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Original article

Nutritional Feasibility of Flour Purification

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Abstract

The aim of this work is to calculate the nutrient and economic loss associated with different extract rate (ER) flours for use in the production of flat Arabic bread (Kmaj), and to come up with recommendations for decision makers on the feasibility of raising the ER of the flour used in its production. A review of literature was undertaken through a comprehensive search of pertinent work using keywords: wheat purification, whole wheat bread, white bread, Arabic bread in the databases of PubMed, Scopus and Google scholar. The levels of protein, vitamins, minerals and fiber content of the various ER levels of Hard Red Winter wheat flours, obtained from published literature were tabulated and averaged. Loss of the nutrients based on the nutrient content of this flour was calculated and graphically represented from the tabulated data. Analysis of Variance was performed with means separated by Duncan Multiple Range Test using SPSS program. Correlations between the different variables, and prediction equations of nutrient losses from the extraction rates of this flour were constructed. The review, supported with figures, concluded that using higher (ER) flour in bread production would result in its improved nutritional value, and in economic savings especially for countries which rely on wheat imports to feed their populations. The millers welcomed the suggestion to increase the ER of the straight grade flour to 80%, while bakers had reservations about the idea citing negative impact of the bran and the resulting consumer rejection of the bread. Based on these results, it is recommended to increase the extraction rate of the flour used in the production of the subsidized flat bread to at least 80%.

Keywords: Whole Wheat Flour, White Flour, Flat Bread, Nutrients, Extraction Rate

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INTRODUCTION

Anatomically**,** wheat grain is composed of the endosperm which makes about 81-83% (W/W) of the kernel and constitutes all of the flour obtained, the bran which includes the aleurone layer (about 13-15%), and the germ (2-3%) (Szuba-Trznadel et al.2024). The amount of flour obtained from 100 Kg. of wheat is known as extraction rate (ER) (JISM,2005). The lower the ER of the flour, the lighter it is in color due to lower bran content, but the lower it is in vitamins, minerals, and protein. Straight grade flour, with ER ranging between 72-80%, is the most commonly- produced flour grade by millers, and used for bread production worldwide including Middle East and North Africa (MENA) region countries. In addition to flour, bran and germ are also produced as byproducts in the mills, and used as animal feed, in the production of high- fiber bakery products ,and as nutritional supplement (Mohammadi et al.,2020; Brandolini and Hidalgo,2012).

The degree of purity of the flour used in bread production, and hence its ER, is influenced by a number of factors and considerations including social, economic and political, as consumers usually prefer lower extraction bread due to its more appealing light color, and more palatable mouthfeel (Kwak et al.,2019; Tauferova and Hellingerova (2023)). The classical example of the influence of the economic considerations on the extraction rate of flour is the introduction of the scratch stage to the milling system in the UK during WWII to increase the amount of bran in the flour, and increase the ER and the amount of flour obtained from the same quantity of wheat (Kent and Evers, 1994). Higher ER flour is obtained in the mill by a number of methods such as increasing each of break release (Li and Posner, 1989) and the surface of bran finishers, or lowering the amount of tempering water (Kweon et al., 2009),or simply by adding bran to the finished flour (Yan and Ma, 2022).

The flour used in bread production varies worldwide in the different countries. In Jordan, 75% ER is used by bakeries for the subsidized thin Kmaj production (Amr & Ajo,2005), compared to 78-80% in Lebanon (Georges et al., 2018), 82% in Egypt (Hussein et al., 2024); while in Tunisia 87% ER is used for the production of French – type bread (Al-Jawaldeh,2025). Egyptian Baladi bread contains more fiber as the sheeted doughs are dusted with bran (Fahmy and Abd-Elmaksoud,2020). Bread in the USA and European countries is prepared from 72-76% extraction rate flours (Bakerpedia,2023) which meets the upper extraction limits of the straight grade flour set by those countries.

