





Use of chicken eggshell to improve dietary calcium intake in rural sub-Saharan Africa

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Abstract

Undernutrition resulting from inadequate access to high-quality, nutritious food is a widespread issue in sub-Saharan Africa impacting the health and survival of mothers and their children. Inadequate dietary intake leads to a deficiency in nutrients including calcium, required for growth and physiological functioning. This study investigated the potential of increasing dietary calcium intake by the addition of heat-treated ground eggshell to locally prepared food. A mixed methods approach of literature review, Delphi expert survey and focus group discussions with women of childbearing age in rural Tanzania, were used to assess the practicality, safety, and acceptability of consumption of ground eggshell. Chicken eggshell has high calcium content (380 mg of calcium/gram) and bioavailability comparable to calcium carbonate (~39%) with 1 g sufficient to provide one half of a sub-Saharan African adult female's dietary calcium needs. *Salmonella* was indicated as the most likely threat to human health through eggshell consumption. Experts agreed that eggshells boiled for 10 min when preparing hard-boiled eggs with a further 20 min cooking of crushed eggshell in staple foods would eliminate identified egg-associated pathogens. Five focus groups ($n = 46$) indicated eggshells were perceived as waste. However, there was an indication of general acceptance of the approach and a willingness to consider the incorporation of ground eggshells into their diets. Development of suitable communication methods are required to convey benefits and safe preparation methods. Ground eggshell could be a highly equitable method of increasing calcium intakes across rural sub-Saharan Africa where calcium intake is low and village poultry ownership common.

KEYWORDS

calcium deficiency, diet, egg, food and nutrition security, nutritional adequacy, resource-limited settings

1 | INTRODUCTION

Undernutrition continues to be a widespread issue in low-income countries globally, impacting infant and child survival (Black et al., 2013). Maternal undernutrition restricts foetal growth increasing

the risk of neonatal death or stunting in infants who survive. Combined with wasting, micronutrient deficiencies and suboptimal breastfeeding, undernutrition as a whole is estimated to be the cause of 3.1 million child deaths annually (45% deaths in 2011; Liu et al., 2015). Undernutrition is a significant problem in Tanzania, one of the world's poorest countries (The World Bank, 2016) where the

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prevalence of stunting among children under 5 years of age was 37% in 2013 with children in rural areas most affected (National Bureau of Statistics Ministry of Finance Dar es Salaam and Office of Chief Government Statistician President's Office, Ministry of State, President Office, State House and Good Governance, 2014). In Tanzania, 68% of the population live in rural areas (The World Bank, 2015), and 80% of rural households are subsistence farmers (United Nations, 2017) who are often food insecure and rely on government subsidised food rations (United Nations, 2013). Around 40% of the rural population continues to fall below the basic needs poverty line and 20% below the food poverty line (National Bureau of Statistics (NBS) [Tanzania], 2013).

Nationally, dietary diversity is poor and evidence shows that rural-dwelling women and infants' diets are low in energy, protein, fat and micronutrients including iron, zinc, and calcium (Food and Agriculture Organization of the United Nations [FAO]; National Bureau of Statistics [NBS] [Tanzania], 2010; Kulwa, Mamiro, Kimanya, Mziray, & Kolsteren, 2015). Calcium is an important micronutrient required for growth and maintenance of teeth and bone and has an essential role in muscle contraction, blood clotting, and nerve conductivity (Mann & Truswell, 2012). Furthermore, calcium is an important factor in regulating the cardiovascular system and an adequate intake is recommended to prevent hypertension (van Mierlo et al., 2006) and preeclampsia. A recent meta-analysis of 13 randomised controlled trials showed that calcium supplementation during pregnancy in populations at risk of low calcium intake reduces the incidence of preeclampsia by 55% and is associated with a reduced risk of preterm birth and increased birthweight (Hofmeyr, Lawrie, Atallah, Duley, & Torloni, 2014). Daily calcium supplementation (1.5–2.0 g oral elemental calcium) of pregnant women in populations with a low dietary intake is a current recommendation of the World Health Organization (WHO), to reduce the risk of preeclampsia (World Health Organization (WHO), 2016). However, a number of issues have been noted in calcium supplementation to prevent preeclampsia in low-income countries including effective dose, timing of initiation, and mode of administration (Omotayo et al., 2016). Prenatal supplements in Australia contain about 125 mg of calcium per dose.

