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## Functional Foods From Millets: Nutritional Composition and Health Claims

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### ABSTRACT

Millets, a group of small-seeded cereals grown mainly in dry regions of Africa and Asia, are increasingly described as functional foods, and statements about their nutrient content, antioxidant activity and benefit in diabetes or heart disease now circulate widely in advisory and commercial material. This narrative review asks how much of that language the published literature actually supports. It draws on work on the composition of pearl, finger, foxtail, proso, kodo and related millets, on their phenolic compounds, starch and fibre, on anti-nutritional factors and traditional processing, and on the wider evidence for whole grains, and it reports no new data. Millets are best described as nutrient-dense staples with distinctive phenolic and mineral profiles whose composition varies with species, variety and milling. Most evidence for specific health effects comes from laboratory assays and animal experiments, while controlled human studies of millets themselves are few, so claims are often borrowed from whole grains in general. Goitrogenic flavones and mineral-binding phytate are real but manageable concerns, and processing changes the picture in both directions. The review concludes that millets are a sound and under-used part of a varied diet, that large health claims are not yet established, and it sets out the kind of study that would settle the main questions.

**Keywords:** Millets; Functional foods; Phenolic compounds; Glycaemic response; Anti-nutritional factors; Food processing; Narrative review

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**Article Class:** Review Article

### 1. Introduction

Millets are an untidy botanical group rather than a single crop. The name covers several small-seeded grasses, among them pearl, finger, foxtail, proso, kodo and little millet, that have been grown for a very

long time in dry regions of Africa and Asia (1, 2). They tolerate poor soil and short rains better than most cereals, and for many households they were the everyday grain long before rice and wheat became cheap.



In recent years the same grains have acquired a second reputation. Advisory leaflets, health columns and product labels describe millets as functional foods, a phrase that implies benefits beyond ordinary nutrition (3, 4). Claims about antioxidant activity, blood glucose control, cholesterol, even cancer prevention appear alongside the older and better-founded claims about fibre and minerals. Some of this language rests on real laboratory findings. Some of it is a loose extension of what is known about whole grains in general, and some has no obvious source at all.

This review does not report new measurements. It asks a narrower question: for each of the things said about millets, what kind of evidence stands behind it, and how far will that evidence carry? We describe what is known about composition and phenolic content, starch and fibre, anti-nutritional factors and traditional processing, then set the laboratory and animal findings against the human data. The article is a narrative synthesis; no local or primary data are presented, and none of the figures or tables contains measured values. The aim is to separate what has been measured in millets from what has merely been borrowed from other cereals.

## 2. Literature Review

### 2.1 Millets as a Group of Crops

The archaeology of millet is older than most written records. Evidence from northern China places the cultivation of proso, or common, millet very early in the history of agriculture (1), and the grains remain staples across the Sahel, the Indian subcontinent and parts of East Asia. Reviews of their uses stress how versatile they are, from porridge and flatbread to fermented drinks, and note recent interest in them as ingredients for gluten-free and speciality foods (2).

### 2.2 Nutrient Composition

Millets supply starch as their main energy source, together with protein, a modest amount of fat and a useful quantity of fibre and minerals. Surveys of the proximate and mineral composition of several species show that the values differ between species and between samples of the same species (5), and comparisons with wheat, barley and other cereals suggest that millets sit within the same broad range for most nutrients while differing in the details (6). Finger millet is often singled out for its mineral content, particularly calcium (7).

Two cautions belong here. The first is that composition tables are averages of samples that differ in variety, soil, climate and milling, so a single quoted figure hides a wide spread. This is one reason the same grain can look remarkable in one paper and ordinary in the next. The second is that content is not the same as supply. What reaches the bloodstream depends on how much of a mineral the grain gives up during digestion, which is where the anti-nutritional factors discussed below enter. A reader who sees only a composition table has seen about half of the nutritional picture.

### 2.3 Phenolic Compounds and Antioxidant Activity

Cereals contain phenolic compounds, mostly in the bran and outer layers, and in sorghum and millets these are often present in larger amounts than in the common cereals (8, 9). Much of the phenolic content is bound to cell wall material rather than free, and work on several millets found that these insoluble bound forms made a large contribution to measured antioxidant capacity (10). Extracts of soluble and bound phenolics from millet seeds were also shown to scavenge free radicals and reactive oxygen species in chemical assays (11). Among several millets compared by electron spin



resonance, kodo millet showed particularly strong free-radical quenching (12).

These are genuine findings, and they are the foundation of most antioxidant claims. They are also findings about extracts and test tubes. The step from a radical-scavenging assay to a benefit in a living person involves absorption, metabolism and delivery to tissues, and for many polyphenols the amount that reaches the circulation in an active form is small (13). Reviews of bioactive compounds in foods are careful on this point: laboratory activity is a reason to look further, not a demonstration of effect (14, 15).

