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Research Article

Micronutrients Fortification of an Infant Porridge Based on Quinoa and Fonio Nutritional Properties

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Abstract

Problem: Commercial infants supplement porridges often contain insufficient mineral levels to meet Codex Alimentarius nutritional requirements, especially Iron, Zinc, Calcium and Copper. Objective: This study aims to determine the ability of fonio (*Digitaria iburua*) or quinoa (*Chenopodium quinoa*) to correct micronutrients deficit in Nutrimix, an infant porridge flour used in Togo. *Methodology*: This study is an experimental comparative research conducted from February 2025 to July 2025. Various formulas containing different concentrations of quinoa grain flour and fonio grain flour were developed and analysed, to assess the impact of substituting quinoa grain flour or fonio grain flour to maize in a basic infant formula, called Nutrimix, already marketed by Togolese Institute of Agronomic Research. The cereals used to supplement Nutrimix flour were selected using a reasoned approach. Various substitutions were experienced to increase the mineral content of the final formula, especially Iron and zinc, most problematic nutrients during the complementary feeding of infants, with Copper and Calcium, expected to help meet Codex Alimentarius requirement. Five (5) formulas were developed by substituting maize with quinoa at different quantity of the final formula: 50 g of quinoa for Q1, 100 g for Q2, 150 g for Q3, 200 g for Q4 and 316 g for Q5. The same method was used for the five (5) formulas with fonio. These formulas were analysed to determine their nutritional profile, then compared to the Nutrimix formula using Student Test of means comparison. The best formula that increased Nutrimix micronutrient content was determined based on three (3) criteria: availability of the crop, significative difference of composition with Nutrimix and higher mineral content. *Results*: comparison of fonio and quinoa formulas to the Nutrimix shows a significant increased iron (4.58 to 59.19 mg/kg), zinc (19.03 to 27.4 mg/kg), sodium (65.59 to 90.52 mg/kg), and copper (<0.03 to 5.35 mg/kg) but the calcium level slightly decreased (from 542 to 417.7 mg/kg). *Conclusion*: Partial substitution of maize with quinoa and fonio significantly improved essential mineral content in infant porridges and represents a promising strategy for fighting against micronutrient deficiencies.

Keywords

Quinoa, Fonio, Nutritional Composition, Infant Porridge, Malnutrition

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1. Introduction

Child undernutrition remains a major public health concern in Togo. The national surveys on 2022 indicates that approximately 27% of children under five years suffer from chronic malnutrition [1]. Malnutrition encompasses deficiencies, excesses, or imbalances in nutrient intake of nutrients [2]. Malnutrition, in all its forms, includes undernutrition (wasting, stunting, and underweight), inadequate vitamins or minerals, overweight, obesity, and resulting diet-related noncommunicable diseases [3]. Undernutrition is particularly critical during the complementary feeding period (6-24 months), when inadequate dietary diversity and poor nutrient intake may impair growth and development. Economic constraints further limit access to nutrient-rich foods, especially in low-income households [4]. One solution is to introduce during the diversification age, locally available foods with rich nutritional profile.[5].

Considering Fonio, two species are produced in Togo, the white fonio grains (*Digitaria exilis*) and the black fonio grain (*Digitaria Iberia*) [6]. Both varieties of fonio presents a good chemical composition and nutritional properties [7], making them a good source of Mg, Fe, K, Zn, Ca, Cu, and Na [8], and particularly good candidates in formulating infant porridge, raising their interest in complementing actual infant formula when increasing their mineral content.

Quinoa, as a rich nutritional crop, is also very used when formulating infant formula, or in substitution of widely used crops. [9] However, its culture is actually not effective in Togo, as it is still in its early stages of being introduced and extension by FAO [10]. Quinoa constitutes as well a good alternative when formulating infant formula, due to its composition in bioavailable essential amino acids [11], rich in methionine and lysine [12] with a good mineral content including Fe, Mg, zinc [13] and its good agroecological adaptation [14].

