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Most national, mandatory flour fortification standards do not align with international recommendations for iron, zinc, and vitamin B_{12} levels

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ABSTRACT

As national flour fortification standards are one of the policy documents developed to guide food fortification, the objective was to compare national, mandatory wheat and maize flour fortification standards to World Health Organization (WHO) fortification guidelines. For each nutrient in 72 countries' standards, the type of compound was noted as 'yes' if it was included in international guidelines or 'no' if it was not. Nutrient levels in standards were classified as lower than, equal to, or higher than those suggested by WHO. If another food (i.e. rice, oil, milk) was mass fortified with a nutrient categorized as "lower than," the classification was changed to "less than recommendation and included in other mass fortified food". At least 61% of standards included one or more recommended compounds for all nutrients in standards for wheat flour alone (iron, folic acid, vitamin A, zinc, vitamin B_{12},), wheat and maize flour together (iron, folic acid, vitamin A, zinc, vitamin B_{12}) and maize flour alone (thiamin, riboflavin, niacin, pyridoxine); no country included pantothenic acid in its maize flour standard. For folic acid, vitamin A, thiamin, riboflavin, niacin and pyridoxine, at least 50% of standards (1) met or exceeded WHO suggested levels, or (2) were lower than suggested levels and another food was mass fortified with the specific nutrient in the country. For iron, zinc and vitamin B_{12}, less than 50% of standards met (1) or (2). In conclusion, iron, zinc and vitamin B_{12} may require the most attention in national fortification standards.

1. Introduction

Food fortification is a public health intervention utilized worldwide to prevent and control micronutrient deficiencies and insufficiencies (Micronutrient Forum, 2015). Wheat and maize are among the most produced staples in the world (FAO, 2018) making their flour good candidates for fortification. In 2008, fortification partners convened a workshop "to develop consensus on 'practical and feasible recommendations' for public health authorities, food regulators, and the milling sector to initiate flour fortification" (Serdula, 2010). The workshop deliberations contributed to the World Health Organization's (WHO) interim consensus statement for wheat and maize flour fortification (WHO, 2009), the first such international guideline for flour fortification. The consensus statement centered on five nutrients: iron, folate, vitamin B_{12}, vitamin A and zinc. The recommended nutrient levels and compounds were largely based on reviews of efficacy trials (iron (Hurrell et al., 2010), vitamin B_{12} (Allen et al., 2010), vitamin A (Klemm et al., 2010)), reviews of effectiveness and safety evidence (folic acid (Berry et al., 2010)), modeling simulations (zinc (Brown et al., 2010)) and considerations of country experiences.

WHO's updated guidelines for maize flour and corn meal fortification (WHO, 2016) included the same five micronutrients, plus thiamin, riboflavin, niacin, pyridoxine, and pantothenic acid. National decision makers may use international recommendations to guide the development or modification of standards for the nutrients, nutrient levels, and fortification compounds that must be added to fortified flour. Besides

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international recommendations, country decision makers may consider several factors when setting flour fortification standards, including, but not limited to nutrient needs and deficiencies of the targeted population, flour consumption profile, and fortification costs (WHO, 2009). These standards are one of several documents that countries use to set food policy, providing the regulatory framework for governments to monitor food fortification (Marks et al., 2018).

Research suggests that adoption and adaptation of the WHO interim consensus statement—for iron compounds and levels used in flour fortification—contribute to reductions in anemia prevalence (Barkley et al., 2015; Hurrell, 2015). Hurrell and colleagues compared the iron compound and iron levels used in countries' and World Food Programme-sponsored wheat flour fortification programs and found that only 9 of 78 programs used WHO-recommended compounds at the level proposed (Hurrell et al., 2010).

Two additional evaluations of country wheat flour fortification standards have been completed, though they have been limited in their scope (Pachón et al., 2015; Walani et al., 2020). In both, investigators assessed if the fortification compounds in the standards included at least one compound in WHO recommendations. They also determined if, based on flour extraction rate and flour availability, the nutrient levels in standards were lower than, equal to, or higher than the suggested levels in recommendations. One global assessment determined that 8 of 13 large-scale flour fortification programs used one of the iron compounds and 2 of 13 programs used at least the WHO recommended level of iron (Pachón et al., 2015). Additionally, the levels of iron, folic acid, vitamin B_{12} and zinc were lower than those in the guidelines. Another analysis compared folic acid in wheat and maize flour fortification programs from five East African Community countries and determined that only two standards had folic acid levels that were greater than or equal to WHO recommendations (Walani et al., 2020).

To date, no evaluation exists of countries' flour fortification standards and how they compare to WHO suggested levels for iron, folic acid, vitamin B_{12}, vitamin A and zinc (for wheat and maize flour) or for thiamin, riboflavin, niacin, pyridoxine, and pantothenic acid (for maize flour). Therefore, the study objective was to assess how each country's standard aligns with international guidelines for both levels and compounds of nutrients used.

2. Methods

As no data on human subjects were used, no approval from an ethics committee was solicited.

For this analysis, countries' fortification standards provided most of the information required (Food Fortification Initiative, 2017): flour mandated to be fortified (wheat, maize, both); year the current standard was issued; nutrient concentration (in parts per million); and fortification compound(s) to be used for each of the nutrients. Few standards specified the flour extraction rate (≤0.8% ash for low extraction and >0.8% ash for high extraction (Hurrell et al., 2010)); this information was largely obtained in written communication from Quentin Johnson, PhD (personal communication). Wheat and maize flour availability (in grams per capita per day) was obtained from the Food and Agriculture Organization (FAO) of the United Nations (FAOSTAT, 2016). The most recent year with data available was 2013. When FAO flour availability data were not available, other sources were reviewed from written conversation with Peter Ranum (e.g. for Kosovo ((personal communication)).

