Fortification basics

Wheat Flour

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Wheat is one of the most widely produced cereal crops in the world and most is destined for human consumption.

Used in a broad range of every day food products, it makes up a significant percentage of energy intake – particularly in the Americas and Western Asia (**Table 1**).

A relatively small number of industrial mills process whole wheat into wheat flour which is then used in a range of applications including bread, biscuits and pasta.

Due to its broad geographic availability, consumer acceptance, stability and versatility, wheat flour is considered a highly suitable vehicle for delivering micronutrients to large segments of the global population.

Table 1: **Per capita wheat supply in selected countries, 2013**[1]

Country	Food supply quantity (person/day)
Turkey	466 g
Egypt	402 g
Jordan	375 g
Pakistan	311 g
Uruguay	300 g
Chile	287 g
Argentina	282 g
Saudi Arabia	245 g
South Africa	165 g
Peru	154 g
Bolivia	137 g

Country	Food supply quantity (person/day)
Venezuela	135 g
Guatemala	98 g
Mexico	96 g
Kenya	95 g
Ethiopia	86 g
Indonesia	70 g
Philippines	63 g
Nigeria	57 g
Tanzania	44 g
Ghana	40 g

Micronutrient content of wheat and wheat flour

Whole wheat is a good source of vitamins B1 (thiamine), B2 (riboflavin), niacin, B6 (pyridoxine) and E, as well as iron and zinc. Yet, because most of these valuable nutrients are concentrated in the outer layers of the wheat grain (**Figure 1**), a significant proportion is removed during the milling process depending on the flour type with extraction rates ranging from 40% for white flour (405 type) to 70-75% in terms of flour for bread (type 1050) and 100% for whole grain flour (**Figure 2**).

Figure 1: **Schematic diagram of the wheat grain**

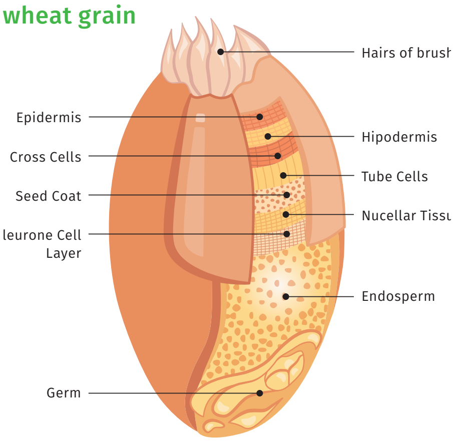
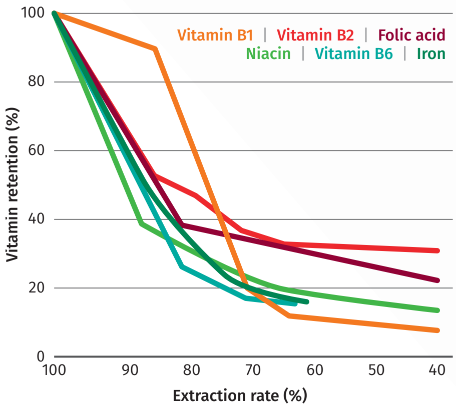


Figure 2: **Changes in micronutrient content of wheat grain with milling[2]**



Flour for bread has mainly an extraction rate of 70-75%

Fortifying wheat flour

In developed countries, the practice of adding micronutrients, such as vitamins B1, B2, niacin and iron, to wheat flour is recognized as an effective way to improve the nutritional profile of the food supply, compensating for the nutrients lost during the milling process. In countries where the overall diet of a population is lacking specific micronutrients, the World Health Organization (WHO) recommends further fortification. Table 2 shows recommended levels of iron, zinc, vitamin A, folic acid and vitamin B12 based on the amount of wheat flour consumption.