Bread, prepared from different ER wheat (*Triticum aestivum*) flours, is the staple food in many parts of the world (Callejo,2011). In the Levant countries and Egypt, the flat pocket- forming bread known as Kmaj, Pita, Lebanese, pocket, Baladi, and Arabic bread is the most common type (Georges et al.,2018; Amr and Al-Khamaiseh,2022), although other types such as Hamam ,Sammoun, Mashrooh, Mankoosh, Shrak, Saj, and Armani etc… are also produced (Amr, 1988). Flat pocket bread is produced following the straight dough method, and baked mostly in continuous, mechanical ovens at temperatures up to 500°C for less than a minute, which results in pocket formation due to steam puffing of the loaves, rather than oven rise as in pan and French types (Amr and Ajo,2005).

In addition to being a calorie carrier, pocket bread serves a number of roles in a typical meal including dipping, spooning, rolling, pocket formation and plate lining (Amr, 1988). However, other types of bread are produced to perform one or more of these functions, and are treated differently during production with respect to fermentation regime, sheeting, proofing and baking time& temperature, and method (Amr and Ajo,2005).

The nutritional value of the unfortified bread depends on the degree of ER of the flour used in its production (Slavin et al. ,2000; Bwarshi et al. ,2022). Whole grain bread (100% ER) contains all nutrients in the wheat grain including protein, minerals, vitamins, antioxidants and enzymes (Ragaee et al.,201; Zong et al., 2016; Li et al.,2023). Lower ER bread suffers more nutrient loss, which is compensated for by supplementing the flour with vitamins and minerals in the forms of restoration or fortification (Cardoso et al.,2019; Shehadeh,2021, WHO,1998). Other factors affect nutritional value of bread include baking temperature and time, and fermentation regime (Bwarshi,2019).

It is well established that consuming high – fiber foods including whole- grain and bran bread is associated with improved health including reduced risk of diabetes, cardiovascular diseases and cancer (Sawicki et al.,2023), despite its high content of the antinutrients phytic acid and tannins which bind non- heme divalent iron as well as Mg and Ca (Amr,1986; Brier et al., 2015). Indeed, a number of health concerned world, local and regional organizations including World Health Organization (WHO) recommended the consumption of 2-3 whole- grain servings/ day to achieve the desired health benefits (Ferruzi et al., 2014; ucsfhealth,2024). Among Arab countries, only the Sultanate of Oman has guidelines for whole grain consumption and recommends 2-3 servings/ day (Ferruzi et al., 2014).

Although consumption of whole-grain bread falls short of the recommended levels (Damman et al.,2013), there has been increased demand for this type of bread worldwide (Doblado-Maldonado et al., 2012; Sluyter et al., 2022). In many Middle Eastern Arab countries, there has been increased whole-grain bread production by most bakeries which is due to the increased health awareness, and demand for healthy foods by consumers (Alfawaz et al.,2020, Hoteit et al.,2024) However, the less -than hoped demand on this healthy staple is due mainly to eating habits by consumers, organoleptic quality and high price of whole-grain bread (Barrett et al., 2020).

The effect of flour ER on dough rheology and sensory properties of bread has been the subject of a number of studies. It has been reported (Mueen-ud -din et al., 2010; Rababah et al.,2019; Taufverova and Hellingerova,2023) that high ER flours showed decreased stability and mechanical Tolerance Index (MTI) of the dough, while water absorption and dough development time increased, which could present a problem for bakers by demanding more caution while handling doughs prepared from this type of flour (Li and Wu,2024).

The objective of this work is to review the literature on the composition of the different ER flours with respect to their content of vitamins and minerals. Tabulate the values and use them to calculate the amounts of nutrient losses suffered by producing different ER flours, and the percent contribution of each 100 grams of each flour extraction to the Estimated Average Requirements (EAR). Finally, the economic saving per each 1 million tons of wheat imports upon increasing the ER in the mill by 1% .