Micronutrient supplementation and food fortification have been successful in addressing stunting in several contexts (Bhutta et al., 2013; Zerfu & Ayele, 2013), but the sustainability is often challenged by funding, supply and access issues, low acceptability, and/or poor compliance, especially by the rural poor (Darnton-Hill & Mkparu, 2015). Chicken eggshell is a potential source of calcium that is readily available and accessible to rural communities; over 85% of rural households in sub-Saharan Africa (SSA) keep poultry (Guèye, 2000). In general, these communities use all edible parts of the animal for food consumption (Alao, Falowo, Chulayo, & Muchenje, 2017). The potential use of ground eggshell is consistent with these practices. In Nigeria, limestone and ground fish were both showed to heal calcium deficiency rickets in the majority of children in a 6-month period (Thacher, Bommersbach, Pettifor, Isichei, & Fischer, 2015).

Chicken eggshells are used in the manufacture of some food products, as a calcium additive, for example, in rice crackers and confectionery, in Japan (Kewpie, 2014; Mine, 2008) and in Slovakia, a calcium supplement, that contains calcium carbonate from eggshell powder is available (Rovenský, Stancíková, Masaryk, Svík, & Istok, 2003). Ground

Key messages

- Chicken eggshell contains approximately 380 mg calcium per gram and 1 g could provide 50% of an adult female's daily requirement.
- Experts involved in an e-Delphi survey agreed that eggshells boiled for a total of 30 min would pose no risk to human consumption.
- Equipment and skills needed are present in rural areas and the concept of incorporating eggshell into foods was generally accepted.

eggshell as a dietary calcium source has not been reported in SSA. Furthermore, no studies have been found that evaluate the practicality and acceptability of this method of dietary supplementation.

This study investigated the potential of increasing dietary calcium intake by adding ground, chicken eggshell to food in SSA. Preparation methods and associated food safety risks were evaluated. Practicality and acceptability of the proposed methods for preparing ground eggshell and including it in food as a dietary supplement were investigated in rural Tanzania.

This study contributes to an ongoing project in Tanzania and Zambia, which seeks to test opportunities to enhance the key role that women play in strengthening household nutrition in an ecologically sustainable manner (Alders et al., 2014).

2 | METHODS

2.1 | Development of an eggshell preparation method

A literature review was conducted to determine the following:

- (1) calcium content and bioavailability of ground eggshells of different bird species;
- (2) food and nutrients that improve or impair eggshell calcium absorption; and
- (3) ways to make ground eggshell safe and palatable for human consumption.

Three databases, PubMed, Web of Knowledge, and Medline, were searched in March 2016 for qualitative and quantitative research published between 1976 and 2016. Subject and keyword (multipurpose) search terms related to eggshell, food safety, and nutrition were combined using Boolean operators. Search terms were eggshell* AND chicken OR poultry AND *availability OR digestibility OR *nutrient* OR safety OR calcium OR limitations OR vitamin* OR sanit* OR foodborne OR health OR salmonella OR diet* OR dietary supplement OR composition AND human nutrition OR sub-Saharan Africa OR Africa OR children OR adult* OR women OR food insecurity OR human* OR eating. Reference lists of relevant articles were hand searched for additional references. Citation searches were also conducted on relevant articles. The recommended daily allowance of

calcium set by the WHO for women (including the maternal life stages of preconception, pregnancy and lactation) and children were compared against calcium content per mean gram of ground chicken eggshell from the literature review. A method of preparing ground eggshell and adding it to food was then proposed.

2.2 | e-Delphi survey to evaluate food safety risks

A two-round modified e-Delphi survey containing both qualitative and quantitative questions was conducted to ascertain expert opinions on microbial food safety risks regarding human consumption of chicken eggshell (Appendix S1). The Delphi method is a structured communication process consisting of at least two rounds of questionnaires peppered with opinion feedback to evoke and refine group judgement of experts (Boulkedid, Abdoul, Loustau, Sibony, & Alberti, 2011; Rowe & Wright, 1999). Both rounds of the survey were pretested for ease of completion, readability, and clarity by independent reviewers from the University of Sydney. A panel of individuals from existing personal networks of researchers with expertise in egg-associated pathogens was selected. Nineteen experts (16 experts from personal contacts and three from snowball sampling) were contacted; six participated in the initial round; five completed the second-round survey. The five were internationally recognised experts from Australia, Belgium, Canada, Scotland, and USA with experience in resource-limiting settings. Four were university professors, and one was an international research centre programme leader. Their self-reported expertise was related to egg microbiology, egg production systems, poultry microbiology, poultry medicine, poultry health, and food safety.