Table 2: **Average levels of nutrients to consider adding to fortified wheat flour based on extraction, fortificant compound and estimated per capita flour availability[3]**

Nutrient	Flour extraction rate	Compound	Level of nutrient to be added in parts per million (ppm) by estimated average per wheat flour availability (g / day)			
			<75	75-149	150-300	>300
Iron	Low	NaFeEDTA	40	40	20	15
		Ferrous Sulphate	60	60	30	20
		Ferrous Fumarate	60	60	30	20
		Electrolytic iron	NR	NR	60	40
	High	NaFeEDTA	40	40	20	15
Folic Acid	Low or High	Folic acid	5.0	2.6	1.3	1.0
Vitamin B12	Low or High	Cyanocobalamin	0.04	0.02	0.01	0.008
Vitamin A	Low or High	Vitamin A Palmitate	5.9	3	1.5	1
Zinc	Low	Zinc Oxide	95	55	40	30
	High	Zinc Oxide	100	100	80	70

NR: not recommended

Fortification requirements

The process of flour fortification is simple. The first step is to formulate a premix blend containing the required vitamins and minerals – in formats which are suitable for this application. This approach is far more effective than adding the micronutrients individually, as it offers a number of important advantages:

- Enhanced consistency and homogenous distribution of micronutrients.
- Ability to test the addition rate of the premix via only one or two micronutrients in the flour (depending on legislation).
- Lower costs due to the reduced purchase, transport and storage needs of one ingredient compared to many.
- Easier logistics in terms of adding one micronutrients to the flour.
- More likely to promote an effective quality assurance system.
- Reduction in quality control requirements for incoming raw material.

Ensuring homogeneity of micronutrients in the fortified flour is essential not only to avoid any negative impact on the sensorial characteristics of the final product, but also to ensure accurate dosage in every batch. This means that similar particle size distribution must be addressed as part of the fortification process, irrespective of whether it involves the addition of a single nutrient or vitamin-mineral-premix. A consideration which has the added advantage of helping to prevent segregation taking place during production, packaging or transportation.

The standard for wheat flour and its particle size in general is set by the Codex Alimentarius[4] which states that: "98% or more of flour shall pass through a 212 micron (No. 70 sieve)," according to analysis method AOAC 965.22.

Further detailed direction on compliance is provided by the USDA Commodity Requirements for wheat flour and bread flour for use in international food assistance programs.[5]

This includes a framework for products containing encapsulated vitamin A palmitate (250,000 IU vitamin A palmitate/g) – the form of vitamin A commonly used in flour fortification – such as:

- at least 98% of encapsulated vitamin A palmitate must pass through a US standard No. 50 sieve (297 µm), a minimum of 90% through a US Standard No. 60 sieve (250 µm) and at least 45% through a US Standard No. 100 sieve (149 µm).

The same framework requires a vitamin A stability test in fortified wheat or bread flour – such as:

- No more than 20% of vitamin A's original activity must be lost when fortified wheat flour is stored for 21 days at 45°C in a sealed container – where the target level is 11,000 IU vitamin A palmitate/lb and moisture content between 13.5-14.5%.

Iron fortification is also subject to clear guidelines. When average daily consumption of low extraction (<=0.8% ash) wheat flour is 150g-300g, the recommendation is for 20ppm iron as NaFeEDTA or 30ppm as dried ferrous sulphate or ferrous fumarate to be added. If sensory changes or costs limits the use of these compounds, electrolytic iron at 60ppm is the second choice. However, electrolytic iron is not recommended for daily wheat flour intake of <150g.[3] Formulating them in combination with iron chelates (eg NaFeEDTA), can improve overall bioavailability[6] – especially in whole grain flour. In addition coarser particles have a tendency to segregate on pneumatic conveying systems during production and so may be extracted by magnets used to remove contaminants.

For high-extraction wheat flour (>0.8% ash), NaFeEDTA is the only iron compound recommended. Many countries have adapted their legislation accordingly and specify the use of this more bioavailable form (**Table 6**).