Information was extracted into Excel, and a country's standard was compared to guidelines. First, it was determined if a country's standard included recommended compounds (Table 1).

If a country's standard did not include any recommended compounds for a particular nutrient, the subsequent steps in the methodology were skipped for that nutrient (i.e. 22 were skipped for iron and 2 for zinc). If a country's standard included recommended compounds as specified above, the standard's nutrient level was classified as "lower than", "equal to" or "greater than" WHO recommendations (Fig. 1a). For example, when wheat flour is the only food fortified in a country and intake or availability of wheat flour is 75–149 g per person per day, the recommendation is that 2.6 parts per million (ppm) folic acid be added to flour (WHO, 2009). If a country's availability of flour was 80 g per person per day, and amount of folic acid specified in the fortification standard was 1.0 ppm, that country's folic acid standard was classified as "lower than" recommendations for wheat flour.

Table 1
World Health Organization recommended compounds for each nutrient assessed in the analysis of national, mandatory standards for flour fortification.

Nutrient	Wheat flour only	Wheat and maize flour
Iron	Ferrous sulfate, ferrous fumarate, NaFeEDTA, and electrolytic iron (WHO, 2009)	Ferrous sulfate, ferrous fumarate, NaFeEDTA, and electrolytic iron (WHO, 2009)[a]
Folic acid	Folic acid (WHO, 2009)	Folic acid (WHO, 2009)[a]
Vitamin A	Vitamin A palmitate (WHO, 2009)	Vitamin A palmitate (WHO, 2009)[a]
Zinc	Zinc oxide (WHO, 2009)	Zinc oxide (WHO, 2009)[a]
Vitamin B_{12}	Cyanocobalamin (WHO, 2009)	Cyanocobalamin (WHO, 2009)[a]
Thiamin	NA[b]	Thiamin, thiamin hydrochloride, thiamin mononitrate (WHO, 2016, 2006)[b]
Riboflavin	NA[b]	Riboflavin (WHO, 2016)[b]
Niacin	NA[b]	Niacin, niacinamide, nicotinic acid, nicotinamide (WHO, 2016, 2006)[b]
Pyridoxine	NA[b]	Alternate spellings of pyridoxine, pyridoxine hydrochloride, pyridoxine hydrochloric acid (WHO, 2016; SCOGS, 2017) [b]
Pantothenic acid	NA[b]	Calcium pantothenate (WHO, 2016)[b]

NA, not applicable.

[a] None of the countries in the analysis mandate fortification of maize flour alone; if they mandate maize flour fortification, they also mandate wheat flour fortification. For these nutrients, countries' standards for wheat and maize flour were assessed together against the interim statement (WHO, 2009).

[b] The wheat and maize flour fortification interim statement (WHO, 2009) does not include this nutrient. For these nutrients, countries' standards for maize flour only were assessed using the WHO guideline on fortification of maize flour and corn meal recommendations as reference (WHO, 2016).

Every country with a mandate for maize flour fortification has a mandate for wheat flour fortification as well. For those countries, the wheat and maize flour standards for iron, folic acid, vitamin A, zinc and vitamin B_{12} were analyzed simultaneously (Fig. 1b). The FAO-reported availability (FAOSTAT, 2016) of each flour was summed per country (e.g. 77 g/person/day wheat flour + 192 g/person/day maize flour = 269 g/person/day flour). If the nutrient levels specified in standards for both flours were above the recommended levels for the summed flour availability, the country's standard was classified as "greater than" recommendations for flour (e.g. if the summed flour availability was 269 g/person/day, the recommendation is that 30 ppm of iron in the form of ferrous fumarate be added to low-extraction flour, since country standards for wheat flour (55 ppm) and maize flour (40 ppm) were both above 30 ppm, then that country's iron standard was classified as "greater than" recommendations for flour). The same process was followed if both flours' standards were "lower than" or "equal to" recommendations based on the summed flour availability.

If the standard for one flour was in a different category than the standard for another flour (e.g. "lower than" WHO recommendations for maize flour and "higher than" WHO recommendations for wheat flour), then a different process was followed (Fig. 1c). For example, the wheat flour fortification level in the standard for the compound ferrous fumarate was multiplied by the wheat flour availability to generate the theoretically assumed daily nutrient intake from fortified wheat flour per person (e.g. 40 mg iron/1000 g flour X 87.8 g flour/person/day =