Considering the richness of those cereals, using them when formulating follow-up products for young children allies with the idea of combating micronutrients deficiencies during diversification age. Considering WHO indications [15], nutritional values of infant porridges formulas developed with different quantities of fonio and quinoa constitute good references of food-food micronutrients fortification, which could be very useful when formulating therapeutic food for malnourished children nutritional recovery. This study was aimed to analyze the impact of progressive maize substitution with quinoa or fonio on the mineral content of a reference infant porridge formula, in order to improve the quality of infant follow up product when promoting local underutilized crops with great nutritional profile.

2. Material and Methods

2.1. Study Design

The experimental comparative study was conducted at the Togolese Institute of Agronomic Research (ITRA), from February to July 2025. The study was initiated in Lomé university research laboratory, LASBASE (Laboratory of Biomedical sciences and environmental Health), and all analysis were performed at the Food Quality Control Laboratory (LCQA) of ITRA, while infant porridge formulations were performed at ITRA's food technology platform.

The substitution was done in order to raise mineral content of Nutrimix; Maize was substituted with either Fonio or Quinoa. Five (5) compositions were formulated using quinoa and five (5) others using fonio. The reference formula is the Nutrimix, and in the Nutrimix, maize was substituted at different percentage with quinoa (Q formulas) and with fonio (F formulas). All formulas obtained were analysed in laboratory to determine their nutritional composition.

2.2. Equipments Used to Make Flour Formulations

For the formulation, mill (HUNT N°2A PREMIER MILL, UK), scale (OHAUS, USA), sorting tables, drying tables, electric oven (JUNO, Germany), welding machine (CYNOX, Chine), small plastic bags (0.5L capacity), labelling marker and small containers were used.

2.3. Vegetal Material

Ten (10) formulas were analysed in total: five (5) formulas using Quinoa grains, rice, soybeans, maize. Quinoa formulas were labelled Q (for quinoa) with the corresponding number, as depicted in Table 2.

The five (5) other formulas (F formulas) composition were developed with black fonio grains, rice, soybeans, maize. Fonio formulas were labelled F (for fonio) with the corresponding number, as depicted in Table 3.

The quinoa grains were produced in 2022 at the Togolese institute of agronomic research- Dapaong center located at north of Togo. Quinoa grains were washed ten times with clear water in order to eliminate the saponins present in the grain's pericarps, method developed by ITRA. After washing, the grains were dried naturally under the sun on drying tables and then roasted for ten minutes in the oven (JUNO, Germany) at 180 ℃.

Black fonio grain, rice, soybeans, maize were purchased at the local market of Agoe Assiyeye; they were sorted manually to eliminate stones and dust, then washed manually in large basins with clear water, dried on drying table under the sun for two (2) days and finally roasted for ten (10) min each in the oven (JUNO, Germany) at a temperature of 180 ℃.

After roasting, the different products were cooled in room temperature (22 -25 ℃) during 1 hour. Then formulas were constituted by weighing different amounts of the roasting products according to the composition tables with a scale

(OHAUS, USA); the scale capacity is 520 g, calibrated in concordance with the requirements of ISO/IEC 17025 version 2017 [16]. After weighing, products were grinded in a traditional electric mill (HUNT N°2A PREMIER MILL, UK) twice times during ten (10) minutes each time. The different flours obtained were cooled in a cooling room with ambient temperature (22 -25 ℃) for 4 hours, before being conditioned in plastic isotherm bags sealed with an electric welding machine (CYNOX, China), compliance to the recommendations of the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) [17]. Each bag was labelled with the corresponding formula code.

2.4. Material and Methods Used for the Physicochemical Analysis

Protein dosage was performed using Kjeldahl method, according to the requirements of ISO 20483 [18]. The Kjeldahl method is based on the acidic conversion of the total organic nitrogen in ammonium, which becomes ammonia through alkaline treatment, followed by the distillation and condensation of ammonia; quantity of total nitrogen is then determined through the acido-basic titration of the condensate. Manipulations were performed in a distiller (BUCHI, Germany).