Fortification process

The micronutrients are usually added at a dosage of 100-500g/t through a gravimetric or volumetric feeder (**Figure 3**) which is positioned towards the end of the milling process. The most commonly used volumetric device consists of a motor- driven feed screw which rotates inside the chamber to push the premix through an outlet spout. The addition rate of the premix to the flour can be regulated and managed by adjusting the motor speed of the spindle.

The premix can be fed directly into the flour either by gravity or by air convection with the aid of a pneumatic system. Whichever method is chosen, it is very important to ensure that the micronutrients and flour are mixed well in order to achieve a homogeneous consistency – an outcome which is largely dependent on the position of the feeder.

Experience has shown that in a gravity driven system, the best site for adding micronutrients is before the mid-point; along the screw conveyor that collects flour from the mill passages and just before the bulk storage or sacking (**Figure 4**). When it comes to a pneumatic system, however, a remote centralized location is preferable.

Table 3: **Example of a premix composition**[7]

Nutrient	Level / kg flour	Product Form	g product form / kg premix
Vitamin A	5950 IU	Vitamin A Palmitate 250	88.147
Thiamine	1.94 mg	Thiamine Mononitrate	8.864
Riboflavin	1.77 mg	Riboflavin FP	6.901
Niacin	23.7 mg	Niacinamide	85.212
Pyridoxine	2.63 mg	Pyridoxine Hydrochloride	11.840
Folic Acid	1.43 mg	Folic Acid	5.852
Vitamin B12	5.00 mg	Vitamin B12 1% SD	1.852
Iron	15 mg	NaFeEDTA	428.00
Zinc	30 mg	Zinc oxide	134.253
Carrier			q.s.

Figure 3: **Volumetric feeder to add micronutrient premix**

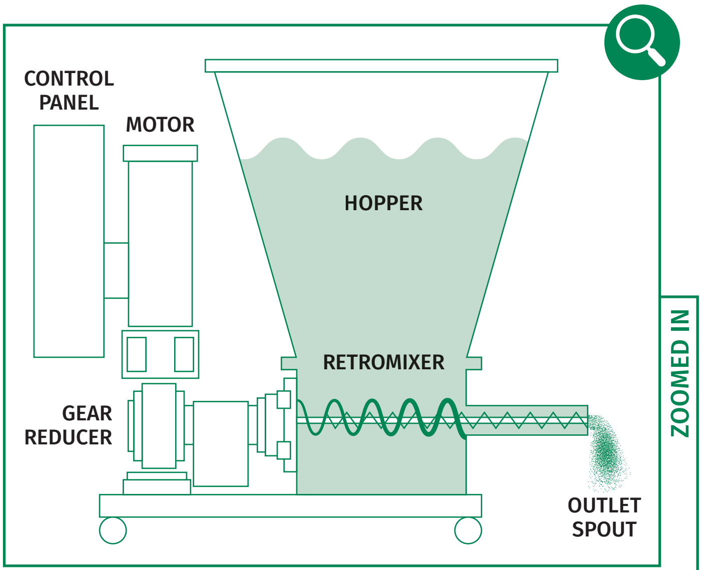
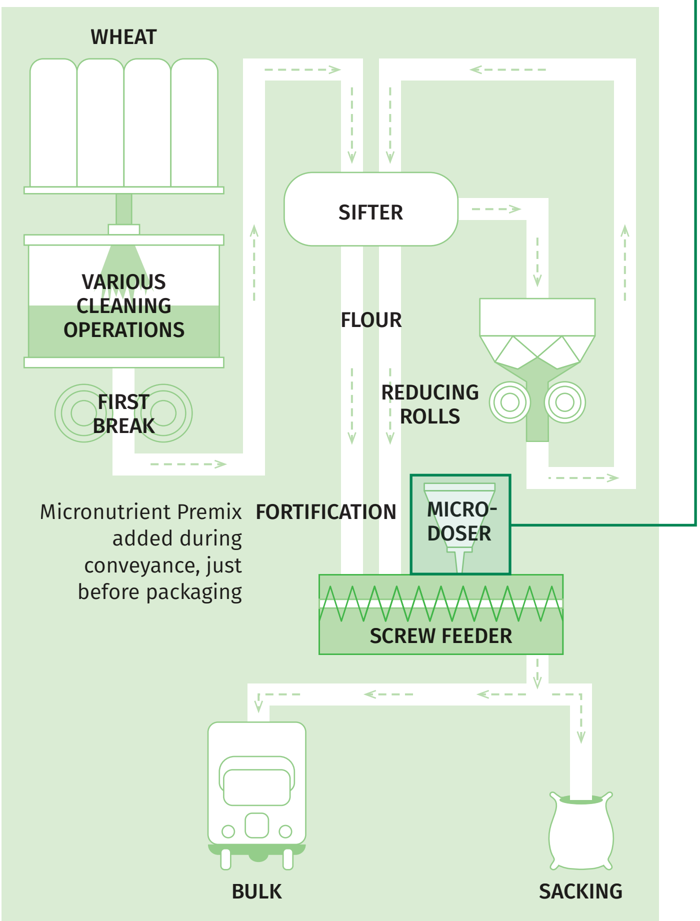