METHODOLOGY

Nutrient content of flour: Some B vitamins (thiamin, riboflavin, niacin, pyridoxin and folic acid), protein and mineral content of different ER flours were obtained from published literature and unpublished graduate work (supervised by the corresponding author) (Barrette et al.,2020; Bwarshi,2019; Kent and Evers,1994; Slavin et al.,2000; Shehadeh,2021; USDA,2014). The percent loss of each nutrient, based on whole grain Hard Red Winter flour, was calculated and graphically represented. Contribution of 100 grams of flour to the EAR of vitamins and minerals was calculated for the various ER flours.

Statistical analysis: Using SPSS (IBM,2020) program; the effect of ER on vitamin loss and content was calculated by Analysis of Variance followed by Duncan Multiple Range test for mean separation. Correlations and regression between the various variables was performed.

Millers and bakers' perspective: Ten of each of millers and bakers from Amman/ Jordan area were interviewed to explore their opinion on increasing the ER of the flour used in the government-subsidized bread to 80%. The interview included discussions of the economic, social and technical challenges of increasing the extraction rate of the flour from both millers' and bakers' perspectives.

RESULTS AND DISCUSSION

Vitamin content of the various extraction wheat flours : Data in table1 show the vitamin content of the various ER flours as in a number of works (Kent and Evers, 1994; Slavin et al.,2000; Bwarshi,2019 ; USDA,2014). Data show that wheat flour content of B group vitamins increases by increasing its extraction rate.

Table 1. Vitamin content of different extraction rate flours milled from Hard Red Winter wheat*

	Extraction rate						
Vitamin** (ug/g)	65	75	80	85	95	100	*p*-value
Thi	1.45±0.05b	1.95±0.25b	2.73±0.68b	4.41±0.39a	5.08±0.33a	5.41±0.39a	0.001
Rib	0.21±0.16c	0.23±0.17c	0.41±0.05cb	0.64±0.06ab	0.81±0.02a	0.93±0.03a	0.009
Nia	7.70±4.30a	10.10±4.90a	11.95±6.05a	15.55±5.45a	21.40±2.10a	24.60±0.60a	0.167
Pyr	0.70±0.60c	0.85±0.55c	1.58±0.13cb	2.74±0.66b	6.20±0.40a	6.90±0.60a	<0.001
Fol	0.05±0.01c	0.09±0.02c	0.10±0.02c	0.42±0.04b	0.54±0.01a	0.58±0.01a	<0.001

*Values are means of three replicates followed by standard error (SE). Means within the same row with the same matching letters are not significantly different (P≤0.05) according to Duncan Multiple Range Test, n=18.All values are on dry matter basis.

** Thi= Thiamin; Rib=Riboflavin; Nia= Niacin; Pyr= Pyridoxin; Fol= Folic Acid.

(Sources: Kent and Evers, 1994; Slavin et al.,2000; Bwarshi,2019 ; USDA,2014).

Among the B vitamins studied, niacin (B3) levels are the highest among all other vitamins with values ranging between 7.7 and 24.6 ug/g in 65% (patent) and 100% (whole wheat) ER flours respectively. The level of this vitamin was not significantly (P≤0.05) influenced by the extraction rate, indicating that it is available throughout the grain parts (bran and endosperm layers), though more in the outer layers of the grain, particularly the aleurone layer. Aleurone is the outermost layer of wheat endosperm and is lost with the bran fraction. Practically, no significant amounts of niacin are lost when bread from refined flour is consumed as it is the most heat stable (retained) B- vitamin in flat bread (Shehadeh,2021). Consequently, niacin was excluded from micronutrient surveys carried out in Jordan (JMOH,2019). The nutritional value of the bread is improved further by fortification of the Straight-Grade flour with B- vitamins including niacin. Even after fortification, niacin levels remain higher in whole wheat flour than in the fortified Straight Grade flour (Shehadeh,2021) which justifies a review of flour fortification levels where high ER (80% or above) is used.