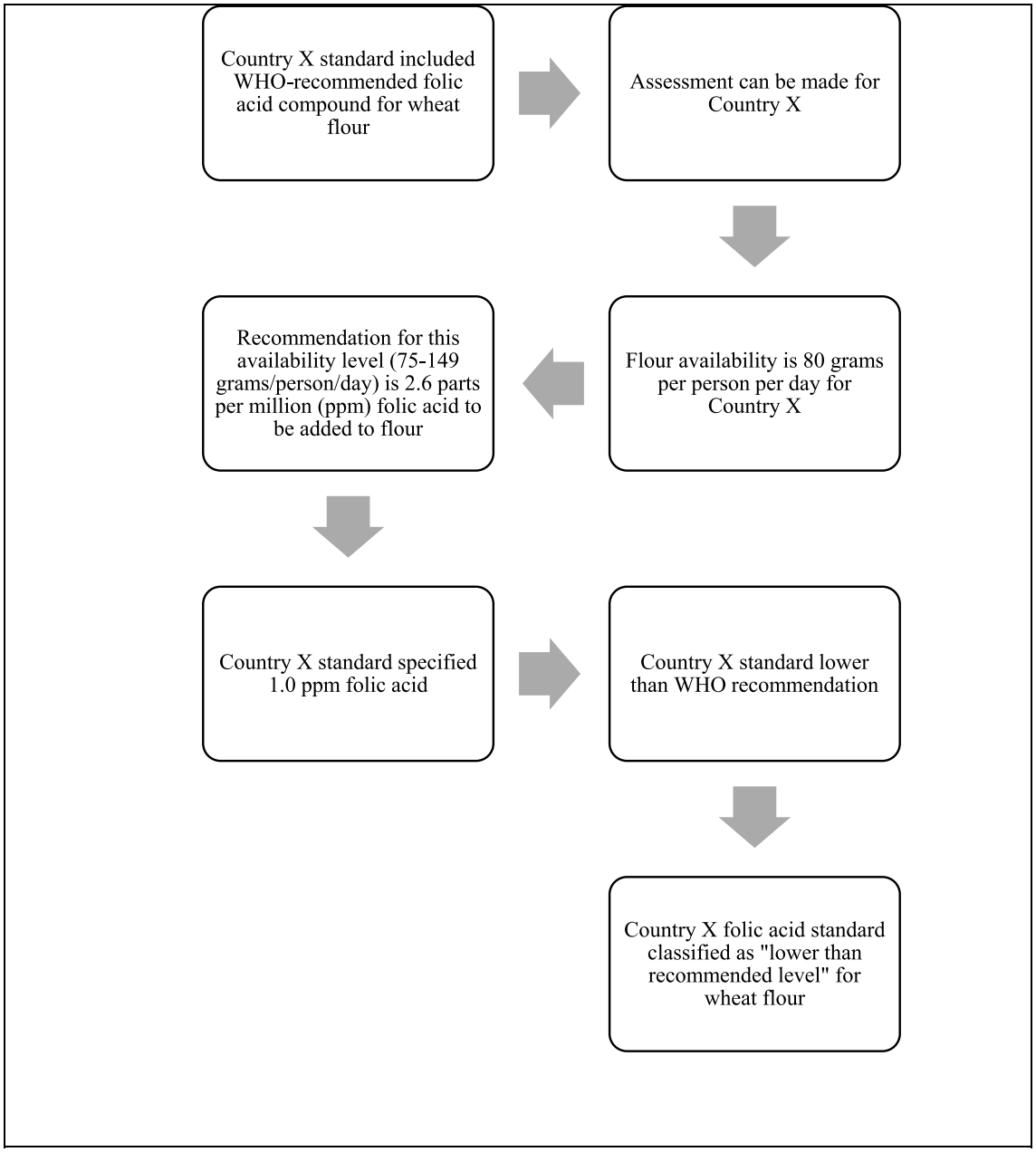

Fig. 1a. Example calculations completed in comparing national standards to international guidelines for flour fortification: wheat flour only.

3.5 mg iron/person/day). The same was done for maize flour (e.g. 10 mg iron/1000 g flour X 214.94 g flour/person/day = 2.15 mg iron/person/day) and these were summed (e.g. 3.5 mg iron/person/day + 2.15 mg/iron/person/day = 5.65 mg/iron/person/day).

The FAO-reported availability (FAOSTAT, 2016) of each flour was summed per country (e.g. 87.8 g flour/person/day wheat flour + 214.94 g flour/person/day maize flour = 302.74 g/person/day flour). The intake or availability categories used in calculations to generate the interim consensus statement were identified (Hurrell et al., 2010) (p S14): 50 g/person/day for the <75 g/person/day category, 113 g/person/day for the 75–149 g/person/day category, 225 g/person/day for the 150–300 g/person/day category, and 350 g/person/day for the >300 g/person/day category. The summed flour availability was multiplied by the nutrient levels for that category in recommendations to generate the amount of nutrient a person would consume daily if recommendations were followed (e.g. 350 g flour/person/day (for the >300 g/person/day category) X 20 mg iron/1000 g flour = 7.0 mg iron/person/day).

The theoretical amount of nutrient contributed by fortified wheat and maize flour based on a country's standard was compared to the amount of nutrient contributed by fortified flour based on recommendations (e.g. 5.65 mg iron/person/day from standards versus 7.0 mg iron/person/day). If the first number was lower than the second, the country was classified as having nutrient standards "lower than" recommendations; if the numbers were equal, the classification was "equal to"; and if the first number was greater than the second, the classification was "greater than".

Analyses were completed under two scenarios. The first did not consider whether other foods are mass fortified in the country. The second scenario considered whether milk is mass-fortified, based on information given by Héctor Cori (personal communication), or whether maize flour, oil, rice, salt or wheat flour (Global Fortification Data Exchange, 2017) is mandated to be fortified with the specific nutrients of interest. For example, if a country's standard for vitamin A in wheat

