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Zinc bioaccessibility in finger millet porridge blended with zinc-dense mushroom

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A B S T R A C T

Introduction: Zinc deficiency is a common health problem among people who rely heavily on cereal-based foods. Consequently, most people from low-income families, particularly young children in Sub-Saharan Africa, who rely mainly on cereal-based meals, have suffered from Zinc deficiency-related health issues. It is therefore recommended that children who show signs of zinc deficiency like poor growth and cognitive impairment be fed zinc-rich meals; however, in severe cases, they should be given zinc supplements to reduce risks of morbidity and mortality. In that regard, since edible mushrooms are nutritionally rich and contains essential minerals as well as health-promoting compounds, they are a promising tool for improving the nutritional and health quality of commonly carbohydrate-rich foods.
Objective: The objective of this study was to examine the Zinc bioaccessibility and sensory properties of HMT finger millet porridge blended with Zinc-dense mushroom.
Methods: Oyster mushroom (*Pleurotus ostreatus*) was grown on rice straw enriched with zinc sulfate at various concentrations. After reaching full maturity, the mushrooms were harvested, dried, and milled into a fine powder. Zinc-rich mushroom powder was mixed with millet flour in various proportions and used to prepare porridge. The zinc bioaccessibility in millet-mushroom flour blends was determined using a simulation method of gastro intestinal digestion. In addition, panelists comprising of mothers and caregivers of children aged between 6 and 23 months were asked to evaluate the sensory attributes of millet-mushroom porridge.
Results: Adding Zinc to growth substrates had a significant ($p<0.05$) effect on mushroom yield. Control substrates without Zinc yielded 120 g of mushroom per kilogram substrate. However, when 100 mg Zinc was added to the substrate, the yield increased by 65.6%. The study further noted that substrates with Zinc beyond 100 mg had a negative effect on mushroom yield. Consequently, substrates with the highest Zinc level (600 mg) produced the lowest mushroom yields. Increasing substrates Zinc content, on the other hand, had positive effect on mushroom Zinc levels. Substrates without Zinc produced mushrooms containing 8.9 mg Zinc, which increased by 30.9% when 600 mg Zinc was added. Furthermore, HMT finger millet porridge without mushrooms had a phytates: Zinc molar index of 60.3, which decreased to 34 when 20% (w/w) mushroom proportions were added. Despite having the highest bioaccessible Zinc with the least effect on texture and appearance, a 20% mushroom proportion in HMT finger millet porridge considerably compromised the taste, aroma and general consumer acceptability.
Conclusion: Amending HMT finger millet flour with mushroom powder improved Zinc bioaccessibility of the porridge. However, when added beyond a certain limit, mushroom reduced organoleptic qualities of the porridge, which affected overall consumer acceptance. The study recommends, therefore, that mushroom powder be added to finger millet flour in the appropriate proportions to enhance nutritional and health benefits of porridge while minimizing possible negative impacts on sensory properties.

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1. Introduction

Micronutrients play a critical role in infant growth and development, maintenance of body tissues, reproductive health, and normal function of immune system and vision [1]. Therefore, those who are deficient in micronutrients exhibit poor growth, cognitive impairment, and an increased risk of morbidity and mortality [2].

Micronutrient deficiency is common in developing countries, particularly among infants and children from low-income families [3]. According to recent studies, one of the major causes of micronutrient deficiency is overreliance on plant-based foods with high micronutrient inhibitors and animal-based foods with low micronutrient content [4]. Cereals, for example, contain high levels of phytates and tannins, both of which are major anti-nutrients that significantly reduce absorption of micronutrients such as zinc, iron, -calcium etc. in the human gastro intestinal tract [5]. Most animal-based foods are also low in micronutrients, with only a few exceptions, such as meat, fish, and shellfish, being high in micronutrients such as zinc and iron [6].