The second highest B-vitamin in the flour is Thiamin (B1) with values ranging between 1.45 ug/g and 5.41 ug/g in 65% and 100% extraction flours respectively. This vitamin increased significantly (P≤0.01) by increasing flour extraction to levels up to 80%. Egyptian Baladi bread is produced from 82% or higher extraction flour, thus maintaining its high level especially as the sheeted doughs are dusted with bran (Fahmy and Abd-ElMaksoud,2020). Thiamin level in the 75% ER flour used in the production of most bread types in Jordan, is lower than niacin level even in higher extraction grades of flour. Unlike niacin, this vitamin is more concentrated in the bran (mainly aleurone layer) as compared to the interior layers of the endosperm.

Pyridoxine (Vitamin B6) is the third highest of this group in the flour with values ranging between 0.7 ug/g and 6.9ug/g in 65% extraction (patent), and whole wheat flour respectively. This indicates clearly that it is more concentrated in the bran than the previous two vitamins, as its level increased sharply in the fractions containing higher bran levels.

The other two vitamins folic acid(B9) and riboflavin (B2) follow the same patterns with respect to their levels in the flour. They start to increase significantly in flours above 80% extraction rates. Their concentrations in the whole wheat flour are 5-10 folds that in the patent flour (below 70% extraction). This pattern indicates that they are more concentrated in the bran than the other vitamins.

Increasing extraction rate of the flour above 80% results in increased levels of B vitamins to levels equal to, or even more than, those in the fortified Straight-Grade 75% ER flour (Shehadeh,2021).

Vitamin Loss as a result of flour purification:

Data in table 2 show the loss of B vitamins as a result of flour purification as calculated from the data in table 1 using whole wheat flour content as base for calculation . It is clear that as the extraction rate increases the vitamin loss decreases although not linearly. Nurit et al. (Nurit et al., 2016) reported significant losses of B vitamins from purified wheat milling fractions, although some of these vitamins were in the bound form and could be released in further processing steps of bread making. Batifoulier et al. (2006) also reported that the purification of flour is the most important factor in determining its content of B vitamins. This is due to the fact that most vitamins and other bioactive compounds are concentrated in both the bran, especially the aleurone layer, and the germ of the grain, which are lost with flour purification (Meziani et al., 2021; Lebert et al., 2022). This underlines the importance of including the highest possible amounts of bran in the flour to get the benefit of these vitamins. The greatest loss of individual vitamins was in case of folic acid (B9) followed by pyridoxin (B6). This is due to their higher levels in the bran compared to the endosperm. Batifoulier et al. (2006) reported moderate losses of thiamin, riboflavin and pyridoxin in low extract flours. Niacin suffered the least losses in the lower extraction flours (65-75% extraction) compared to other vitamins which supports early suggestion of its presence throughout the grain and not only in the aleurone layer of wheat (Petrovska-Avramenko et al.,2016). There was no significant difference between the highest ER (95-100) flours in the loss of all vitamins, as they include almost similar proportions of grain parts including bran and germ, albeit folic acid and pyridoxin suffered less losses at 95% extraction indicating their concentration in the bran.

Table 2. Effect of extraction rate of the Hard Red Winter wheat flour on the vitamin loss (%)*

Vitamin**	Extraction rate (%)					
	65	**75**	**80**	**85**	**95**	**100**
Thi	72.5a	64.0a	50.0ab	32.5cb	13.5cd	0.0d
Rib	77.5a	75.5a	56.0ab	31.0bc	13.0c	0.0c
Nia	68.5a	58.5a	51.0a	36.5a	12.5a	0.0a
Pyr	90.5a	88.0a	77.0a	38.5b	7.5c	0.0c
Fol	91.0a	84.5a	83.5a	28.0b	7.0c	0.0c

* Based on the content of 100% extraction and data in table 1. Each value is the average of 3 replicates. Values in the same row with the same matching letters are not significantly ($P \leq 0.05$) different according to Duncan Multiple range test, n=18.