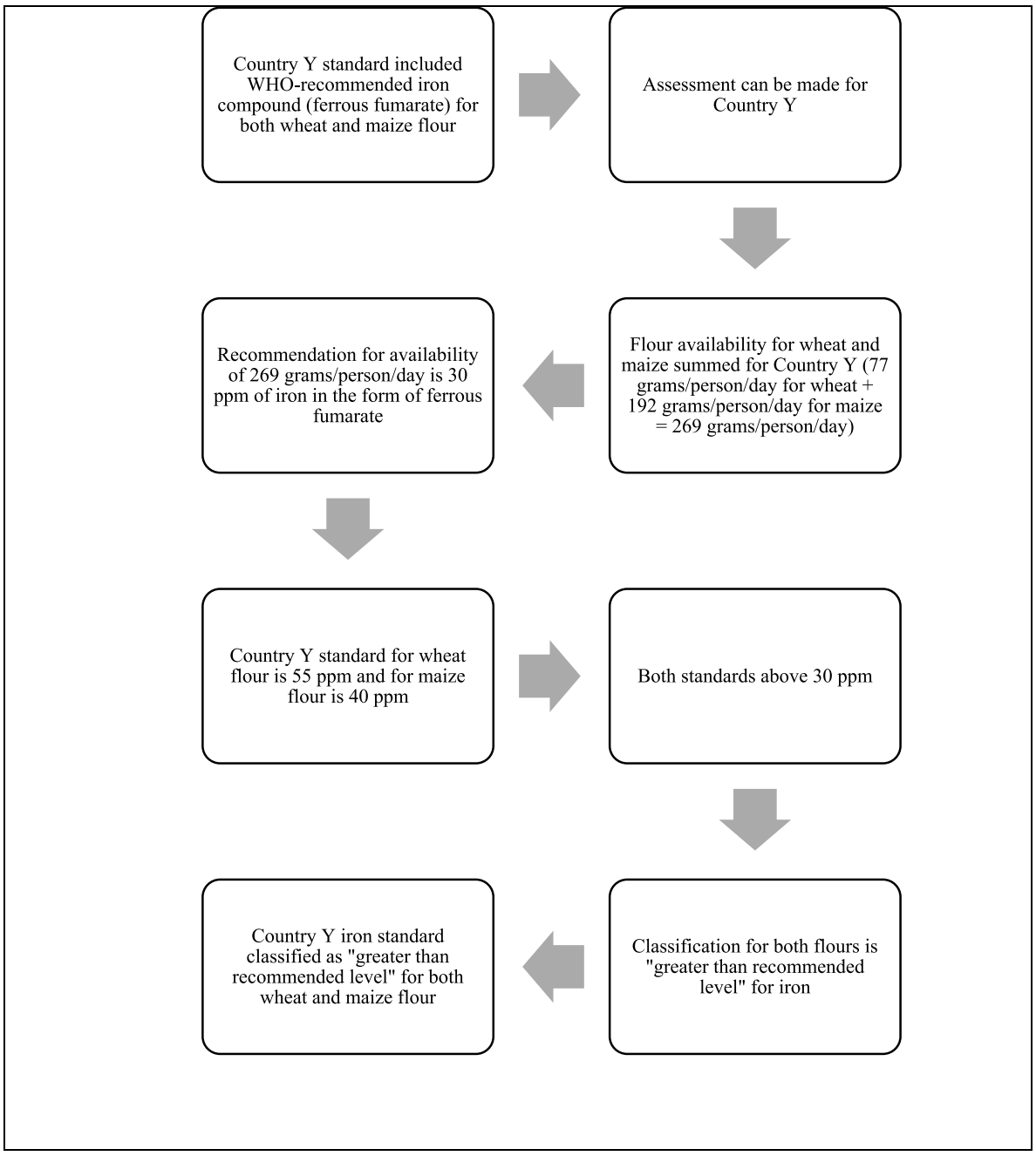

Fig. 1b. Example calculations completed in comparing national standards to international guidelines for flour fortification: wheat and maize flour, assessment of both standards in concordance.

flour was classified as “lower than” WHO recommendations, and that country has mandatory fortification of oil with vitamin A, that country’s classification was changed to “less than WHO recommendations and included in other mass fortified food” for vitamin A in wheat flour.

The percentage of WHO-suggested nutrient levels that were met by national standards was calculated for nutrients with a large sample size: iron (n = 34 of 56 countries with iron standards) and folic acid (n = 39 of 41 countries with folic acid standards) in countries with only mandatory wheat flour fortification. Specifically, the country’s nutrient level in mg/kg was the numerator, the WHO recommended level of nutrient based on the flour extraction rate and fortification compound in mg/kg was the denominator, and the quotient was multiplied by 100. The 25th percentile was arbitrarily selected as the cutoff to identify standards that were significantly lower than WHO recommendations and similarly the 75th percentile for those significantly higher than recommendations.

3. Results

As of 1 January 2017, 85 countries had mandatory fortification of wheat flour only or both wheat and maize flour (Table 2); of these, 16 countries also had mandatory fortification of maize flour (WHO, 2016).

Fortification standards were obtained for 72 of these countries: 57 countries that only mandate wheat flour fortification and 15 countries that mandate both wheat and maize flour fortification. Most countries with only mandatory wheat flour fortification include iron and folic acid in their standards. In countries with both mandatory wheat and maize flour fortification, at least 47% include iron, folic acid, vitamin A, zinc and vitamin B_{12} in their standards. Most countries with standards for maize flour fortification include thiamin, riboflavin and niacin. No country’s standard for maize flour included pantothenic acid. For all nutrients, most standards include at least one recommended fortification