#### **2.4 Starch, Fibre and the Glycaemic Response**

The glycaemic index was introduced to rank carbohydrate foods by the blood glucose rise they produce relative to a reference food (16), and later work linked the concept to questions about diabetes and cardiovascular disease while also showing how contested it can be (17). International tables list values for a great many foods, and they remind the reader how much the figure for one food depends on the variety, processing and method of testing (18, 19). Millets appear unevenly in such tables, and values for one preparation cannot be assumed to hold for another.

There is a plausible mechanism behind the interest in millets and blood glucose. Phenolics from the seed coat of finger millet inhibited the digestive enzymes alpha-glucosidase and pancreatic amylase in vitro (20), and in diabetic rats, diets containing several millets were reported to improve measures of glycaemic status and oxidative stress (21). Dietary fibre adds a second route, since viscous and fermentable fibres slow absorption and have well-recognised metabolic effects (22). What is missing is the middle step: well-controlled studies in people, using a defined portion of a defined millet

preparation, with glucose and insulin measured over time. A benefit that disappears once the whole meal is considered is not one a household would notice.

#### **2.5 Anti-Nutritional Factors, Goitrogens and Processing**

Cereals and legumes contain phytate, which binds iron, zinc and calcium in the gut and lowers their absorption, and millets are no exception (5, 23). For populations that depend on plant foods the effect is not trivial, and estimates of iron availability must account for it (24). Polyphenols and some proteins that resist digestion add further complications to protein digestibility and amino acid availability (25).

Millets have a second and more specific concern. Studies in the 1980s reported that pearl millet had antithyroid effects in animals, and the activity was traced to C-glycosylflavones in the grain (26). Reviews of goitrogens in food and water place this within the larger story of iodine deficiency, where diet can aggravate a shortage but rarely creates one alone (27). The concern is real and deserves a place in any balanced account; it does not justify avoiding millets, only attention to iodine intake in places where deficiency is common.

Traditional processing changes much of this. Soaking whole cereal and legume seeds lowers phytate and can improve the proportion of iron and zinc available for absorption (28). Germination and fermentation of finger millet were found to alter carbohydrate, amino acid and phytate content and to raise the extractability of minerals (29), and reviews of traditional practices treat these methods as a practical way to improve micronutrient availability in plant-based diets (30). Decortication, in contrast, yields a softer and milder flour but removes much of the outer grain where



fibre, minerals and phenolics are concentrated (8, 31). A food prepared by fermentation is a different exposure from the same grain eaten as plain porridge.

### 3. Materials and Methods

#### 3.1 Scope and Question

The question was whether the common health-related statements made about millets are supported by published evidence, and by what kind. Statements were grouped into a few families: nutrient and mineral supply, antioxidant and phenolic activity, glycaemic and metabolic effects, and safety concerns related to anti-nutritional factors. The scope was deliberately limited to millets eaten as foods, and to work available in the published literature up to the date of this issue.

#### 3.2 Literature Assembly

This is a narrative synthesis and not a systematic review. No formal database search protocol was registered, no search string was run to exhaustion, and no count of records screened is reported. Sources were assembled by following the reference lists of recent reviews on millets, sorghum phenolics and functional foods, and by reading the primary studies they cited. The reader should assume that relevant studies, particularly those in regional journals, have been missed.

#### 3.3 Appraisal Framework

Each claim was placed on a simple ladder of evidence, from chemical assays and cell models, through animal experiments, to short-term human studies, long-term human trials and observational cohorts. Beside every claim we noted whether the evidence concerned millets themselves, a related grain, or whole grains in general, and whether the preparation tested resembled what people actually eat. Table 3 gives the result in compressed

form. Writing the type of evidence beside each claim is a small habit, but it prevents a good deal of later confusion. No numerical scoring was attempted, because the published studies differ too much in design to be scored on one scale, and no pooled estimate was calculated.

### 4. Results

#### 4.1 What Millets Contribute to the Diet

The first finding is the least dramatic and the best supported. Millets are energy-dense staples that also provide protein, fibre and a range of minerals, and their composition is broadly comparable with that of the major cereals (5, 6). Table 1 lists the main species with a distinctive feature and a point of caution for each. The picture it gives is of a diverse group, not a uniform superfood: a statement true of finger millet may not hold for pearl or foxtail millet, so claims that treat the whole group alike deserve caution.

Each row rests on the sources cited.