Finger millet (*Eleusine coracana*) is a popular cereal crop that is widely consumed throughout Africa, India and China. When compared to other cereal crops, finger millet contains a higher carbohydrate content as well as minerals such as calcium (344 mg/100g) and potassium (408 mg/100 g), besides polyphenols and dietary fibers which have numerous health benefits [7]. In addition to health benefits, finger millet food products have pleasant taste, aroma and good texture [8]. Millet is commonly milled into fine flour and used to make food products like porridge, which is a popular staple food in Sub-Saharan Africa. The flour can be combined further with maize (*Zea mays*) flour, pearl millet (*Cenchrus americanus*) flour, or sorghum (*Sorghum bicolor*) flour, either separately or in blends to improve porridge texture [9].

Finger millet porridge is rich in carbohydrates and when not supplemented, it is limited in meeting nutritional needs of consumers [10]. People, particularly children who rely heavily on finger millet products such as porridge are more likely to suffer from stunting and muscle wasting [11]. In result, concerted efforts are being made to improve the nutritional quality of porridges through the addition of other nutritious foods. Recent studies by Kalumbi et al. [12]; Marcel et al. [13] and Okoye et al. [14], attempted to improve the nutritional quality of porridges by supplementing cereal flours with soy bean (*Glycine* max (L) Merr) flour, amaranth (*Amaranthus cruentus* L.) flour, and pigeon pea (*Cajanus cajan*) flour, respectively. However, this does not address the issue of micronutrient deficiencies associated with cereal-based foods.

Edible mushrooms are rich in proteins, fibers and vitamins, all of which are essential for human health [15]. In addition, they contain health-promoting compounds with antioxidants, antimicrobial, antitumor, and anti-inflammatory properties [16]. Besides, due to their unique ability to bioaccumulate metals from their environments [17,18], mushrooms are viewed as potential foods that can be used to improve the micronutrient content of other foods. In that regard, there is need to observe the bioaccumulation factors in harvested mushrooms to avoid any potential health risk on humans [19].

There have been a few attempts to incorporate mushrooms into other foods; classic examples are bakery products including bread, cookies, cakes, muffins, and biscuits [20–23]. The limitation of this strategy, however, has been alterations in taste and aroma of the mushroom-infused foods, which low consumer acceptance [24]. The objective of this study was thus to examine the Zn bioaccessibility and sensory properties of HMT finger millet porridge blended with Zn-dense mushroom.

2. Materials and methods

2.1. Production of mushrooms on rice straw enriched with zinc sulfate

Growing mushrooms on substrates enriched with zinc sulfate ($ZnSO_4$) was performed following the procedure described by Zięba et al. [25], with some modifications. Briefly, rice straw substrates were soaked in a solution of $ZnSO_4$ in concentrations of 50 mg/kg, 100 mg/kg, 200 mg/kg, 400 mg/kg and 600 mg/kg. Substrates without Zinc (Zn) were used as control. Substrates were pasteurized at 121 °C for 30 min. The sterile substrates were then inoculated with actively growing oyster mushroom spawn (obtained from the Mushroom Culture Collection, Industrial Microbiology and Biotechnology Research Center, KIRDI, Nairobi, Kenya) at the rate of 5% (w/w) and left in the dark until the reproductive phase. Following that, the substrate bags were moved to the growing room and placed on open shelves at controlled temperature of 19–22 °C, where they were exposed to day light/night darkness conditions. The substrates were watered thrice a day to maintain $ZnSO_4$ in soluble form, and relative humidity of the room at 80–90% in order to promote mushroom fruiting.

2.2. Preparation of flours

2.2.1. Preparation of mushroom flour

Mushroom caps from substrates with varying $ZnSO_4$ concentrations were harvested separately at maturity, chopped into small flakes, and steam blanched for 3 min. The blanched mushrooms were dried at 50 °C to <10% (w/v) moisture content before milled into fine (mesh size ~32 mm) flour. The flours were stored separately in clean food grade plastic buckets for further experiments.

2.2.2. Preparation of millet flour

The finger millet flour was prepared following the procedure described by Onyango and Wanjala [26]. Twenty-five kilograms of heat-and moisture-treated (HMT) finger millet [27] were purchased from open-air market in Kisumu County, Kenya. The HMT millet was washed with clean tap water, dried to <10% (w/v) moisture content using an electric oven (MRC Inc., Hagavis, Israel) before milled into a fine (mesh size ~32 mm) flour using a hammer mill (Bühler AG., Uzwil, Switzerland). Native millet (not HMT) was used

as a control and went through the same procedure. The flour samples were separately stored in clean food grade plastic buckets for further experiments.