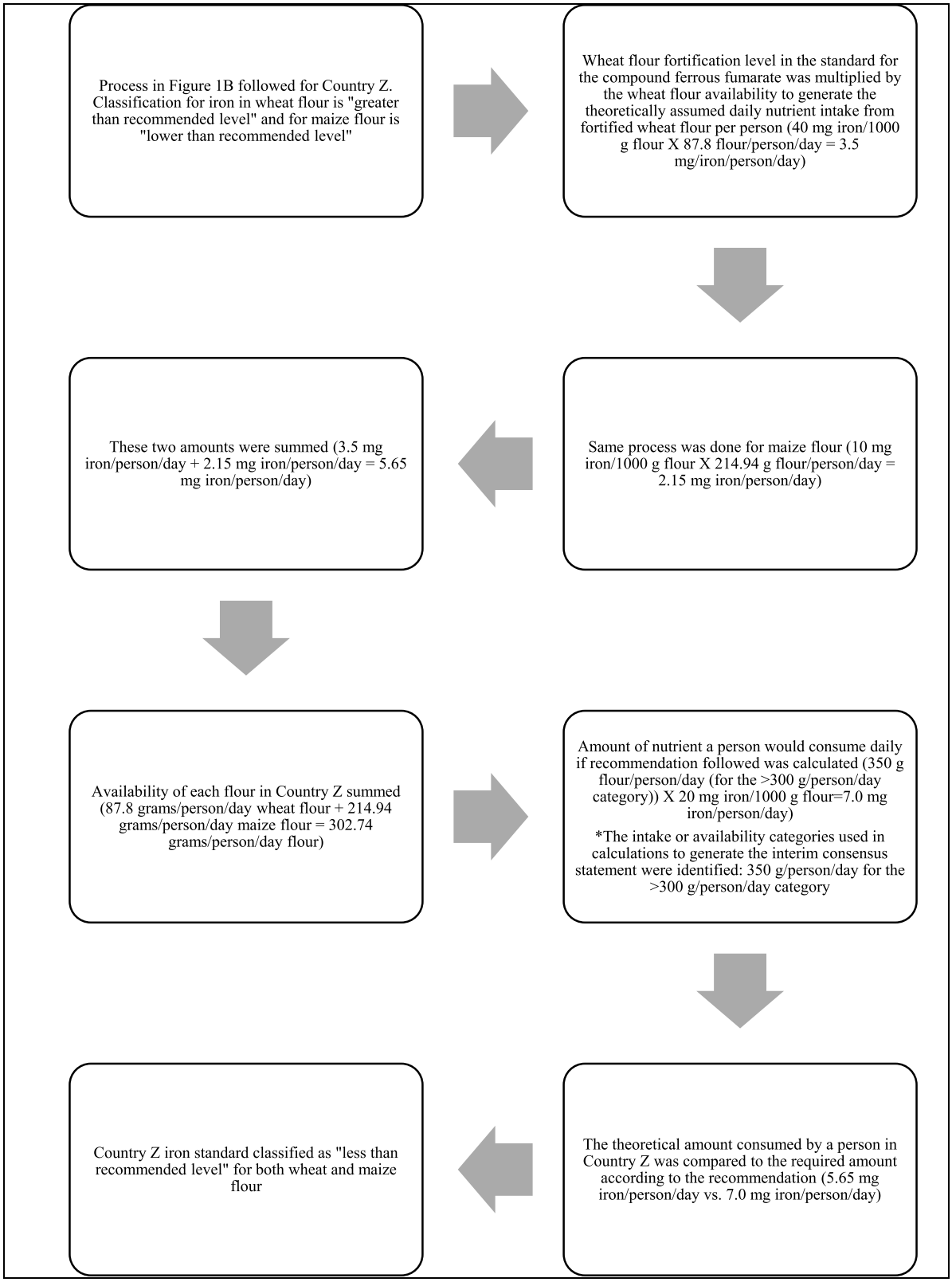

Fig. 1c. Example calculations completed in comparing national standards to international guidelines for flour fortification: wheat and maize flour, assessment of both standards not in concordance.

compound (Table 3).

The greatest number of compounds was observed for iron (Table 4).

Other nutrients included in standards were calcium, vitamin B_6 and vitamin D (Table 2).

For countries that include recommended iron compounds in their standards, 18 countries with only mandatory wheat flour fortification and 7 countries with mandatory fortification of wheat and maize flour had iron levels equal to or greater than WHO recommendations

Table 2
Nutrient standards in countries with mandatory fortification of wheat flour only or both wheat and maize flours as of 1 January 2017.

Item	Wheat flour only	Wheat and maize flour
Countries with mandatory fortification	69	16
Countries with official fortification standards[a]	57	15
Countries with standards for[b]		
Iron	56	15[c]
Folic acid	41	14[c]
Vitamin A	5	8[c]
Zinc	11	9[c]
Vitamin B_{12}	6	7[c]
Thiamin	NA[d]	13[d]
Riboflavin	NA[d]	13[d]
Niacin	NA[d]	13[d]
Pyridoxine	NA[d]	5[d]
Pantothenic acid	NA[d]	0[d]
Countries with standards for[e]		
Calcium	18	1
Vitamin B_6	2	7
Vitamin D	3	1

NA, not applicable.

[a] Countries whose official fortification standards the investigators were able to obtain (Food Fortification Initiative, 2017).

[b] These nutrients are included in WHO interim statement for flour fortification (WHO, 2009) and guidelines on fortification of maize flour and corn meal (WHO, 2016).

[c] None of the countries in the analysis mandate fortification of maize flour alone; if they mandate maize flour fortification, they also mandate wheat flour fortification. For these nutrients, countries' standards for wheat and maize flour were assessed together against the interim statement (WHO, 2009).

[d] The wheat and maize flour fortification interim statement (WHO, 2009) does not include this nutrient. For these nutrients, countries' standards for maize flour only were assessed using the WHO guideline on fortification of maize flour and corn meal recommendations as reference (WHO, 2016).