The survey assessed microbial risks associated with the type of egg production systems (large-scale commercial, small-scale commercial, and village). The survey evaluated the following aspects: level of microbial contamination risk; possible source (s) of contamination; likelihood and mode of contamination ("vertical", "mechanical" or "both"); ranking of eight common eggshell-associated pathogens; likely existence of pathogens that could cause food safety problems in humans in general and specifically in a SSA village; the microbial risks of the inclusion of ground chicken eggshells in commonly eaten foods in central Tanzania; and the likelihood that the proposed preparation method for eggshell powder would be a risk. Experts were also asked to comment on the proposed method for preparing eggshell powder in relation to food safety risks.

The two-round survey was conducted on the online platform SurveyMonkey, over 5 months. Each round was open for 2 weeks. A summary of initial round responses was sent to panellists by email to consider before they participated in the second round. Consensus measurement began in the second round with 80% agreement required for consensus. The responses "Do not know" and "Uncertain" were combined for analysis.

Qualitative data from the e-Delphi survey were organised into themes with similar statements. Quantitative data were collated using Microsoft Excel 2013 (Microsoft Corp., USA) and analysed using SPSS Statistics version 22 (IBM Corporation, USA). In the initial round, 4-point Likert-scale questions were described as median, 25th and 75th percentiles and range. The ranking of pathogens was expressed as count.

2.3 | Focus group discussions on acceptability and practicality of ground eggshell

Five focus group discussions (FGDs) to investigate the concept, acceptability, and practicality of ground eggshell for human consumption were conducted in January 2017 in five villages in Iwondo Ward, Mpwapwa District, Dodoma Region, Tanzania. These wards were selected for the overall study by the larger projects's Country Coordinating Committee based on: the level of child undernutrition; an absence of existing nutrition-oriented interventions; and a willingness by leaders at the regional, district, and ward level to be involved. Recruitment to the groups was undertaken by community leaders in each village who invited available women at random. The purpose and nature of the study was explained to the participants and written consent obtained. Participants were provided with a complimentary meal after the discussion group.

Each discussion group was held in a neutral location in the village. Discussions were facilitated by an investigator in a semi-structured format in English with simultaneous Swahili translation. All of the FGDs were audio-recorded and later transcribed and translated. The investigator made fieldnotes on the non-verbal interactions of the participants during the discussions. Questions were related to normal practice of food preparations, egg consumption and uses, acceptability, and practicality of preparing and using ground eggshell (Appendix S1).

Analysis of the transcripts was carried out by manual coding and thematic analysis (Braun & Clarke, 2006). Codes were drawn out from the transcripts in an inductive manner. From these initial codes, the data were then grouped into broad themes to provide a basis for further subtheme analysis using Microsoft Excel 2013 (Microsoft Corp., USA). The investigator's field notes on non-verbal communication and behaviour during the discussion groups were used to supplement the transcript data across the major themes.

2.4 | Ethical approval

Ethical approval for the e-Delphi survey was provided by the Human Research Ethics Committee (HREC) as an amendment to the broader project to which this study contributes, "Strengthening food and nutrition security through family poultry and crop integration in Tanzania and Zambia" (National Institute of Medical Research in Tanzania, NIMR/HQ/R.8a/Vol.IX/1690; University of Sydney, HREC #2014/209). The focus group research was approved by the Clinical Research and Ethical Review Board at the Royal Veterinary College (#2016/1612).

3 | RESULTS

3.1 | Framework development

Eight published articles were found (dating from 1998 to 2015), reporting calcium content and bioavailability of eggshells, mostly from chickens. Eggshell is predominantly calcium carbonate (94%; Vaclavik & Christian, 2014), containing 360–400 mg (average 378 mg) of calcium per gram of eggshell (Table 1; Brun, Lupo, Delorenzi, Di Loreto,

TABLE 1 Calcium requirements by age and reproductive status and contribution of 1 g of chicken eggshell as a percentage of the recommended intake (RI)

| Human life stage | Calcium RI (mg) | Percentage of RI (%) |
|---------------------------|-----------------|----------------------|
| Infants and children | | |
| 0–6 months | 300 | 126 |
| 7–12 months | 450 | 84 |
| 1–3 years | 500 | 76 |
| 4–6 years | 550 | 69 |
| 7–9 years | 700 | 54 |
| 10–18 years | 1,000 | 38 |
| Adult—females | | |
| 19 years—menopause | 750 | 50 |
| Postmenopause | 800 | 47 |
| Pregnant (last trimester) | 800 | 47 |
| Lactating | 750 | 50 |

Note. "WHO/FAO theoretical calcium allowance for animal protein intake 20–40 g" recommended intake (RI) (World Health Organization, 2003) by 1 gram of chicken eggshell. Calcium for chicken eggshell was calculated by taking the mean of the three journal articles measuring content, of approximately 378 mg ($SD = 14.8$) (Brun et al., 2013; Milbradt et al., 2015; A. Schaafsma et al., 2002).