**Table 1.** Common millets and points worth knowing about each.

| Millet         | Distinctive feature                                       | Point of caution                          |
|----------------|-----------------------------------------------------------|-------------------------------------------|
| Pearl millet   | Widely grown in dry areas of Africa and India (2, 6)      | Goitrogenic flavones reported (26)        |
| Finger millet  | Seed coat rich in phenolics; good mineral content (7, 20) | Mineral binding by phytate (5)            |
| Foxtail millet | Cultivated in northern China since early agriculture (1)  | Few human studies                         |
| Proso millet   | Among the earliest cultivated cereals in East Asia (1)    | Limited nutritional data                  |
| Kodo millet    | Strong free-radical quenching in one assay (12)           | Result is from a single laboratory method |

Note: Qualitative summary of the cited literature. Composition varies with variety, growing conditions and milling, so no figures are given.



## 4.2 From Grain Components to Physiological Routes

Figure 1 sets out the chain that any health claim about a millet must travel. A claim begins with a property of the grain, passes through processing and cooking, then through digestion and absorption, and only then reaches a physiological outcome that someone could measure. At each stage something can be lost or changed, and the evidence usually covers only the first few.

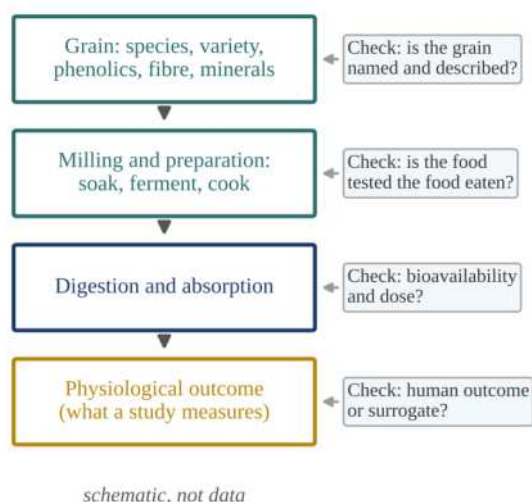


**Figure 1.** Path from millet grain to a health claim, with the checks that sit between them (schematic, not data).

Figure 2 sketches which grain components have been proposed to act through which routes. Phenolics have been linked to antioxidant defence and to enzyme inhibition, fibre to slower absorption and to colonic fermentation, and minerals to nutritional adequacy (20, 22, 32). The matrix records proposals only. A filled cell does not say that the link has been shown in people; it says that someone has suggested it, and several of the suggestions rest on a single laboratory. Where a link has been tested at all, the test has usually been a laboratory assay, so the matrix is better read as a list of questions than as a list of findings, and it is offered as nothing more.

|           | Anti-oxidant defence | Enzyme inhibition | Slower absorption | Gut fermentation | Nutrient supply |
|-----------|----------------------|-------------------|-------------------|------------------|-----------------|
| Phenolics | proposed             | proposed          |                   |                  |                 |
| Fibre     |                      |                   | proposed          | proposed         |                 |
| Minerals  |                      |                   |                   |                  | proposed        |
| Starch    |                      |                   | proposed          |                  |                 |

schematic of proposals, not data

**Figure 2.** Proposed links between grain components and physiological routes (qualitative matrix, not data).

## 4.3 Processing Changes the Answer

Table 2 collects the main traditional treatments and the trade-off each carries. The most useful single observation from this literature is that processing can improve and damage nutritional value at the same time. Soaking, germination and fermentation tend to lower phytate and improve the chance that iron and zinc are absorbed (28, 29). Decortication makes a more palatable product but strips away the layers richest in fibre, minerals and phenolics (31). Which treatment is best depends on whether the goal is keeping quality, taste, mineral supply or phenolic content. Such differences between treatments look minor in a single bowl, yet they repeat at every meal.

Fermentation deserves a separate word, because it is not a single process. Traditional ferments of cereal batters and porridges depend on mixed microbial communities that vary from household to household, and the end product can differ in acidity, enzyme activity and phytate content accordingly (29, 30). That variability is a strength in the kitchen and a headache in the laboratory, since two batches given the same name may not be the same food. It also means that a favourable result from one fermented



product cannot simply be applied to another.

**Table 2.** Traditional processing of millets and what it is meant to achieve.

| Process       | Intended effect                                       | Trade-off                                                     |
|---------------|-------------------------------------------------------|---------------------------------------------------------------|
| Decortication | Softer texture, longer shelf life, milder taste (31)  | Loses fibre, minerals and phenolics from the outer layers (8) |
| Soaking       | Lowers phytate and soluble inhibitors (28)            | Some minerals leach into the water                            |
| Germination   | Activates enzymes; lowers phytate (29)                | Extra time and handling                                       |
| Fermentation  | Breaks down phytate; improves mineral access (29, 30) | Result depends on microbial culture                           |
| Cooking       | Gelatinises starch and softens fibre                  | Heat can reduce some phenolics                                |

Note: Direction of change is described qualitatively and depends on grain, method and duration.