[e] These nutrients are not included in interim statement for flour fortification (WHO, 2009) nor in the WHO guidelines on fortification of maize flour and corn meal (WHO, 2016).

(Table 3). Some countries mass fortify other foods with the same nutrients as fortified flour, and thus an initial classification of having flour standards "lower than" WHO recommendations may be misleading. For example, three countries with only mandatory wheat flour fortification that were classified with "iron standards for flour lower than WHO recommendations" have mandatory rice fortification with iron (Table 3). When other mass fortified foods are taken into consideration, the standards for 21 countries with only mandatory wheat flour fortification and 7 countries with mandatory wheat and maize flour fortification had iron levels equal to or greater than WHO recommendations or had another food mass fortified with iron (Table 3). The comparable figures for countries with mandatory wheat flour and those with mandatory wheat and maize flour fortification are 24 and 11 for folic acid, 3 and 7 for vitamin A, 3 and 2 for zinc, and 2 and 3 for vitamin B_{12}. For countries with standards for maize flour fortification, 13 that include recommended thiamin compounds had thiamin levels greater than or equal to WHO recommendations or had another food mass fortified with thiamin. The same was true for 13, 12 and 4 standards for riboflavin, niacin, and pyridoxine, respectively, in maize flour standards.

Among 34 countries with recommended iron-fortification compounds for wheat flour fortification, nine were below the 25th percentile of WHO iron recommendation levels (i.e., <77%) and eight were above the 75th percentile (i.e., >100%) (data not shown). Three countries have mandatory fortification of another food with iron; one country was below the 25th percentile and two were between the 25th and 75th percentiles of WHO iron recommendation levels.

Among 39 countries with wheat flour fortification standards that included folic acid, seven were below the 25th percentile of WHO folic acid recommendation levels (i.e., <58%) and 10 were above the 75th percentile (i.e., >137%) (data not shown). Two countries also had mandatory fortification of another food with folic acid; the amount in wheat flour was between the 25th and 75th percentiles of WHO folic acid recommendation levels.

4. Discussion

Wheat and maize flour fortification standards from 72 countries were compared with international recommendations for flour fortification compound and nutrient level. This is the most comprehensive such analysis completed for food fortification. Most standards include at least one recommended compound for all nutrients analyzed; the notable exception was iron, as only 61% of the standards in countries that mandate wheat flour fortification include at least one recommended compound. Iron had the greatest number of compounds included in standards. WHO nutrient-level recommendations were met or exceeded, or other foods are likely mass fortified, in the following percentage of standards: less than 50% for iron, zinc and vitamin B_{12} in standards for wheat flour only or wheat and maize flour together, 50% or greater for folic acid and vitamin A in standards for wheat flour only or wheat and maize flour together, and 50% or greater for thiamin, riboflavin, niacin and pyridoxine in standards for maize flour only. Pantothenic acid is not included in this list because no country had standards for this nutrient. While this nutrient is present in unprocessed maize (WHO, 2016), there is no evidence of pantothenic acid deficiency being a global health problem (WHO, 2004).

4.1. In context

The results of this review are generally in line with the results of the largest previous assessment conducted (Hurrell et al., 2010) and in disagreement with the results of the smaller previous evaluations conducted on the topic (Pachón et al., 2015; Walani et al., 2020). The first assessment completed was limited to iron (Hurrell et al., 2010). They concluded that only 9 of 78 programs used a WHO-recommended compound at a WHO-recommended level; this was mainly due to the iron compound not being specified. Their methodology differed in that they included World Food Programme programs, countries with voluntary fortification, countries planning fortification, and they used compound and level information from a handbook instead of from standards. Among the 38 countries with mandatory wheat flour fortification that they included, for 18 they noted the iron compound was unspecified. However, in the current assessment, the iron compounds were noted for 12 of these countries, suggesting that the analysis overestimated the number of countries that do not follow WHO recommendations. Their analyses are consistent with the results of the current review in identifying that more standards need to include recommended, bioavailable iron compounds.

Another evaluation was also limited to iron (Pachón et al., 2015). In the analysis, 13 large-scale flour (wheat, maize, other) fortification programs were assessed for the iron compound and level reportedly used. The iron compound was not specified for 4 programs; in the remainder, 8 (62%) used a WHO-recommended compound. A comparison of iron levels with recommendations could not be completed for 6 programs, often because the flour extraction rate was not specified. In the remaining programs, 2 (15%) used at least the WHO-recommended iron level. The current analysis, evaluating 72 programs with wheat flour fortification alone or in combination with maize flour, found a comparable level of alignment for iron compounds (~60%) and higher alignment for iron levels (~30%).

A third assessment considered only folic acid levels (Walani et al., 2020). Specifically, Walani and colleagues compared folic acid levels in mandatory wheat and maize flour fortification programs of five East African Community countries to WHO 2009 recommendations (Walani et al., 2020). As flour availability data were missing for one country,

Table 3
Comparison of national fortification standards with WHO wheat and maize flour fortification recommendations in terms of fortification compound and nutrient level in countries with mandatory fortification of wheat flour only or both wheat and maize flours, considering other mass-fortified foods.