& Rigalli, 2013; Milbradt et al., 2015; A. Schaafsma et al., 2002), that is equivalent to approximately 1.5 g of calcium per eggshell, based on 42 g sized egg. One gram of ground chicken eggshell provides 69% (on average) of a four-to-six year old's recommended daily intake for dietary calcium (Table 1). Trials suggested that the bioavailability of eggshell calcium is similar to that of calcium carbonate (Brun et al., 2013; Anne Schaafsma & Beelen, 1999; A. Schaafsma et al., 2002), estimated to be 39% from a 500-mg calcium carbonate supplement (Sheikh, Santa Ana, Nicar, Schiller, & Fordtran, 1987).

Calcium requirements are affected by protein and sodium intakes, and generally, the diets of populations in developing countries are lower in sodium and animal protein compared with developed countries (World Health Organization, 2003). Therefore, the WHO calcium recommendations for diets with animal protein intakes of 20–40 g per day were selected for this study (Table 2). Based on the estimated average calcium content of eggshells of 378 mg (Brun et al., 2013; Milbradt et al., 2015; A. Schaafsma et al., 2002) and the WHO recommended intakes of calcium for adult females aged 17 to menopause consuming diets with a low animal protein intake (World Health Organization, 2003), approximately half the eggshell from a 42g egg would provide the WHO recommended intake of 750 mg of calcium daily. Additionally, this would provide six times the amount of calcium that is currently contained in Australian prenatal supplements.

Five articles were found on eggshell preparation for human consumption and included a number of preparation methods, including sterilisation, disinfection and mechanical processing. Sterilisation is a process by which all microorganisms are either destroyed or removed, whereas disinfection is the killing, inhibition, or removal of microorganisms that may cause disease (Willey, Sherwood, Woolverton, & Prescott, 2008). Sterilisation of eggshells has been achieved through the use of laboratory equipment such as an automatic steriliser autoclave (Brun et al., 2013). Chemical agents such as sodium hypochlorite

(bleach) oxidise cellular materials and destroy vegetative bacteria and fungi however not all the spores will be destroyed (Willey et al., 2008). Temperatures above 100°C or saturated steam under pressure are required to ensure sterilisation of bacterial endospores (Willey et al., 2008). Almost all microorganisms die within 30 min at 0.1–0.5% sodium hypochlorite concentrations (Willey et al., 2008). Disinfection methods incorporate the use of 1–2% sodium hypochlorite and/or boiling water (Milbradt et al., 2015; Willey et al., 2008).

A typical household kitchen in SSA does not have the chemical agents or equipment to sterilise eggshell; however, the equipment to disinfect, for example, by boiling, is likely to be available and was selected as the most practical method. Placing eggshell in boiling water disinfects, with time required varying on the organism for removal.

Key components for preparation after disinfection included crushing eggshell into a powder form with the finer grinding of powder particles, reducing the impact on overall meal texture (Brun et al., 2013). The majority of mechanical processing preparation methods used commercial equipment (e.g., Retsch GmbH MM2001, mixer mill) although some used rolling pins, ovens, and other household items for the mechanical processing of eggshell.

Pastoral de Criança, a charity organisation helping Brazil's undernourished communities, teaches families how to create a nutritive powder to help meet nutrient requirements. One of the ingredients in this powder is eggshell. The original technique used to ensure eggshell is safe for consumption uses household methods, that is, placing the eggshell in a bleach solution for 20 min followed by boiling water for 20 min (Pastoral da Criança, 2000). Naves, Prado, Fernandes, and Serafini (2007) tested the method using reduced times for both boiling and bleaching and two eggshell drying processes, that is, sun drying for 2 hr and oven drying at 60°C for one and a half hours. Both methods provided adequate protection; however, the sun-dried sample had some microbial contamination (Naves et al., 2007). Milbradt et al. (2015) also compared two preparation methods of 1% sodium hypochlorite solution for 5 min followed by 10 min in boiling water or boiling water for only 10 min. Both treatments showed satisfactory sanitation according to the Brazilian microbiological standard and *Salmonella* was not detected in either sample (Milbradt et al., 2015).