Figure 4: **Simplified flow chart for flour milling**



Micronutrient stability

The stability of vitamins in foods is more precarious than minerals due to their sensitivity to heat, oxidizing and reducing agents, as well as light and other kinds of physical and chemical stress. In flour, however, vitamins are relatively stable but there are important considerations. Vitamin A, for example, is adversely affected by both high humidity and temperatures, so encapsulated forms are widely used to overcome this issue. There is also some evidence of minor losses of other vitamins during flour storage (**Table 4**).

Yet when it comes to using fortified wheat flour in key applications, nutrient retention is generally good. Baking can be carried out at a hot 200°C, but the temperature inside the product will be significantly lower; resulting in only limited loss of vitamin A and no change to over 90% of the other added vitamins (**Table 5**).

Table 4: **Stability of vitamins in flour (12%) stored for 6 months at room temperature**[8]

	Label claim (per kg)	Initial content (per kg)	Retention (%)
Vitamin A	16000IU	18000 IU	100
Vitamin B1	6.4 mg	7.1 mg	101
Vitamin B2	4.0 mg	4.0 mg	100
Vitamin B6	4.4 mg	5.6 mg	100
Niacin	52.9 mg	56.0 mg	100
Folic acid	0.7 mg	0.7 mg	96
Iron	88.1 mg	94.6 mg	100
Moisture		***12.1 %***	***12.5***

Table 5: **Nutrient losses during typical bread baking**[8]

Vitamin	Level added (per kg)	Retention (%)	
		After baking	After 5 days at room temperature
Vitamin A	2204 IU	95	95
Vitamin B1	4.0 mg	101	100
Vitamin B2	2.44 mg	101	101
Vitamin B6	2.67 mg	105	105
Niacin	3.33 mg	102	106
Folic acid	0.42 mg	105	102
Iron	55 mg	105	NR

NR: Not run.

Quality control

It is important to establish quality control standards for both commercial premixes and fortified flour.

Levels of micronutrients in flour can be determined via simple methods – traditionally fluorometric for B1 and B2 and spectrophotometric for iron – or by using more sophisticated equipment such as HPLC for vitamin A, folic acid and niacin.

In addition, two portable devices can be used to test levels of specific nutrients while also offering the added advantage of enabling in-field measurement.

- iCheck Fluoro:[9] uses a fluorometric analytical technique – known as UV excitation – to measure vitamin A concentrations in flour and vitamin-mineral-premixes following extraction with organic solvents. (The same approach can be applied to sugar, milk and biological fluids such as breast milk). This method is pre-calibrated and comes complete with vials containing a certified volume of reagents, which deliver precise and reliable results. With no need for the additional services of an external laboratory, this is an ideal quantitative method for monitoring vitamin A production levels.
- iCheck Iron:[9] employs a colorimetric method and is supplied with pre-filled reagent vials. It is suitable for testing iron in foods such as flour, vitamin-mineral-premixes, lipid nutrient supplements, soy and fish sauces.