Nutrient	Wheat flour only, n (%): how standards compare to international guidelines								Wheat and maize flour, n (%): how standards compare to international guidelines							
	Include a recommended compound					Cannot determine[c]	Include non-recommended compound[d]	Total countries with standards[e]	Include a recommended compound					Cannot determine[c]	Include non-recommended compound[d]	Total countries with standards[e]
	Lower than[a]	Equal to[a]	Greater than[a]	Lower than & included in other fortified food[b]	Sub-total				Lower than[a]	Equal to[a]	Greater than[a]	Lower than & included in other fortified food[b]	Sub-total			
Iron	13 (23%)	10 (18%)	8 (14%)	3 (5%)	34 (61%)	2 (4%)	20 (36%)	56 (~100%)	3 (20%)	1 (7%)	6 (40%)	0 (0%)	10 (67%)	4 (27%)	1 (7%)	15 (~100%)[f]
Folic acid	15 (37%)	4 (10%)	18 (44%)	2 (5%)	39 (95%)	2 (5%)	0 (0%)	41 (100%)	2 (14%)	0 (0%)	10 (71%)	1 (7%)	13 (93%)	1 (7%)	0 (0%)	14 (100%)[f]
Vitamin A	1 (20%)	0 (0%)	1 (20%)	2 (40%)	4 (80%)	1 (20%)	0 (0%)	5 (100%)	0 (0%)	1 (13%)	2 (25%)	4 (50%)	7 (88%)	1 (13%)	0 (0%)	8 (~100%)[f]
Zinc	6 (55%)	2 (18%)	1 (9%)	0 (0%)	9 (82%)	1 (9%)	1 (9%)	11 (100%)	5 (56%)	0 (0%)	2 (22%)	0 (0%)	7 (78%)	1 (11%)	1 (11%)	9 (100%)[f]
Vitamin B_{12}	3 (50%)	2 (33%)	0 (0%)	0 (0%)	5 (83%)	1 (17%)	0 (0%)	6 (100%)	3 (43%)	1 (14%)	2 (29%)	0 (0%)	6 (86%)	1 (14%)	0 (0%)	7 (100%)[f]
Thiamin	NA	NA	NA	NA	NA	NA	NA	NA	0 (0%)	0 (0%)	9 (69%)	4 (31%)	13 (100%)	0 (0%)	0 (0%)	13 (100%)[g]
Riboflavin	NA	NA	NA	NA	NA	NA	NA	NA	0 (0%)	1 (8%)	11 (85%)	1 (8%)	13 (100%)	0 (0%)	0 (0%)	13 (~100%)[g]
Niacin	NA	NA	NA	NA	NA	NA	NA	NA	1 (8%)	1 (8%)	5 (38%)	6 (46%)	13 (100%)	0 (0%)	0 (0%)	13 (100%)[g]
Pyridoxine	NA	NA	NA	NA	NA	NA	NA	NA	1 (20%)	0 (0%)	1 (20%)	3 (60%)	5 (100%)	0 (0%)	0 (0%)	5 (100%)[g]
Pantothenic acid	NA	NA	NA	NA	NA	NA	NA	NA	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)[g]

NA, not applicable.

[a] Based on comparison of a country's fortification standard to the WHO interim statement (WHO, 2009) or guidelines (WHO, 2016). For example, if the amount of folic acid suggested by WHO for low-extraction flour was 2.6 parts per million (ppm), and the country's fortification standard was less than 2.6 ppm, that country's folic acid standard was classified as "lower than" international guidelines. If the country's fortification standard was 2.6 ppm, it was classified as "equal to" international guideline. If the country's fortification standard was less than 2.6 ppm, it was classified as "greater than" international guidelines.

[b] Based on comparison of a country's fortification standard to the WHO interim statement (WHO, 2009) or guidelines (WHO, 2016), the nutrient was classified as "lower than" international guidelines. Additionally, this country mass fortifies milk, oil, rice or salt with the same nutrient.

[c] Alignment between country standards and international guidelines could not be determined because of one of two reasons: the fortification compound is not specified in the country standard or because the availability of flour is not available from FAO (FAOSTAT, 2016) or other sources.

[d] The country standard did not include a recommended compound (per Table 1).

[e] Totals may not add to 100% because of rounding.

[f] None of the countries in the analysis mandate fortification of maize flour alone; if they mandate maize flour fortification, they also mandate wheat flour fortification. For these nutrients, countries' standards for wheat and maize flour were assessed together against the interim statement (WHO, 2009).

[g] The wheat and maize flour fortification interim statement (WHO, 2009) does not include this nutrient. For these nutrients, countries' standards for maize flour only were assessed using the WHO guideline on fortification of maize flour and corn meal recommendations as reference (WHO, 2016).

Table 4
Fortification compounds included in flour fortification standards in countries with mandatory fortification of wheat flour only or both wheat and maize flours as of 1 January 2017.

Nutrient	Wheat flour only[a]	Wheat and maize flour[b]
Iron	Carbonyl iron (n = 2) **Electrolytic iron (n = 5)**[c] Elemental iron (n = 7) **Ferrous fumarate (n = 21)** **Ferrous sulfate (n = 18)** Others (n = 1)[d] Reduced iron (n = 5) Unspecified (n = 18)	**Electrolytic iron (n = 1)**[c] **Ferrous fumarate (n = 7)** **Ferrous sulfate (n = 3)** Iron (n = 1) Iron bisglycinate (n = 2) Reduced iron (n = 1) **Sodium iron EDTA (n = 7)** Unspecified (n = 1)
Folic acid	**Folic acid (n = 39)** Vitamin B_9 (n = 1)	**Folic acid (n = 14)**
Vitamin A	Retinol acetate (n = 1) Retinol palmitate (n = 1) **Vitamin A palmitate (n = 2)** Unspecified (n = 1)	Retinol palmitate (n = 1) Retinyl palmitate (n = 3) **Vitamin A palmitate (n = 5)**
Zinc	**Zinc oxide (n = 9)** Unspecified (n = 2)	**Zinc oxide (n = 9)**
Vitamin B_{12}	**Cyanocobalamin (n = 3)** Vitamin B_{12} (n = 3)	Vitamin B_{12} (n = 7)
Thiamin	NA	**Thiamin (n = 4)** **Thiamin hydrochloride (n = 1)** **Thiamin mononitrate (n = 10)**
Riboflavin	NA	**Riboflavin (n = 13)**
Niacin	NA	Aluminum nicotinate (n = 1) **Niacin (n = 4)** **Niacinamide (n = 11)** **Nicotinamide (n = 3)**
Pyridoxine	NA	**Pyridoxine (n = 4)** **Pyridoxine hydrochloride (n = 1)**
Pantothenic acid	NA	NA[e]