Lipid dosage was performed using Soxhlet method, with a Soxhlet extractor (NANBEI, China), according to the requirements of ISO 734 [19]. The fat contained in the sample is dissolved in hexane inside a balloon, during five (5) hours period. Then the solvent is evaporated using the Rotavapor, allowing recuperating the fat left down in the ballon, which is weight to determine the total fat percentage.

For the carbohydrates dosage, quantity of carbohydrates is determined after subtracting from the total percentage (100%) the water content (WC), the protein content (PC), the ashes content (AC) and the lipid content (LC), according to the CAC/ vol IX ed I requirements.

Water content was determined through the drying method: the sample is weighed before drying, and then dried in an oven (ARGOLAB, Germany) containing calcium chloride and phosphoric anhydride, according to the NF ISO 24557 [20] requirements. After drying, the dried sample is weighed and water content is determined by subtracting the dried sample weight from the wet sample weight.

Ashes content is determined through sample incineration, according the ISO 2171 [21] requirements. The sample is incinerated in the oven (VOLCA V50) at 550 ℃ during five (5) h, and after incineration, the ashes are weighed.

For the mineral content, minerals were measured by Atomic Absorption Spectrometer, according to NF EN 14084 [22] method, where initial concentration of the cation to be determined is deduced from the absolute value of the intensity of spectral emission.

2.5. Formulation and Comparative Studies

The reference formula used for Fortification/substitution was the Nutrimix formula, commercialized at the Togolese institute of agronomic research, constituted of maize, soybeans and rice (Table 1).

Table 1. *Reference formula (Nutrimix) composition.*

Ingredients	Maize (g)	Soybeans (g)	Rice (g)
Quantity (g)	632	263	105

Five (5) quinoa formulas were obtained by substituting at different percentages maize with quinoa grain flour; those formulas were labelled Q with the corresponding number, as presented in the Table 2 below.

Table 2. *Quinoa formulas composition.*

Formulas	Maize (g)	Quinoa (g)	Soybeans (g)	Rice (g)
Q1	582	50	263	105
Q2	532	100	263	105
Q3	482	150	263	105
Q4	432	200	263	105
Q5	316	316	263	105

Five (5) fonio formulas were obtained by substituting at different percentages maize with fonio grain flour; those formulas were labelled F with the corresponding number, as presented in the Table 3.

Table 3. *Fonio formulas composition.*

Formulas	Maize (g)	Fonio (g)	Soybeans (g)	Rice (g)
F1	582	50	263	105
F2	532	100	263	105
F3	482	150	263	105
F4	432	200	263	105
F5	316	316	263	105

All Q and F formulas as well as the reference formula were analysed.

2.6. Statistical Analyses

All measurements were performed in duplicate and the means were calculated; the data were collected in Excel after transcriptions verification. Macronutrients and micronutrients (mineral elements) mean in the formulas were compared to the Nutrimix nutritional mean values. The results were exported to Stata 16 IC Software from Stata Corp LLC to compare the means of the Q and F formulas with values of the reference (Nutrimix) values using the T-test. Statistical significance was set at $P<0.05$.

2.7. Units Conversion

Codex Alimentarius reference values units were expressed in g/100Kcal, µg/100Kcal and mg/100Kcal; they were converted in g/100 g and mg/100 g, considering that 100 g of Nutrimix energetic value is 438.17 Kcal. Hundred (100) Kcal is equivalent to 22.828 g; all the values were multiplied by 100 g and divided by 22.828 g to have units in g/100 g and mg/100 g.

3. Results

Nutrimix analysis results showed a deficit in micronutrients, when compared to whether Codex Alimentarius or WHO recommendations.

Table 4. *Nutritional composition of Nutrimix and comparison to Codex Alimentarius and WHO recommendations (2002).*

NUTRIENTS	UNITS	NUTRIMIX	OMS	CODEX ALIMENTARIUS
Protein	%m/m	18.72	15.00	>7.88
Fats	%m/m	12.73	8.00	>15.34
Carbohydrates	%m/m	62.19	64.00	< 55.03
Iron	mg	0.458	9.3	4.4 – 13.2
Zinc	mg	1.9	4.1	2.2
Sodium	mg	6.5	320.0	NA
Copper	mg	0.001	NA	NA
Calcium	mg	54.22	400.00	394.35

Considering essential minerals for food diversification, it appears that Nutrimix is highly deficient in iron and slightly deficient in zinc compared to Codex Alimentarius and WHO recommended values.