**Thi=Thiamin, Rib=Riboflavin, Nia=Niacin, Pyr=Pyridoxin, Fol=Folic acid.

Correlations and regression between extraction rate of flour and its vitamin content: Table 3 shows the correlation coefficients between the extraction rates and the vitamin content of the flour. Data show that there are highly significant (P ≤0.01) positive correlations between the ER of the flour and its content of all vitamins. Correlations between all vitamins was also highly significant except in case of niacin which correlated only significantly (P≤0.05) with thiamin, riboflavin and pyridoxin. Its highly significant correlation with folic acid indicates similar distribution pattern within the grain despite the variation in the levels of the two vitamins.

Table 3. The Correlations between Extraction Rate and Different Vitamin content.

Vitamins		Extraction rate (%)	Thi ug/g	Rib ug/g	Nia ug/g	Pyr ug/g	Fol ug/g
Thi ug/g	R	0.935**		0.935**	0.651*	0.916**	0.959**
	p-value	<0.001		<0.001	0.022	<0.001	<0.001
Rib ug/g	R	0.909**	0.935**		0.593*	0.939**	0.932**
	p-value	<0.001	<0.001		0.042	<0.001	<0.001
Nia ug/g	R	0.798**	0.651*	0.593*		0.695*	0.735**
	p-value	0.002	0.022	0.042		0.012	0.006
Pyr ug/g	R	0.926**	0.916**	0.939**	0.695*		0.932**
	p-value	<0.001	<0.001	<0.001	0.012		<0.001
Fol ug/g	R	0.928**	0.959**	0.932**	0.735**	0.932**	
	p-value	<0.001	<0.001	<0.001	0.006	<0.001	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 4 shows the results of the regression analysis between the vitamin content and the extraction rate as independent variable. The same table shows the variables of the prediction equations Y=α+β X where Y is the vitamin content and X the extraction rate

Table 4. Linear Regression analysis between the vitamins (X dependent variable) and the extraction rate (Y independent variable).

Vitamins	β	Std. Error	95% CI	α	p-value *	R2 Change	% of Change	p-value *
Thi (ug/g)	0.126	0.015	0.09-0.16	-6.98	<0.001	0.873	87.3	<0.001
Rib (ug/g)	0.023	0.003	0.02-0.03	-1.34	<0.001	0.827	82.7	<0.001
Nia (ug/g)	0.505	0.121	0.24-0.77	-26.83	0.002	0.636	63.6	0.002
Pyr (ug/g)	0.200	0.026	0.14-0.26	-13.51	<0.001	0.857	85.7	<0.001
Fol (ug/g)	0.017	0.002	0.01-0.02	-1.6	<0.001	0.861	86.1	<0.001

**p*-value is significant at the 0.01 level.

Minerals, protein and fiber: Table 5 shows the protein, fiber and mineral content of the various ER flours. All of these nutrients increase in the flour by increasing its extraction rate. It is well known that all nutrients, with exception of starch i.e. energy, are less concentrated in the inner parts of the wheat grain (Kent and Evers,1994). Higher ER means less percentage of starch and more of these nutrients. This is due to the fact that most minerals are concentrated in the outer layers of the grain mainly as phosphates and carbonates of calcium, magnesium and potassium (Kraler et al.,2014 ; Brier et al.,2015). Their high levels impart a dark color on higher extraction flours and cause them to have a higher ash content, the level of which is used for flour grading by regulatory agencies (JISM, 2005; Awulachev,2020). Lower ER flours produce bread with lighter, and more appealing color than the darker higher ER ones. Unlike, the minerals and fiber, the protein is distributed more evenly in all flour extractions, and consequently there is little observed difference in the protein content between the high and low ER flours (table5). Protein, although more concentrated in the aleurone layer, its absolute quantity is higher in the endosperm which makes the bulk of the grain where it is present in the interstices of cells as adhering and wedge proteins (Vose,1978).

Figure 1 shows the effect of flour refining on the loss of minerals, fiber and protein. As expected, there is more loss of minerals in the lower extraction flours. Crude fiber, which is composed mainly of cell wall components, is concentrated in the bran and follows the same distribution pattern as the minerals i.e. more concentrated in the bran than in the inner parts of the grain. Hence, lower extraction flours have less fiber than higher extraction ones (figure 1). Dietary fiber in wheat is usually more than crude fiber as it includes, in addition to cell wall components, such compounds as pectin, parts of starch and resistant starch (Dai and Chau,2017). Due to its distribution pattern throughout the grain, there was little observed difference in the loss of protein as a result of flour purification between the flours within the low-extraction group (65-80%) and those within the higher extraction (85-100%) (figure 1).