Understanding the relative merits of each assay method in the context of individual macronutrients will help analysts determine the most appropriate approach.[10,11]

Whatever direction is taken, it is important to establish an adequate and reproducible sampling procedure. Samples should be representative and random; they also need to be packed and stored appropriately to minimize vitamin losses. While sample sizes for the analysis of vitamin-mineral-premixes may be rather small (2-5 g), when it comes to fortified wheat flour or corresponding food applications (e.g. where the premix is diluted) significantly larger volumes are needed. Final sample quantity will vary depending on the micronutrient to be tested, sample preparation (grinding, cutting, homogenization), food composition and analytical method.

Legislation

The compulsory fortification of flour with various nutrients is becoming increasingly common across the world. Currently over 70 countries have mandates in place (**Table 6**) – and this figure is likely to rise.[12]

With low costs and simple technology, it is one of the most popular strategies in the fight against micronutrient malnutrition.

Table 6: **Compulsory flour fortification worldwide**[13]

Country	Iron	Type Iron	Zinc	Vit B9	Vit B12	Vit B3	Vit B2	Vit B1	Vit A
	MINIMUM ADDED LEVELS (mg / kg flour)								
Bolivia	30	FF	–	1.5	–	35.6	2.6	4.4	–
Canada	44	m*	–	1.5	–	53	4	6.47	–
Chile	30	m*	–	1.8	–	13	1.3	6.3	–
Costa Rica	45	FF	–	1.8	–	45	3.6	5.4	–
Dominican Republic	55	FF	–	1.8	–	55	4	6.2	0.39
Ecuador	55	FF	–	1.7	–	40	4	4	–
El Salvador	55	FF	–	1.8	–	55	4.2	6.2	–
Ghana	58.5	FF	28.3	2.08	0.01	59	4.5	8.4	2
Guatemala	60	FF	–	0.4	–	37.5	3	5	–
Honduras	55	m*							
Jordan	32.25	FF	20	1.5	0.007	35	3.6	3.56	1.5
Kenya[14]	20 30	NaFeEDTA FF	30	2.0	0.02	50	6.0	9.0	1.0
Nigeria	40	NaFeEDTA	50	2.6	0.02	45	5	6	2
Mexico	40	m*	40	2	–	35	3	5	–
Philippines	87.5	m*	–	–	–	–	–	–	4.75
Saudi Arabia	30	m*	–	1.5	–	52.91	3.96	6.38	–
South Africa[15]	15	NaFeEDTA	30	1.43	0.005	23.7	1.77	1.94	1.79
Tanzania[14]	20 30	NaFeEDTA FF	30	2.0	0.02	50	6.0	9.0	1.0
UK	16.5	m*	–	–	–	16	-	2.4	–
USA	44	m*	–	1.54	–	52.8	3.96	6.38	–
Venezuela	20	FF	–	–	–	20	2	1.5	–

FF: Ferrous Fumarate. m* = more than one iron compound. Data needs to be checked for their currentness, as legislation might change.

Costs

With additional costs passed to the consumer of as little as approximately 0.01 USD/5 kg flour (depending on the fortifiant mix),[16] fortifying wheat flour is much less expensive than is generally assumed; largely thanks to low production expenses for millers which comprise:

- Modest capital expenditure for the feeders depending on whether a gravimetric or pneumatic system is installed – with the former commanding a higher cost – as well as the quality of the chosen device.
- Low recurring costs for premix; a solution containing iron, folic acid and other B vitamins, for example, is usually less than 3 USD / metric ton of flour.[16]
- Recurrent costs for quality control which, if routinely analyzed, will ensure any problems are resolved quickly and the fortificant delivers the maximum health impact.[17]

Government subsidies to fortify flour with a premix; in place in some countries, including Jordan, Iran and Iraq, where it is viewed as an investment in the health of their populations.[16]

The benefits of flour fortification far outweigh their associated costs, as shown in **Table 7**. The cost of adding folic acid to flour e.g. is minimal, especially when compared to the cost of treating children with spina bifida.