First, fonio formulas (F) macronutrients means values were compared to Nutrimix (N).

Table 5. Comparison of macronutrients means value between Nutrimix and Fonio formulas.

Macronutrients	F1 vs N		F2 vs N		F3 vs N		F4 vs N		F5 vs N	
	Δ	p	Δ	p	Δ	p	Δ	p	Δ	p
Protein	0.01	0.99	1.00	0.42	-0.63	0.62	0.28	0.79	1.09	0.39
Fats	2.08	0.028*	2.74	0.000*	3.72	0.007*	5.08	0.000*	2.95	0.000*
Carbohydrates	0.43	0.69	0.02	0.99	-1.07	0.37	-0.87	0.43	0.46	0.754

Δ: difference between F values and N (F-N) * significative differences

Then quinoa formulas (Q) macronutrients mean values were compared to Nutrimix (N).

Table 6. Comparison of macronutrients means value between Nutrimix and Quinoa formulas.

Macronutrients	Q1 vs N		Q2 vs N		Q3 vs N		Q4 vs N		Q5 vs N	
	Δ	p	Δ	p	Δ	p	Δ	p	Δ	p
Protein	0.22	0.85	-1.08	0.35	-0.99	0.39	-0.05	0.97	-0.63	0.56
Fats	4.66	0.000*	2.96	0.000*	4.56	0.000*	6.11	0.0002*	4.17	0.0001*
Carbohydrates	-0.16	0.878	3.76	0.0507	1.60	0.218	1.48	0.2856	0.12	0.906

Δ: difference between Q values and N (Q-N) * significative differences

There is no significant impact neither for carbohydrates nor for proteins rates when substituting maize with fonio (Table 5) and quinoa (Table 6); but a little diminution of fats level for fonio and significant diminution ($p<0.0002$) for quinoa.

After macronutrients comparison, micronutrients were also compared. First, fonio formulas (F) mineral elements mean values were compared to Nutrimix (N).

Table 7. Micronutrients composition for F formulas and comparison to Nutrimix.

Micronutrients	F1 vs N		F2 vs N		F3 vs N		F4 vs N		F5 vs N	
	Δ	p	Δ	p	Δ	p	Δ	p	Δ	p
Ashes	0.12	0.222	0.15	0.019*	0.05	0.289	0.04	0.3001	0.02	0.924
Iron	-37.67	0.0001*	-47.35	0.000*	-55.12	0.0001*	-50.03	0.0001*	-41.54	0.000*
Zinc	-3.24	0.0005*	-3.18	0.0005*	-3.12	0.0013*	-3.52	0.0034*	-3.15	0.0003*
Sodium	10.34	0.0014*	13.35	0.0021*	1.58	0.075	-7.75	0.0058*	-9.5	0.0003*
Copper	-3.56	0.0002*	-3.71	0.0000*	-3.8	0.0000*	-4.08	0.0000*	-3.7	0.0000*
Calcium	159.63	0.0000*	166.35	0.0000*	127.17	0.0000*	131.43	0.0000*	149.47	0.0000*

Δ: difference between F values and N (F-N) * significative differences

There is a significant raise of the iron rate when substituting at least 6% maize with fonio, showing the significant iron complementation of fonio. As well, a slight raise of the zinc level even though increasing the substitution percentage does not increase zinc concentration, showing a weak impact of fonio complementation on zinc level.

Then, Quinoa formulas (Q) micronutrients mean values were compared to Nutrimix (N).