Table 5. Mineral, protein and crude fiber content of different extraction wheat flours*.

	Extraction Rate					
Nutrient	65	75	80	85	95	100
Calcium(mg/100g)	23±0.71	27±2.0	28±0.73	15±0.97	44±0.59	45±1.2
Phosphorus(mg/100g)	131±2.47	140±11.0	164±3.06	225±2.83	376±3.58	410±2.8
Zinc(ppm)	10.3±0.35	10.3±2.0	11.0±0.28	16.7±0.73	23.2±0.89	27±0.94
Cupper(ppm)	1.25±0.16	2.45±0.8	2.3±0.14	2.6±0.12	3.3±0.19	3.8±0.02
Iron(ppm)	10±0.21	13±0.9	15±0.30	28±0.57	33±0.15	35.5±0.59
Protein(N*6.25)	12.3±0.16	13.11±0.8	12.9±0.19	13.4±0.12	13.5±0.14	13.8±0.07
Crude fiber(g/100g)	0.17±0.01	0.17±0.005	0.26±0.02	1.0±0.002	1.9±0.005	2.2±0.002

*Values are means of 3 replicates ±standard error SE on dry matter basis.

(Sources: Kent and Evers; Shehadeh, 2021; Slavin,2000)

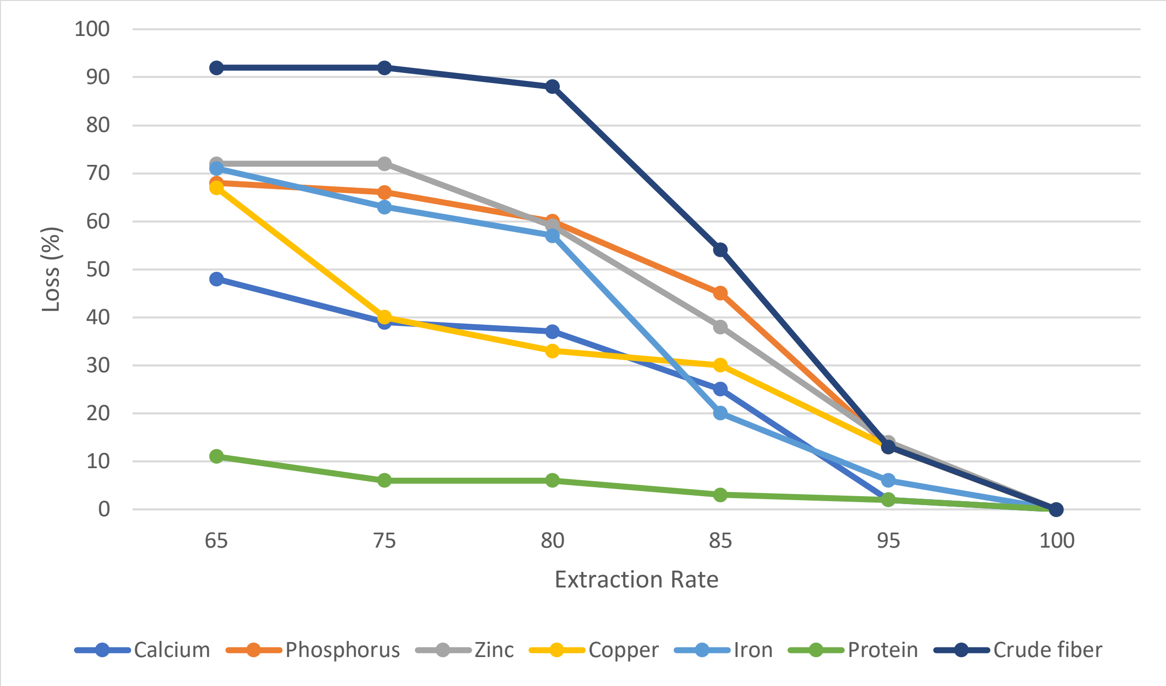

Figure 1. Percent loss of protein, fiber and minerals in different extraction rate Hard Red Winter wheat flours as calculated from table 5 based on 100% extraction flour.