From these studies, we proposed a preparation method incorporating the WHO "Five keys to safer food" (a programme designed to stop microorganisms causing illness):

- Wash hands before handling eggshell;
- Wash and sanitise all surface and equipment used for food preparation;
- Wash broken eggshell (contents removed/used) under water;
- Roughly crush the eggshell and remove (peel off) the eggshell membrane;
- Boil eggshell for 10 min;
- Dry eggshell in a low oven or sun dry on a clean tray;
- Crush eggshell in mortar and pestle until a powder consistency; and
- Store in an airtight container.

TABLE 2 Calcium intake recommendations required to ensure calcium adequacy for the majority of women and children

| Human life stage | WHO/FAO (animal protein intake 20–40 g) ^a | Canada and United States ^b | Australia ^c | WHO/FAO (developed countries) ^d |
|-----------------------------|---|---|--|---|
| | 2004 | 2010 | 2006 | 2004 |
| | Recommended intake (RI) (mg/day) | Recommended dietary allowance (RDA) (mg/day) | Recommended dietary intake (RDI) (mg/day) | Recommended intake (RI) (mg/day) |
| Infants and children | | | | |
| 0–6 months | 300 | 200 ^e | 210 ^f | 300 |
| 7–12 months | 450 | 260 ^e | 270 ^f | 400 |
| 1–3 years | 500 | 700 | 500 | 500 |
| 4–5 years | 550 | 1,000 | 700 | 600 |
| 6 years | 550 | 1,000 | 700 | 600 |
| 7–8 years | 700 | 1,000 | 700 | 700 |
| 9 years | 700 | 1,300 | 1,000 | 700 |
| 10 years | 1,000 | 1,300 | 1,000 | 1,300 |
| 11 years | 1,000 | 1,300 | 1,000 | 1,300 |
| 12 years | 1,000 | 1,300 | 1,300 | 1,300 |
| 13–14 years | 1,000 | 1,300 | 1,300 | 1,300 |
| 15–18 years | 1,000 | 1,300 | 1,300 | 1,300 |
| Adult-females | | | | |
| 19 years—menopause | 750 | 1,000 | 1,000 | 1,000 |
| Postmenopause | 800 | 1,200 | 1,300 | 1,300 |
| 70+ years | 800 | 1,200 | 1,300 | 1,300 |
| Pregnancy (<18 years) | - | 1,300 | 1,300 | - |
| Pregnancy (>18 years) | 800 | 1,000 | 1,000 | 1,200 |
| Lactating | 750 | 1,000 | 1,000 | 1,000 |
| Adult - males | | | | |
| 19–50 years | 750 | 1,000 | 1,000 | 1,000 |
| 51–65 years | 750 | 1,000 | 1,000 | 1,000 |
| 66–70 years | 800 | 1,000 | 1,000 | 1,300 |
| 70+ years | 800 | 1,200 | 1,300 | 1,300 |

^aTheoretical calcium allowance. Values based on lower calcium excretion. (World Health Organization, 2003).

^b(Health Canada, 2010).

^c(National Health and Medical Research Council, 2006).

^dBased on Western European, American & Canadian data (World Health Organization, 2003).

^eAcceptable intake.

^fAdequate intake.

3.2 | E-Delphi survey

The panel reached consensus on the microbial contamination risk related to four out of nine pathogens to human eggshell consumption (Table 3). They agreed 100% that the Enterobacteriaceae family, in particular, *Salmonella*, would be a threat to ground eggshell consumption, whereas *Mycoplasma* and Newcastle disease virus would not. Eighty percent of experts agreed that all organisms, except *Bacillus cereus* which is a soil rather than a poultry pathogen, would become innocuous to human consumption after eggshells were subjected to 10 min in boiling water and 20 min while preparing a maize flour dish being cooked in boiling water (Table 4).

3.3 | Focus group discussions

A total of 46 women of childbearing age participated in the FGDs, which lasted between 48 and 72 min. The authors stopped after five

FGDs due to data saturation becoming evident (Fusch & Ness, 2015). Practicality of preparing and using ground eggshell, eggshell and equipment availability, skills and human resources, and batch preparation methods were themes common to all FGDs.

The majority of participants reported that they do not regularly eat eggs due to low poultry ownership associated with chickens dying, low productivity of laying poultry, eggs being kept for reproduction and income, and eggs being an expensive food item to purchase. Most participants discussed the importance of selling chickens (and occasionally eggs) to provide income; however, most expressed a desire to eat more eggs. The response to “What is currently done with eggshells?” was “They are disposed of” with only one participant adding the eggshell to her chicken feed. Therefore, shells from any accessible eggs are available.