Table 8. *Micronutrients composition for Q formulas and comparison to Nutrimix.*

Micronutrients	**Q1 vs N**		**Q2 vs N**		**Q3 vs N**		**Q4 vs N**		**Q5 vs N**	
	Δ	**p**	**Δ**	**p**	**Δ**	**p**	**Δ**	**P**	**Δ**	**P**
Ashes	0.14	0.029*	-0.12	0.696	0.07	0.152	0.11	0.0197*	0.12	0.3033
Iron	-44.31	0.0001*	-51.19	0.0001*	-48.46	0.0000*	-49.26	0.0000*	-52.11	0.0001*
Zinc	-3.26	0.0014*	-5.14	0.0008*	-6.13	0.0004*	-6.26	0.0009*	-8.13	0.0009*
Sodium	-10.46	0.0033*	-0.59	0.198	-15.8	0.0008*	-5.32	0.0009*	-25.02	0.0000*
Copper	-4.85	0.0000*	-4.55	0.0000*	-4.63	0.0000*	-5	0.0000*	-5.31	0.0000*
Calcium	171.45	0.0000*	160.03	0.0000*	155.35	0.0000*	142.14	0.0000*	124.3	0.0000*

Δ: difference between Q values and N (Q-N) * significative differences

There is a significant increase in iron content when at least 6% of the maize is replaced with quinoa, which demonstrates quinoa's significant iron content In addition, a slight increase in zinc content was observed; however, the increase in the substitution percentage of quinoa did not lead to an increase in zinc concentration, indicating that the addition of quinoa had little impact on zinc concentration.

4. Discussion

Children malnutrition arises from 6 months to above, when food diversification is not properly accomplished. There are different barriers to proper food diversification, such as lack of knowledge about food nutritional profiles, economical issues or cultural issues. One solution is to privilege crops with rich nutritional profile when formulating infant supplement food formulas. The Tables 5 and 6 have shown that the overall protein and carbohydrates quantity is not really impacted by the substitutions, either when comparing F formulas to Nutrimix ($p>0.05$) or Q formulas to Nutrimix ($p>0.05$). This portrays similar macronutrients profile among cereals, even though fonio and quinoa, referred as "ancient cereals", substitution largely support healthier formulas, considering the fact that ancient cereals are distinguished by their dense nutritional profiles of essential macronutrients (notably high-quality proteins, dietary fiber, and beneficial fatty acids) [23]. However, for fats concentrations comparison, there is a slight difference between fonio formulas and Nutrimix ($p<0.05$), and a significant difference between quinoa formulas and Nutrimix ($p<0.0002$). From those results, it occurs that maize substitution should be done at a level that do not drastically decrease the fats amount in the final formula, as fats plays an important role in child growth, in the central nervous system development and energy intake [24]; another alternative is to complement the final formula with oleaginous grains that can complement fats lack. For the micronutrients content analysis, 5 minerals were measured and compared: iron, zinc, copper, sodium and calcium. Iron level comparison in fonio formulas as well as in quinoa formulas to Nutrimix shown a significant raise ($p<0.0001$). This result supports the fact that fonio and quinoa grains flour contains higher iron level than maize flour, 56.5 mg/kg for quinoa and 13.04 mg/kg for fonio. These results enhance the impact of food-to-food fortification [25], especially using high micronutrients profile crops. The increase of iron level in infant formulas helps in energy production and cell metabolism, essentially improving oxygenation, haemoglobin levels and growth factors such as growth factor-1 (IGF-1), for physical growth; a good iron level is also required to sustain neuronal production and synaptic activity [26]. For zinc levels comparison between F formulas and Nutrimix, as well as Q formulas and Nutrimix, results shows an overall increase, with $p<0.01$ for F formulas as well as Q formulas which is supported by fonio and quinoa medium zinc content, 36.2mg/kg for quinoa and 6.82 mg/kg for fonio versus 19.03 mg/kg for Nutrimix. Substitution is still important if it allows gaining more essential mineral content, and zinc presence allows a good ponderal gain [27] by increasing the production of insulin-like growth factor [28]. Iron and zinc levels obtained were consistent with the values obtained with Weanimix analysis, a cereal-legume blend developed by the United Nations Children's Fund. The Ghanaian government, promoted this cereal-legume blend, as an alternative to *koko*, a cereal based infant flour, made with fermented maize. Iron obtained in F2 formula was at 51.67 mg/kg, compared with 56.00 mg/kg in the Weanimix, and Zinc was at 22.28 mg/kg in F2 compared to 28.00 mg/kg in the Weanimix [29]. Calcium level decrease with the substitution ($p<0.001$), either for F formulas comparison to Nutrimix or for Q formulas comparison with Nutrimix. This finding confirms observations from several African complementary-food studies. Analysis of locally produced complementary foods commercialized in Benin, Burkina Faso, Ghana and Senegal shows that calcium levels were below recommended levels in almost all products investigated, with only one sample meeting the criterion. Fortified products globally contains higher calcium concentrations than non-fortified products [30]. Similarly, recent experimental work on complementary porridges based on African indigenous crops showed substantial variation in calcium concentration among formulations, demonstrating that the choice and proportion of individual ingredients can strongly influence calcium density. Lower calcium levels does not minimizes the substitutions impact, as some studies implies that calcium intake ranges (240 to 400 mg/day) may result in optimal calcium absorption with minimized calcium loss [31]. Substituted formulas calcium levels still covers part of it, and formulas can be enriched with locally green leaves that can raise calcium amount. Sodium level in the other hand increased with the substitution, although, differences were very variable; in F1 and F2 sodium were lower ($p=0.0014$ and $p= 0.0021$); F3 and F4 were higher ($p = 0.0058$ and $p = 0.0003$), however Sodium level in F3 was not significantly different from Nutrimix ($p = 0.075$). These constatations were the same with quinoa formulas, although Q1, Q3, Q4 and Q5 were significantly higher than Nutrimix ($p < 0.01$), whereas Q2 sodium level was practically the same as in Nutrimix ($p = 0.198$). Considering the fact that Sodium (Na) is an important growth factor, and its deprivation inhibits growth, with reduced body, brain weight, length and muscle [32], it is very important to keep its level concordant with reference values (OMS 2002), which is the case with all formulas. Copper as well shows a significant increase in all F and Q formulas compared to Nutrimix ($p<0.001$), enhancing growth improvement, ponderal gain and higher energy intake [33]. When combining all this results, it appears clearly that formulating supplement flour formulas for infant from 6 months old and above with fonio or quinoa constitutes a good source of Iron, Zinc and Copper, minerals that are essential for proper child growth, physically as well as energy intake and brain development [34].