NA, not applicable

[a] Numbers may add up to more than the number of countries with standards for that nutrient (Table 2) because two or more compounds per nutrient may be included in standards.

[b] None of the countries in the analysis mandate fortification of maize flour alone; if they mandate maize flour fortification, they also mandate wheat flour fortification. For these nutrients, countries' standards for wheat and maize flour were assessed together against the interim statement (WHO, 2009).

[c] Bolded text indicates the compound is recommended by WHO (WHO, 2009, 2016, 2006) or FDA (SCOGS, 2017).

[d] Each of these compounds was noted in one standard: carbonyl iron, ferric ammonium citrate, ferric citrate, ferric orthophosphate, ferric phosphate, ferric pyrophosphate, ferric saccharate, ferrous citrate, ferrous gluconate, ferrous glycinate, ferrous lactate, iron oxide, iron powder, iron phosphate, iron pyrophosphate, sodium ferric diphosphate, sodium ferric pyrophosphate, sodium iron EDTA, sodium iron pyrophosphate.

[e] No country included pantothenic acid in its maize flour fortification standards.

comparison of standards with recommendations could not be completed. In the remaining countries, only two had folic acid levels at or above WHO recommendations. These findings were lower than those observed for countries with wheat and maize flour fortification in the current analysis (78%).

4.2. Policy implications

As with any micronutrient intervention, flour fortification can contribute to excess nutrient intakes (WHO, 2017). A starting point to determine this risk is countries where standards have nutrient levels greater than WHO recommendations. Riboflavin (85%), thiamin (69%) and folic acid (50%) are candidates for further analysis. Given the daily intake of flour in the country, what levels of nutrients are ingested, and do they exceed the tolerable upper intake level for an important segment of the population (Institute of Medicine, 2000)? If any evidence suggests that flour is contributing to excessive intakes, the nutrient levels in standards can be reduced (Institute of Medicine, 2000). It is also possible that the combination of wheat flour fortification with other micronutrient interventions may contribute to excess intakes. Therefore, policy makers concerned about high nutrient intakes will need information about the multiple sources of such nutrients and their health impacts. For example, for those nutrients where persistently high intakes pose a health concern (WHO, 2004), country decision makers may want to review nutrition biomarker data to determine if there is any evidence of toxicity.

Besides international recommendations, country decision makers may consider several factors when setting flour fortification standards (WHO, 2009). These include the nutrient needs and deficiencies of the targeted population, the flour consumption profile, sensory and physical effects of fortification on foods made with fortified flour, other fortified foods in the country, proportion of the population consuming supplements, and fortification costs (WHO, 2009). Additionally, in countries with important trading partners, regional standards may be set that facilitate commerce (Sablah et al., 2012).

4.3. Conclusions

This study has several strengths. It is a comprehensive analysis of nutrients in the standards of any fortified food. It included 83% of countries with mandatory flour fortification as of January 2017. It considered the latest WHO recommendations for maize flour fortification, and it included standards written in any language. The main limitation is that the standards that were reviewed may not represent the latest version that a country has. FAO flour availability data were used as a proxy for flour intake data (FAOSTAT, 2016). Also, this review is focused on documentation, not the implementation or monitoring of these standards in countries.

In conclusion, the nutrients that may require the most attention in flour fortification standards are (1) iron because 36% of standards did not include recommended compounds and (2) iron, zinc and vitamin B_{12}, as fewer than 50% of standards' nutrient levels met WHO recommendations. This potentially reduces the delivery of needed nutrients to 434 million people living in countries with flour fortification standards that are lower than WHO recommendations. The nutrients that likely need the least attention because nearly all standards' nutrient levels meet or exceed WHO recommendations and other foods are fortified with the same nutrient, are vitamin A in wheat and maize flour standards and thiamin, riboflavin, niacin and pyridoxine in maize flour standards, although attention should be paid to avoid risk of overconsumption, especially when multiple interventions are in place.

Author note

Co-authors are employed with Emory University, the World Food Programme, UNICEF, Centers for Disease Control and Prevention, World Health Organization and the Food Fortification Initiative. All of these organizations help country leaders promote, plan, implement, monitor or evaluate fortification of industrially milled wheat flour or maize flour.

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CRediT authorship contribution statement

Katherine S. Bobrek: Data curation, Formal analysis, Investigation, Validation, Visualization, Writing - original draft, Writing - review & editing. **Britt Broersen:** Investigation, Methodology, Validation, Writing - review & editing. **Nancy J. Aburto:** Investigation,

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Data statement

As of May 2020, data used in this manuscript can be freely downloaded from the Global Fortification Data Exchange website (FortificationData.org), where the results are visualized in maps.

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