2.2.3. Millet-mushroom flour blends

Mushrooms with the highest Zn contents were selected for milling. The HMT finger millet was mixed with mushroom powder in ratios of 100:0 (control), 95:5, 90:10, 85:15, and 80:20. The 20% (w/w) mushroom powder was chosen as an upper limit following findings by Sheikh et al. [28], that 10% (w/w) or less mushroom proportion in baked products had minimal or no effect on physical, sensory, and overall acceptability. ***2.3. Determination of phytic acid and zinc contents in mushroom-millet composite flours.***

2.2.4. Phytic acid content

The phytic acid content of native millet and millet-mushroom flours was determined using a spectrometer as described by Pelig-Ba [29]. Briefly, 1 g of flour sample was placed in a 75 mL glass beaker, and 20 mL of HCl (0.66 M) was added. After vigorously stirring for 3 h at room temperature, 1 mL of the extract was transferred to a 1.5 mL tube, centrifuged for 10 min at 13000 rpm, and immediately neutralized with 0.5 mL NaOH (0.75 M). Two tubes were labelled as free phosphorous and total phosphorous, respectively. De-ionized waster (0.62 mL), 0.2 mL buffer solution, and 0.05 mL sample extract were added to the tube labelled free phosphorus and vortexed before being placed in a water bath at 40 °C for 10 min. De-ionized water (0.60 mL), 0.02 mL buffer solution at pH 5.5, 0.05 mL sample extract, and 0.02 mL solution were added to the other tube labelled total phosphorus. The contents were vortexed and then placed in a water bath at 40 °C. After 10 min, de-ionized water (0.02 mL) and the equal volume of buffer solution (pH 10.4) were added to the tube labelled free phosphorus, vortexed, and incubated at 40 °C in a water bath for 15 min. Twenty millilitres of buffer solution and 0.02 mL of alkaline phosphatase suspension were added to the tube labelled total phosphorus, vortexed, and placed in a water bath at 40 °C. After 15 min, 0.30 mL of Trichloroacetic acid was added to each tube and the tubes were centrifuged at 3000 rpm at room temperature. 1.0 mL of the sample/standard was pipetted into a 1.5 mL centrifuge tube, followed by 0.5 mL of the prepared colour reagent. Each sample in the centrifuge tube was vortexed and placed in a water bath at 40 °C. After 1 h, the sample was vortexed and 1 mL was transferred to a micro-cuvette for UV/Vis (Shimadzu Corporation, Kyoto, Japan) analysis at 655 nm.

2.2.5. Zinc content

The zinc (Zn) concentrations in mushroom fruiting bodies and finger millet-mushroom flour blends were determined using the Zn analysis method described by the AOAC [30]. Briefly, 2 g of each sample was placed in a platinum dish and charred on a hot plate at 250 °C for 20 min; followed by a further ashing at 550 °C in a muffle furnace for 2 h. The ash was digested in a fume hood with 25 mL HCl (1:1 HCl/distilled water, v/v). After cooling, the mixture was filtered into a 100 mL volumetric flask and filled to the top with distilled water. An Atomic Absorption Spectrophotometer (Shimadzu Corporation, Kyoto, Japan) was used to quantify the concentration of Zn in the digest. A standard curve was constructed using standard solution of Zn of various concentrations (i.e., 0, 2, 4, 6, 8 and 10 ppm). The total Zn concentration of the samples was determined by comparing the absorbance values obtained for the standards with those obtained for the samples.