Table 7: **Summary of annual averted costs and cost savings* of fortifying flour with folic acid**[18]

	Chile	South Africa	USA
Live births with spina bifida prevented with fortification (per year)	107	406	767
Cost of fortification (US $ million / year)	0.2	0.2	4-20
Total direct costs averted (US $ million / year)	2.5	5.6	607.3
Cost savings (US $ / year)	2.3	5.4	603

*The cost savings were calculated comparing the costs of fortification with the treatment of patients with spina bifida. In Chile, based on children with spina bifida and the costs of surgical treatment and rehabilitative services through 20 years of age. In South Africa, they were calculated against the costs of treating infants with spina bifida. In the US, they included the lifetime costs to care for people with spina bifida, plus the value of the time required for others to care for the children.

Impact on public health

Figure 5: **Changes in serum folate levels among women of reproductive age in selected countries after the introduction of folic acid fortification**[19]

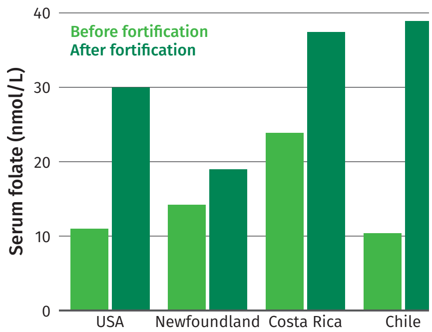


Figure 6: **Changes in the prevalence of neural tube defects in selected countries after the introduction of folic acid fortification**[19]

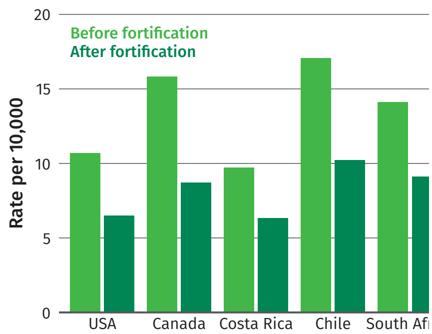
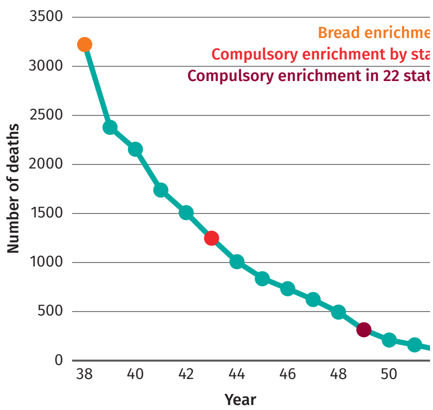


Figure 7: **Death from niacin deficiency in the USA association with wheat flour enrichment**[21]



A growing body of evidence points to the positive public health benefits of fortification initiatives such as:

- The reduction of neural tube defects in selected countries (**Figures 5** and **6**)
- Reduction in deaths resulting from niacin deficiency in the USA (**Figure 7**)
- Decrease in iron deficiency anemia in some countries, with much of this decline attributed to iron fortification in foods such as bread.[22]

Ensuring the success of fortification initiatives in improving the nutritional status of the global population requires cooperation from both governments and the food industry worldwide. It is important that both mandatory and voluntary fortification is properly monitored and enforced.[23]

Fortification programs can improve a population's micronutrient status when three conditions are met:

- Programs are well implemented and monitored
- Coverage and consumption are optimized
- Compounds are added at recommended concentrations.

So part of the process may include choosing high quality vitamin-mineral-premixes with, for example, superior levels of homogeneity, flow and stability. To avoid negative impact on any of these important properties over time – particularly shelf life and organoleptic characteristics – shelf life tests can prove invaluable. Consideration should also be given to using encapsulated product forms or mixes; these are commercially available and can help to further improve stability and ease of application during production.

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