Participants in all groups agreed they have all the equipment required for eggshell preparation including a clay pan, local stove, firewood, metal pan, plate, wooden spoon, water, and local grinder (*kinu*

TABLE 3 Likelihood of contamination and possible mode (s) of transmission of common egg-associated pathogens

| Risk of contamination and mode of transmission of individual pathogens | Risk of contamination (1 = high; 2 = medium; 3 = low; 4 = negligible) | Mode of transmission |
|--|---|--------------------------------------|
| Common egg-associated pathogens | Risk Median (IQR) Min-max | Vertical/ mechanical/ both (n) |
| Avian influenza (HP) | Low 3 (3–3.5) 3–4 | V(1), M(3), B(1) |
| Avian influenza (LP) | Low 3 (2–3.5) 2–4 | V(1), M(3), B(1) |
| <i>Bacillus cereus</i> | Low 3 ^a 2–3 | M(3) |
| <i>Campylobacter</i> | Medium 2 (1–4) 1–4 | V(1), M(3) |
| <i>Mycoplasma</i> | Low 3 (1–3) 1–3 | V(3), B(2) |
| Newcastle disease | Low 3 (3–3) 3–3 | V(1), M(4) |
| <i>Salmonella</i> | High 1 (1–2) 1–2 | V(2), B(3) |
| <i>Staphylococcus aureus</i> | Low 3 (2.5–3.5) 2–4 | M(3), B(1) |

Note. B: both mechanical and vertical; LP: low pathogenic; M: mechanical (microbial transmission to an egg via fomites); HP: high pathogenic; V, vertical (microbial transmission from hen to her chick via the egg).

^aIQR is not available as two out of five experts chose “Do not know” option.

nan mchi). When discussing the eggshell preparation method, participants from all FGDs concluded that they have enough time to try the idea within their normal routine. Overall, the average amount of time the participants spend preparing food is 3 hr per day.

Opinion was divided as to whether preparing a large batch or one eggshell at a time would be most suitable. Many participants felt that preparing a batch would be simpler so the task would not have to be carried out so regularly. However, the problem recognised by many was the availability of eggs to be able to make a large batch. Others questioned the method of grinding the eggshell with the local grinder, preferring the idea of grinding the eggshell at the same time as flour by machine.

All groups cited *ugali* and *mlenda* as their staple diet. *Ugali* is a stiff porridge made from maize or sorghum and prepared by boiling in water. *Mlenda* is made from green leaves, commonly cowpea leaves or young baobab leaves, also boiled. The regular use of boiling and grinding techniques in everyday cooking suggests people have the relevant skills to prepare ground eggshell, and that the methods are acceptable.

In addition, the concept of adding powders to food is familiar. Powdered spices were mentioned frequently, although most participants associated spices with adding flavour to food. Adding nutritional supplements to food was an unfamiliar concept with no participants reporting having ever used them.

Eggshell is generally perceived as a waste product and nearly all participants dispose of eggshells. When the idea of eating eggshell was introduced to each group, it elicited a surprised reaction, with participants laughing or talking privately. Some described the idea as “like what chickens do,” suggesting they had not previously associated eggshell with human nutrition nor perceived it as a human food. Nevertheless, once the concept was explained and understood by participants, the idea of eating something normally discarded appeared acceptable.

In general, understanding of why eggshell might be good for health was low and participants had no prior knowledge of calcium. Some participants did not want to comment on potential health benefits without having tried eating ground eggshell themselves. This suggests that participants relate nutrition and health to taste, experiential feelings of health, and if something is accepted as common practice. When identifying who in their family would benefit the most, none of the participants mentioned pregnant women or breastfeeding

TABLE 4 Expert agreement on risk of individual pathogens to human eggshell consumption in SSA village context

| Pathogens | Expert agreement (number of experts chose this option out of all members of the panel [n = 5]) | | | | | |
|------------------------------|--|----|---------------------------|--|----|---------------------------|
| | This pathogen would be a risk to human consumption of eggshell in SSA villages | | | With 10-min boiling and 20-min cooking time, this pathogen would remain a risk | | |
| | Yes | No | Uncertain/ Do not know | Yes | No | Uncertain/ Do not know |
| Avian influenza (HP) | 3 | 1 | 1 | 0 | 5 | 0 |
| Avian influenza (LP) | 2 | 2 | 1 | 0 | 5 | 0 |
| <i>Bacillus cereus</i> | 2 | 1 | 2 | 1 | 3 | 1 |
| <i>Campylobacter</i> | 3 | 2 | 0 | 0 | 5 | 0 |
| Enterobacteriaceae | 5 | 0 | 0 | 0 | 5 | 0 |
| <i>Mycoplasma</i> | 0 | 4 | 1 | 0 | 5 | 0 |
| Newcastle disease | 0 | 4 | 1 | 0 | 5 | 0 |
| <i>Salmonella</i> | 5 | 0 | 0 | 0 | 5 | 0 |
| <i>Staphylococcus aureus</i> | 2 | 1 | 2 | 0 | 5 | 0 |