5. Conclusion

Analysis of the five (5) F and the five (5) Q formulas proposed as part of this study provides a good basis for child supplement products, and complemented with other high nutritional profile food, can lead to the production of therapeutic food use in clinical recovery of malnourished children. Fonio and quinoa crops are excellent sources of macronutrients and micronutrients. These crops present a good nutritional profile, with the advantages of being locally available, which constitutes good criteria when formulating supplement products in underprivileged economical context. Overall, Q and F formulas showed approximately same level of protein and carbohydrate as in Nutrimix. However, as highlighted in the results, iron, zinc and copper were increased by the substitution, but fats and calcium were lower. Formulas can be improved by the addition of green leaves for the calcium increase or oleaginous grains for fats complementing, depending on the specific objectives aimed by the fortification. More insights about child supplement formulas used at food diversification age, from 6 months old to above, should be part of national programs, helping to decrease the percentage of children suffering from chronic malnutrition.

Abbreviations

WHO	Worldwide Health Organisation
ITRA	Togolese Institute of Agricultural Research
Q	Quinoa
F	Fonio
N	Nutrimix
CA	Codex Alimentarius
ANSES	French Agency for Food, Environmental and Occupational Health & Safety
AOAC	Association of Official Analytical Chemists
FAO	Food and Agriculture Organization
ISO	International Organization for Standardisation
MSHP	Togolese Ministry of Health and Public Hygiene Quality Control
LASBASE	Laboratory of Biomedical, Agri-Food and Environmental Health Sciences
LCQA	Food Quality Control Laboratory
M	Mean
NaOH	Sodium Hydroxide
SOAC	West African Accreditation System
UL	University of Lome

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Author Contributions

Koko Gloria-Elvire Kpakpo: Conceptualization, Data curation, Methodology, Resources, Writing – original draft

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Conflicts of Interest

The authors declare no conflicts of interest.

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