2.2.6. Phytates: zinc molar index

The phytic acid: Zn molar index was determined by dividing the phytic acid and Zn content values (mg/100 g) by their respective molar mass and atomic weight (660.04, 65.01 g/mol respectively). The ratio of each flour and/or flour blend was calculated using equation (1) as described by Hotz and Brown [31].

$$\text{Phytic acid} = \frac{PA\ (\text{mg}/100\ \text{g})/660.04}{\text{Zn}\ (\text{mg}/100\ \text{g})/65.01} \quad (1)$$

2.3. Determination of in vitro zinc bioaccessibility in porridge

The porridge was prepared following the procedure described previously [32]. Briefly, fresh cold water (250 mL) was added to 70 g of finger millet-mushroom flours and stirred to form slurry. A further 650 mL of boiling water was added to the slurry and allowed to boil for 5 min. The porridge was left to boil for additional 2 min without stirring and its Zn bioaccessibility was determined using a simulation of gastro intestinal digestion method [33]. Briefly, pepsin solubilized with 0.1 M HCl was used in gastric phase while pancreatic bile salt solubilized with 0.1 M $NaHCO_3$ was used in the intestinal phase. Twenty grams of flour sample were added to 100 mL of 0.01 M HCl and the pH was adjusted to 2 with 2 M HCl solution. After adjusting the pH, 3.2 mL pepsin was added to the sample followed by incubation and stirring at 37 °C for 2 h. Following that, a 0.5 M NaOH titration was performed to achieve a pH of 7.5 to simulate human intestinal pH. Dialysis was performed in a dialysis membrane for 2 h. After reaching pH 7.5, the dialysis membrane was placed in a 37 °C water bath and stirred for 30 min before adding 5.0 mL pancreatin solution and bile salts and stirring for another 30 min to simulate food digestion in the intestines. The dialysate was then filtered and stored at −20 °C for further analysis. The bioavailable Zn was calculated by dividing the amount of Zn dialyzed by the total Zn content of the original porridge using equation (2) as described by Bosscher [34].

$$\text{Phytic acid : Zinc molar ratio} = \frac{\text{Phytic acid}\ (\text{mg}/100\ \text{g})/660.04}{\text{Zn}\ (\text{mg}/100\ \text{g})/65.01} \quad (2)$$

2.4. Sensory evaluation

The porridge samples with mushroom proportions were analyzed for consumer acceptability as previously described [27,35]. The porridges were cooled to 38 °C, and put into polypropylene containers coded with 3-digit random numbers. Twenty-five panelists who consisted of mothers aged between 18 and 45 years (each with a child below 2 years) attending postnatal clinic were randomly selected to carry out sensory evaluation. Women and their children were chosen as study subjects because they are the most vulnerable to micronutrient deficiencies [36]. The panelists were served with 50 mL porridge and instructed to taste, and fill the evaluation sheets. Clean water was provided to rinse their mouths before tasting subsequent porridge samples. The scores on sensory attributes namely; appearance (colour), texture (mouth feel), taste, aroma and overall acceptability, were used to rank the porridge formulations. A 7-point Hedonic scale, with 7 representing strongly like and 0 representing extremely dislike was used. Prior informed consent was sought from the hospital and the panelists.

2.5. Data analysis

Data was analyzed using SPSS software version 21. The data was expressed as the mean ± standard deviation of measurements from triplicate experiments. ANOVA was used to determine levels of significance ($P < 0.05$).