Note. HP: high pathogenic; LP: low pathogenic.

mothers. Children were frequently cited, with the reasoning that they need a lot of nutrients to grow.

The three main concerns about consumption of eggshell raised during the FGDs were the flavour of the ground eggshell, potential overdosing, and digestion problems. Responses to try eggshell were mixed but overall most participants thought that it was a good idea, very useful, and would like to try it out. Other concerns related to being able to follow the method accurately.

4 | DISCUSSION

This study found that ground eggshell appears to be a safe, practical, and acceptable method to improve dietary calcium intakes in SSA. Eggshell has a bioavailability of about 39%, similar to calcium carbonate supplements and 1 g could provide one half of an SSA adult female's calcium daily requirement. Boiling eggshell for a total of 30 min was found by the e-Delphi expert panel to be adequate to disinfect and be safe for human consumption. Equipment and skills needed are present; however, the concept of nutritional supplements added to food is novel and requires extension materials that increase nutritional understanding to promote its uptake.

Eggshell, like all food, is a possible vehicle for pathogen transfer, able to transmit a variety of diseases to humans. Rough treatment of eggs that results in the cracking or removal of the cuticle, a protein layer on the surface of the shell, and poor personal hygiene by egg handlers increases the risk of microbial contamination and growth (Mayes & Takeballi, 1983). *Salmonella* contamination of eggshell has been noted globally (Whiley, Clarke, & Ross, 2017), and *Salmonella* is a major cause of bacterial infection in SSA (Feasey, Dougan, Kingsley, Heyderman, & Gordon, 2012; Marks et al., 2017). Multiple studies suggested contaminated faeces as probable transmission route of *Salmonella* on eggshells (Gantois et al., 2009; Messens, Grijspeerd, & Herman, 2007).

The expert e-Delphi panel reached agreement that most pathogens identified would not remain a threat to humans when eggshells are subjected to the preparation method proposed. There was uncertainty on *Bacillus cereus*, as two experts considered the possible survival of thermal-stable spores of *Bacillus cereus*; however, the panel suggested there was a low-medium risk of *Bacillus cereus* contaminating eggshell. This pathogen is soil-associated rather than egg-associated and ubiquitous and opportunistic in nature (Helgason et al., 2000; Humphries & Linscott, 2015); therefore, the threat it may pose remains constant among all food sources in our study population setting. Moreover, covering the cooking vessels with a lid during boiling has been shown to be effective in inactivating spores of this pathogen, further reducing risk (Rice et al., 2004).

FGDs explored the practicality and acceptability of the proposed eggshell preparation method. On understanding their nutritional importance, women were positive about potential uses of eggshells and displayed a sense of empowerment. The idea of adding eggshell to grain before being taken to the milling machine, raised by FGD participants, could be practical and would reduce time and labour involved but needs to be trialled in situ to determine whether it is technically and commercially viable. There could be problems with

how effectively the eggshell is ground and its distribution in the flour. Furthermore, if portion sizes of local porridge fluctuate with individual serving sizes, season, and harvest/availability of grain, it would be more challenging to control calcium intake (Bagnol et al., 2016). Each household mills varying quantities of grain at varying frequencies (usually once per week), so a clear recommendation would be needed for the number of eggshells to be added per kilogram of grain if this method of grinding is practical.

Palatability and texture need to be assessed in local foods among all family members, with men typically the “head” of the household as they are influential as to whether a new idea is accepted (Richards et al., 2013). No changes in food flavour, but some changes in food texture were observed in a trial using various foods (Brun et al., 2013) likely due to inadequate crushing and/or sieving, supporting the need for testing in rural conditions. Sieves were proposed to ensure the smoothness of the ground eggshell before adding to food, and this additional step may increase acceptability. Sieves are used in a laboratory setting in the preparation of ground eggshell by Brun et al. (2013) and Naves et al. (2007) and are a commonly available item in rural households. An investigation into alternative preparation methods using village machinery, palatability in local foods, and food safety hazards would help increase practicality and acceptability.

