]18% protein level.

Table 7. ***In-vitro* protein digestibility and biological value of bread fortified with sesame products**

Bread sample	*In-vitro* protein digestibility*	Protein efficiency ratio (PER)	Essential amino acid index (EAAI) (%)	Chemical score (CS) (%)	First limiting amino acid	Second limiting amino acid
Control	71.2[d]	2.14	60.8	34.2	Lys (34.2)	Thre (76.5)
Sesame meal[a]	74.7[cd]	2.17	62.6	67.5	Thre (67.5)	Lys (68.2)
Roasted sesame meal[a]	76.0[bc]	2.32	63.6	60.0	Try (60.0)	Lys (61.5)
Autoclaved sesame meal[a]	77.8[ab]	2.28	64.8	70.0	Try (70.0)	Cys + Me + (74.9)
Sesame protein isolate[b]	80.6[a]	2.35	66.4	74.8	Thre (74.8)	Lys (75.6)
Sesame protein concentrate[a]	78.5[ab]	2.48	66.8	71.8	Thre (71.8)	Lys (72.6)

*Means in the same column with different letters as superscripts are significantly different ($P < 0.05$).
[a]16% protein level.
[b]18% protein level.

isolate was much higher than the other bread–sesame products. These results agree well with those reported by Gonzalez-Agramon and Serna-Saldivar (1988), who found that soybean isolate-fortified tortillas had a higher digestibility than 100% wheat flour and soybean meal-fortified tortillas. Generally, addition of sesame products to bread improved its protein digestibility over the control. Bookwalter *et al.* (1987) reported that fortification of sorghum flour with 15% soy meal increased the digestibility index from 75 to 84.4%. Therefore, the low protein digestibility of wheat could be improved by mixing with highly digestable protein such as those of sesame products. Addition of sesame products to wheat flour also improved the computation of essential amino acids index, protein efficiency ratio and chemical score, especially of sesame protein isolate and concentrate breads which were superior. Although lysine was the first limiting amino acid for full wheat bread (control), it was the second for sesame products. Generally, these results agree well with those noted by El-Adawy (1992), who reported that supplementation of wheat flour with detoxified apricot kernel meal improved the chemical score and essential amino acid index of the mixture.

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