3. Results and discussion

3.1. Mushroom yield on substrates enriched with zinc sulfate

Porridge is a carbohydrate-rich staple food in many Sub-Saharan African communities. It is a popular food because it is inexpensive for many low-income households, particularly in Sub-Saharan Africa. However, porridges made exclusively from cereals are not only low in nutrients, but also contain high concentrations of anti-nutrients [8]. These anti-nutrients including phytates and tannins reduce absorption of essential micronutrients into the human gastro intestinal tract [37]. Because mushrooms are rich in nutrients and other bioactive compounds with immense health benefits, they are a viable tool for improving nutritional value of commonly consumed carbohydrate-rich foods. Consequently, the study developed an in vitro method for evaluating mushroom growth on Zn-containing substrates. Table 1 shows the yield and Zn content of mushrooms grown on rice straw enriched with varying concentrations of Zn. The Zn content of the substrates was found to have a significant ($p < 0.05$) influence on mushroom yield. Increasing the Zn content of the substrate subsequently improved mushroom yield, with substrates containing 100 mg $ZnSO_4$ providing 65% (highest) increase in yields. The study also noted that $ZnSO_4$ levels beyond 100 mg reduced mushroom yield, with substrates containing 600 mg $ZnSO_4$ yielding the least. This implies, that growth substrates should be supplemented with appropriate zinc proportions (50 mg/kg substrate or less) as excess Zn will negatively affect mushroom growth and yield. Similarly, Zn levels in mushrooms increased in direct proportion to the zinc content of the substrates. Zoysa et al. [38] reported a similar pattern of metal accumulation in mushrooms, where Arsenic levels in *P. ostreatus* decreased as Arsenic concentrations in growth substrates increased. Experiments were conducted to determine the extent to which mushrooms can bioaccumulate Zn from Zn-containing substrates. The present findings revealed that Zn levels in mushrooms increased as the Zn content of the substrate increased (Table 1). No significant difference ($p>0.05$) in Zn levels between control mushrooms and those grown on substrates containing 50 mg, 100 mg, 200 mg, or 400 mg of Zn was reported. However, Zn levels in mushrooms produced on substrates containing 600 mg of Zn were 30.9% higher than in mushrooms grown on control. These findings were consistent with previously reported Zn content of *Pleurotus ostreatus* and *Pleurotus florida* grown under similar conditions [16]. Likewise, higher Zn levels reported in this study could be attributed to frequent substrate watering, which could have improved Zn bioabsorption from the substrates. In related studies, metal concentrations in mushrooms were shown to be affected by a variety of factors, the most important of which are mushroom strain, maturation stage, portions used, and ecosystems [39–42]. This study also found that increasing the Zn concentration of the substrate increased Zn levels in mushrooms. Consequently, the Zn content of mushrooms increased from 8.9 mg on control substrates to 11.65 mg on substrate containing 600 mg $ZnSO_4$. Consuming such mushrooms on their own with such high Zn levels is thus not advised, as their zinc concentration exceeds the daily required amount; the permissible Zn limits for children aged 6–23 months and adults are 4–5 mg and 6 mg per kilogram of food, respectively [16]. It follows that the actual amounts of Zn in mushrooms grown on Zn-enriched substrates should be determined in order to determine appropriate amounts to consume or use in the formulation of other food products. Meanwhile in cases where actual

Table 1
Yield and zinc content of mushrooms grown on substrates enriched with $ZnSO_4$.

Substrate formulation	Yield (g)	Zn mg/100 g mushroom
0 mg $ZnSO_4$/kg substrate	120.0 ± 0.3^a	8.90 ± 0.00^a
50 mg $ZnSO_4$/kg substrate	124.1 ± 0.3^b	9.10 ± 0.05^a
100 mg $ZnSO_4$/kg substrate	198.7 ± 0.8^c	9.23 ± 0.03^a
200 mg $ZnSO_4$/kg substrate	154.8 ± 0.4^d	9.35 ± 0.05^a
400 mg $ZnSO_4$/kg substrate	145.4 ± 0.7^e	9.60 ± 0.10^a
600 mg $ZnSO_4$/kg substrate	112.9 ± 0.7^f	11.65 ± 1.45^b

Values are means + standard deviation of triplicate measurements. Superscripts with different letters in the same column indicate significantly different values, $p<0.05$ (Turkey-Kramer test, 95% confidence limit); $n = 3$.

Zn levels cannot be determined; it would be advisable to consume Zn-dense mushrooms alongside foods with no or low Zn content. This is because despite Zn having an intrinsic effect on human health, consuming it in excess (> 50 mg/day) can be toxic and can lead to retardation in growth especially in young children [43]. Nonetheless consuming mushrooms with enhanced Zn content would be advisable because such mushrooms provide not only bioaccessible Zn but also nutrients like proteins, vitamins, and essential minerals, as well as compounds with immense health benefits [15,16]. In that regard, incorporating Zn-dense mushrooms into low-value foods such as porridge is a viable strategy for improving their nutritional and health benefits.