Practical nutritional implications: Figure 2 shows the amounts of nutrients 100 grams of different ER flour contribute to the Estimated Average Requirements (EAR) of the B vitamins included in the study.

As expected, the contribution of the different flours to the EAR increased by increasing their extraction rate. Thiamin and pyridoxin were the highest contributed B vitamins to the EAR, with 54% and 49% respectively, followed by niacin and folic acid. The least contributed vitamin was riboflavin which is due to its low level in the flour (table 1). A daily per capita consumption of 210 grams of whole wheat flour which translates to about 300-350 grams of whole wheat bread (Shehadeh,2021; Amr & Ajo,2005) should provide enough of these vitamins. However, these figures do not account for neither the loss during baking which amounts to about 30% of thiamin, riboflavin and niacin, and about 20% of pyridoxin and folic acid (Bwarshi, 2019), nor their bioavailability which is influenced by a number of factors (Said, 2011).

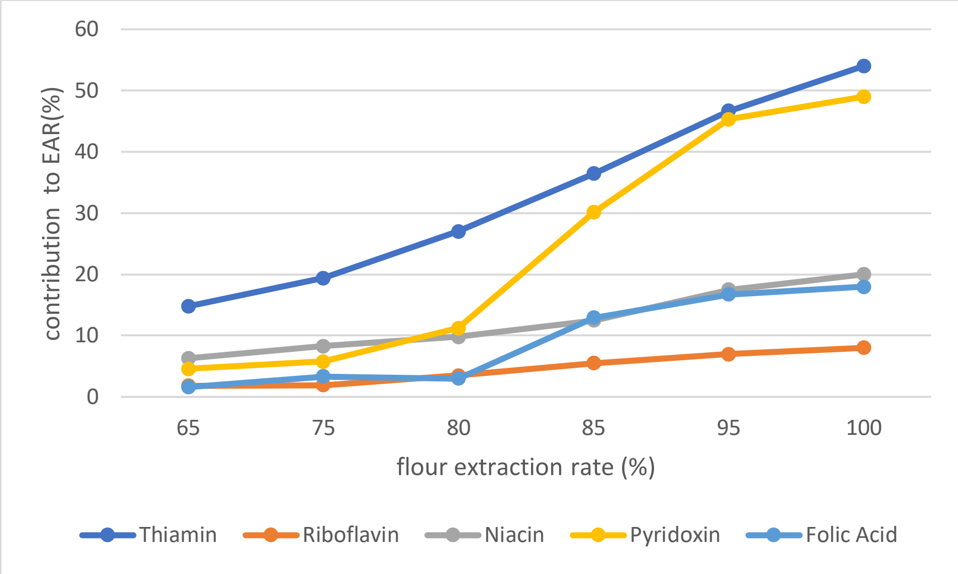

Figure 2. Percent of B vitamin contribution by 100 grams of different extraction flours to EAR.

The same trend is observed in case of protein and minerals, i.e. contribution increases with the ER of flour (figure 3). However, it is noticed that contributions of the different flours to the EAR of protein are similar which is, as indicated earlier, due to the little difference between the different flours in their protein content (table 5). In theory, phosphorus, iron and copper are the most contributed minerals, while zinc and calcium are the least due to both their high requirements, and low absorption and bioavailability by the body since they, and other divalent ions are bound by phytic acid and tannins in the bran (Weaver,2000; Hambidge et al.,2011; Longin et al.,2020) irrespective of their levels in the flour.