The development of a set of comprehensive extension materials, as well as training, would be necessary to communicate persuasively this novel concept. Some form of extension training, ideally involving a physical demonstration and active learning, would be a more appropriate way of communicating the concept and method in this environment.

Although current availability of eggs for consumption appears low, work being done by projects such as “Strengthening food and nutrition security through family poultry and crop integration in Tanzania and Zambia” is expected to increase flock sizes of village chickens through the control of Newcastle disease (Alders et al., 2014). Increased availability of eggs combined with extension messages encouraging consumption of eggs for their nutritional health benefits, rather than for income (Bagnol et al., 2016), could increase egg consumption in these rural areas.

Generally considered a waste product, eggshell has large potential as a low-cost alternative to commercial supplements recommended by the WHO. These supplements are estimated to cost \$11.50 per person for 6 months (World Health Organization (WHO), 2016) or \$1914 million annually (\$ denotes international dollars) for 90% coverage in 34 countries with 90% of the burden of malnutrition (Bhutta et al., 2013). The production of ground eggshell is cost-free, other than time involved, for people who have the necessary equipment and available eggshells—potentially up to 85% of rural households in SSA, who keep poultry (Guèye, 2000).

4.1 | Strengths and limitations

There are several advantages of using an e-Delphi survey as a decision-making tool for subject matters with limited explicit knowledge or historical data (Wentholt, Fischer, Rowe, Marvin, & Frewer, 2010); however, the e-Delphi small panel size ($n = 5$) used is a limitation. Advantageously, the panel members were internationally renowned

experts in their fields. There are no established standards for e-Delphi panel sizes (Akins, Tolson, & Cole, 2005), nor evidence on the impact of small panel size on their effectiveness (Rowe & Wright, 1999) and the inclusion of experts of mixed speciality is believed to improve decision-making (Boulkedid et al., 2011). The e-Delphi provided expert consensus of risk but no microbiological assays for potential pathogens on eggshells in the SSA environment were undertaken. The panel did not reach consensus on the possible mode (s) of transmission of seven common egg-associated pathogens, that is, only three out of five experts agreed; however, consensus was reached on the possible mode (s) of transmission of Newcastle disease.

The advantages of using FGDs as a methodology are that this format allowed participants to contribute questions and enabled the investigator to be responsive to the nature of the discussion. Emerging themes were followed up instantly, gathering more pertinent data. Although Tanzanian translators were used, language barriers may have affected the investigator's full comprehension of the participant's responses. Discussions were in Swahili; therefore, participants who usually converse in local languages may have had difficulty expressing themselves fully in Swahili and may have felt less willing to contribute. Participants may have provided responses they anticipated the investigator wanted or expected, rather than an honest report due to an "asymmetrical relationship" (Dowling, 2010). Moreover, group dynamics may have affected how representative responses were.

5 | CONCLUSIONS

This study found that adding ground eggshell to traditional foods could be considered a safe, practical and acceptable method of increasing dietary calcium intakes in SSA. Equipment and skills needed are present. However, the concept of nutritional supplements added to food is novel and requires extension materials that increase nutritional understanding to promote its uptake. Expert group consensus indicated that *Salmonella* is the most prominent threat to human eggshell consumption but *Salmonella* and other potential pathogens: Avian Influenza virus, *Campylobacter*, *Staphylococcus Aureus*, and Enterobacteriaceae would not remain a risk after boiling.

Because it is possible to eliminate potential pathogens on eggshells, we believe that eggshell consumption as a calcium supplement can be considered safe and could play a role in relieving maternal and childhood calcium deficiency. However, further applied research to assess women of reproductive age's ability to use eggshell and identify any safety issues will be required.

The proposed preparation method could be utilised across rural SSA where calcium intake is low and village poultry ownership common. With increasing village poultry productivity due to Newcastle disease control, we predict that eggshell will be more available and accessible to all, particularly the rural poor who are most at risk of low calcium intakes. Using ground eggshell to increase dietary calcium could be a highly equitable nutritional recommendation.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

CONTRIBUTIONS

RA conceived the research idea, with contributions from FO and BH. JB, YHY, and HD completed one primary research component each and wrote the draft paper. JB and HD wrote subsequent drafts of the paper. WM facilitated fieldwork by HD. FO, BH, WM, and RA contributed to critical revision of the paper. All authors contributed to and approved the final manuscript.

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SUPPORTING INFORMATION

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