3.2. Zinc bioaccessibility of finger millet porridge blended with Zn-dense mushroom

Cereals and cereal-based products contain anti-nutrients like phytates and tannins, which make essential micronutrients like Zn less bioaccessible [31,44]. The present study, thus, amended HMT finger millet flours with different mushroom flour proportions to improve Zn bioaccessibility in finger millet-mushroom porridge. Table 2 shows the phytic acid content (obtained using equation (1)), total Zn content, and phytic acid: Zn molar index (obtained using equation (2)) of millet flour with different proportions of mushroom flour. The HMT millet had a lower phytic acid content (1551 mg/100 g dwb) than native millet (1740 mg/100 g dry weight), indicating that heat moisture treatment reduces phytic acid in cereals [45]. However, Zn content did not differ significantly ($p>0.05$) between native (2.34 mg/100 g) and HMT (2.483 mg/100 g dry weight) millet flours. A similar study by Wanjala et al. [43] reported 1.5–3.5 mg/100 g dry weight for Zn content of varieties of finger millet grown locally in Kenya. Meanwhile there was a reduction in phytic acid content with every increase in mushroom proportion, which resulted in an inverse relationship of percent mushroom and the phytic acid: Zn molar index.

Fig. 1 depicts the in vitro Zn bioaccessibility in HTM finger millet porridge enriched with Zn-dense mushroom powder. The bioaccessibility of Zn increased by 21.7% when porridge was enriched with 20% (w/w) mushroom powder. It followed therefore that the bioaccessibility of Zn in porridge was proportionate to the amount of mushroom used. The native finger millet porridge had the lowest bioaccessible Zn with phytic acid: Zn molar index of 69, which decreased proportionally with the addition of mushroom powder. According to Ishara et al. [46], a diet with a phytic acid: Zn molar ratio >15 has low bioaccessible Zn, 5–15 has intermediate Zn bioaccessibility, and <5 has high Zn bioaccessibility. The study recommends therefore that, whenever possible, a proportion greater than 20% (w/w) of such mushrooms be added to HMT finger millet porridge, as this will not only make more Zn bioaccessible, but will also improve nutritional and health benefits of the porridge.

3.3. Sensory acceptability of millet porridge with added mushroom flour

Sensory attributes are important in determining consumer acceptability of a food product. They are used in the design of quality systems because they are regarded as a technical support for quality assurance during food formulation [47]. In result, sensory evaluation of millet porridge with different mushroom proportions was conducted. Fig. 2 depicts the sensory score of millet-mushroom porridge as reported by the panelists. The sensory acceptability of porridges differed significantly ($p< 0.05$) depending on the proportions of mushroom used with taste and aroma becoming severely compromised at higher levels of mushroom addition. Despite having the highest Zn bioaccessibility, the HMT finger millet porridge with 20% mushroom proportion had the lowest general acceptability score. These findings were comparable with previous studies, in which Ishara et al. [46] found off flavors in maize flour porridge with mushroom, and Ulziijargal et al. [48] and Okafor et al. [49] reported off flavors in baked products with mushrooms. This study, however, found no changes in other physical attributes such as general perception, appearance, and texture, implying that adding mushroom powder up to 20% (w/w) will not significantly affect perception, appearance, or texture of the finger millet products.

Sensory scores: 7 = Like very much; 6 = like moderately; 5 = like slightly; 4 = neither like nor dislike.

3 = dislike slightly; 2 = dislike moderately; 1 = dislike very much.

GA: General acceptability. Bars represent standard error; n = 3.

Table 2
Phytic acid: zinc molar ratios of different millet-mushroom flour blends.

Flour Formulation	Phytic acid (mg/100 g dwb)	Total Zn (mg/100 g dwb)	Phytates: Zn molar index
Native millet	1740.0 ± 0.3^{c}	2.4 ± 0.0^{a}	69.0^{e}
HMT Millet	1551.7 ± 0.4^{bc}	2.5 ± 0.0^{a}	60.3^{d}
HMT Millet+5% mushroom	1187.0 ± 0.4^{abc}	2.8 ± 0.0^{ab}	45.7^{c}
HMT Millet+10% mushroom	1107.2 ± 0.5^{a}	3.1 ± 0.0^{bc}	39.2^{b}
HMT Millet+15% mushroom	1057.7 ± 0.2^{ab}	3.5 ± 0.0^{cd}	37.5^{ab}
HMT Millet+20% mushroom	1027.3 ± 0.6^{ab}	3.8 ± 0.1^{d}	34.0^{a}

Values are mean + standard deviation of triplicate measurements; values with superscripts having different letters in the same column are significantly different at $p<0.05$ (Turkey-Kramer test, 95% confidence limit); n = 3.