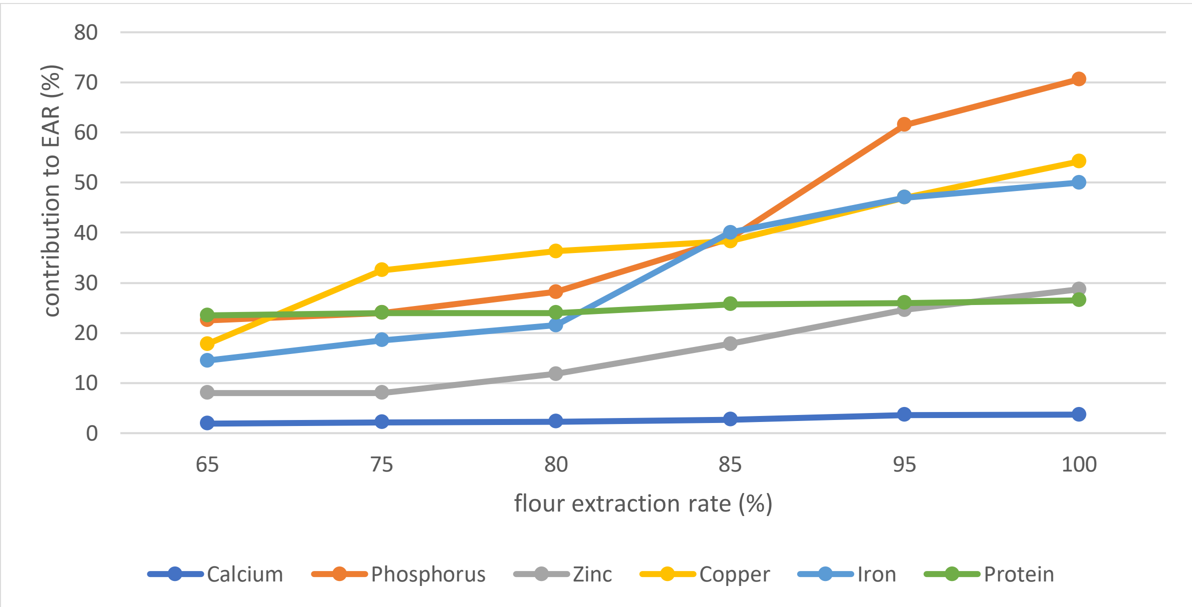

Figure 3. Percent of minerals and protein contribution by 100 grams of different extraction flours to the Estimated Average Requirements (EAR) of these nutrients.

Economic considerations: For most Arab countries which import their wheat from Eastern Europe (USDA,2025) at a cost of about US $400/ton including subsidy, transportation, cleaning loss, and milling cost (JMIT,2025). Each 1% increase in the ER of flour would mean a saving of about 4 million US $ for each 1 million tons of imported wheat.

Millers and Bakers Perspective: Millers and bakers were interviewed to explore their opinion on increasing the ER of the flour delivered to the bakeries to 80%. It was clear that millers had no objection to increasing the ER of the subsidized flour to 80%, citing that this would not present any technical difficulties and that the milling systems are ready to deal with the change. On the other hand, bakers had reservations about the increase due to worries about decreased demand on bread, and difficulties in handling high bran (high bran)doughs which requires special attention, and necessitates changes in the machinery of the existing baking systems. A common problem faced by bakers dealing with other types of bread (Li and Wu,2024).

CONCLUSIONS

This review shows that higher ER flours contain higher levels of B vitamins, protein, minerals and fiber. Niacin is the most abundant B vitamin in wheat flour and riboflavin is the least. Increasing the ER increases the amounts of nutrients in the flour and the bread prepared therefrom, while reducing it results in flour with lower nutritional value due to the high losses of nutrients in the bran lost in the course of purification. It is concluded that increasing the extraction rate of the flour would enhance the nutritional value and health benefits of the bread and could reduce the levels of nutrients added to bread. It also would result in a total saving of about 4 million $ US on each million tons of wheat imports. Using this flour for the preparation of the flat bread would not present serious issues for millers, yet it would require special attention by bakers due to changes in the physical dough properties caused by bran addition.

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