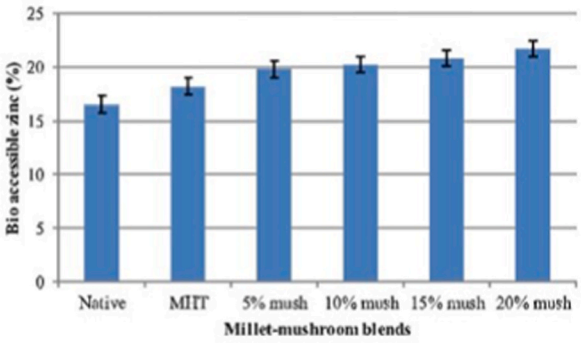

Fig. 1. Bioaccessibility of zinc in porridge made using millet-mushroom flour blends. Bars represent standard error (n = 3).

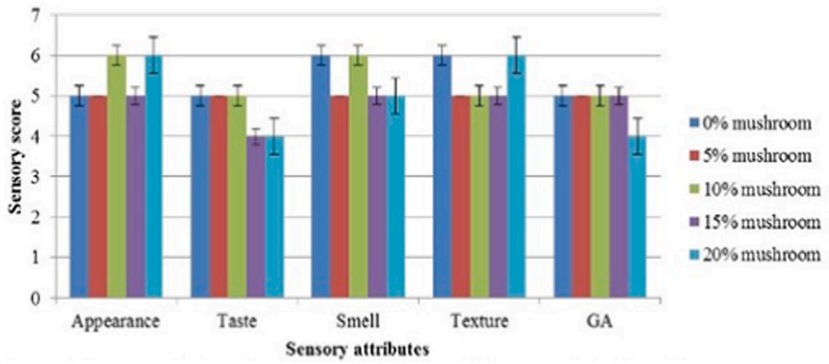

Fig. 2. Sensory attributes of porridge prepared from millet flour enriched with mushroom.

4. Limitations

In this investigation, only one mushroom species was employed, and the reported 50 mg Zn per kilogram of substrate was solely optimal for growth of *P. ostreatus*. A study with different species of edible mushrooms would be required to draw a definitive pattern of how Zn-rich substrates affect mushroom yields. In addition, since different mushroom species have different metal bioaccumulation capacities, further research is needed to ensure that specific metal levels in mushrooms produced using methods described herein or products formulated using metal-dense mushrooms do not exceed WHO recommended limits [50]. Moreover, different cooking methods or inclusion of additives in finger millet-mushroom porridge were not explored in case they could improve sensory qualities of porridge with mushroom proportions beyond 20% (w/w).

5. Conclusion

The findings of this study noted that growth substrates should be supplemented with appropriate amount of $ZnSO_4$ since excess Zn reduces mushroom growth and yield. However, the amount of Zn in the growing substrate determined the amount of Zn in the mushrooms. Moreover, zinc-dense mushrooms introduced unpleasant taste and aroma into the finger millet porridge. The study recommends therefore that better cooking methods be developed or additives be used to improve the organoleptic qualities of finger millet-mushroom porridge. The study, however, opens up possibilities of utilizing nutrient-rich mushrooms to improve the nutritional and health qualities of commonly consumed low-value carbohydrate-rich African foods.

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5.1. Ethical declarations

Authority to conduct research was sought from the Kenyatta University Graduate School and a research permit obtained from the Kenya National commission for Science and Technology and Innovations (NACOSTI/P/20/4521). Consent approval for sensory evaluation was sought from the panelists.

Declarations

Author contribution statement

Karenya S. Luvitaa: Conceived and designed the experiment; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Munyaka A. Wambui: Conceived and designed the experiment; Wrote the paper.

Musieba Fredrick: Conceived and designed experiment; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Ojwang D. Otieno: Conceived and designed experiment; Analyzed and interpreted the data; Wrote the paper.

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e18901.

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