The implication for claims is awkward. A paper that reports the phenolic content of raw whole finger millet says little about decorticated flour, and even less about a fermented batter (10, 30). Studies of health effects rarely describe the preparation in enough detail for the reader to know which of these foods was tested, which makes it difficult to carry any result across to a different dish.

#### 4.4 How Strong Are the Health Claims?

Table 3 summarises the evidence type behind each of the main claims. Antioxidant activity rests on chemical assays and cell models (10, 11). Anti-cancer statements derive from experiments in which phenolic extracts reduced the growth of cancer cell lines or protected DNA in the laboratory (33), which is a considerable distance from preventing cancer in a person. Claims about glucose and lipids rest on enzyme assays and rodent diets (21, 34). In

hyperlipidemic rats, for instance, millet feeding was reported to lower serum triglyceride and C-reactive protein while leaving a measure of oxidative status unchanged (34), a mixed result that leaflets seldom reproduce. The point is not that the laboratory work is poor, only that its result travels less far than its abstract implies.

**Table 3.** Types of evidence behind common millet health claims.

| Claim                 | Evidence mostly available                     | Reading                       |
|-----------------------|-----------------------------------------------|-------------------------------|
| Antioxidant activity  | Chemical assays and cell models (10, 11)      | Suggestive only               |
| Anti-cancer potential | Cell-culture studies (33)                     | Hypothesis                    |
| Lower blood glucose   | Enzyme inhibition and rodent studies (20, 21) | Plausible, untested in people |
| Better blood lipids   | Rodent diet studies (34)                      | Plausible, untested in people |
| Heart protection      | Whole-grain cohort data (35, 36)              | Borrowed from other grains    |
| Mineral supply        | Composition data (5, 24)                      | Depends on bioavailability    |

Note: The reading column is the authors' judgement of how far each type of evidence can carry a claim; it is not a formal grading.

Where human evidence does exist, it mostly concerns whole grains as a category. Cohort studies and meta-analyses link higher whole-grain intake to a lower risk of coronary heart disease and type 2 diabetes (35, 36, 37), and reviews summarise the broader case for cereal foods in heart health (38, 39). The data on cancer are less consistent (40). Millets contribute to few of these datasets as a separate exposure, so applying the findings to them is an extrapolation, a reasonable one perhaps, but an extrapolation all the same.

Figure 3 shows the ladder along which this evidence runs. Most millet claims sit on



the lower rungs, laboratory assays and animal studies, with a small number of human findings available only for whole grains broadly. A reader deciding whether a food deserves a recommendation needs to know which rung a given claim stands on. Claims at the lower rungs are not worthless; they identify what to test. They become dangerous only when they are phrased as if the top rung had been reached.

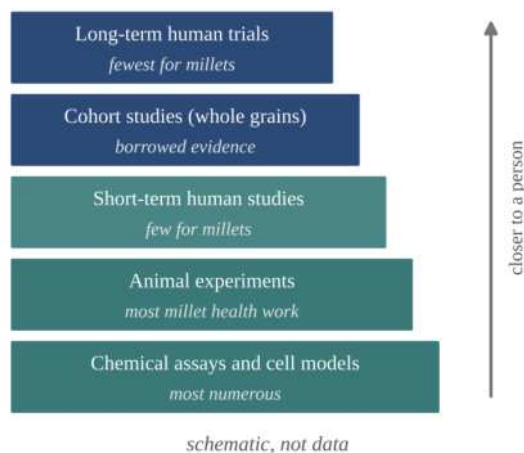


**Figure 3.** Ladder of evidence for a food-based health claim (schematic, not data).

## 5. Discussion

### 5.1 Interpretation

The main finding of this review is conditional. Millets are nutritious, culturally important and agronomically valuable, and in the context of a diet short on variety they are a sound addition. The stronger claims, that they lower blood sugar, protect the heart or prevent cancer, are hypotheses with partial laboratory support and very little direct human testing. That is a modest conclusion, though it is the one the literature will currently carry. Defining a food as functional carries an obligation to show an effect on a relevant outcome at normal intakes (3, 41), and for millets that demonstration is mostly still to come.

The honest position is therefore neither enthusiasm nor dismissal. Critical accounts of functional foods point out how readily marketing runs ahead of evidence, and how plausible mechanisms are mistaken for proven benefits (4, 42). Millets are particularly exposed to this, because they arrive with a pleasing story of tradition, sustainability and local pride, and a story of that kind makes weak evidence feel stronger than it is. These cautions apply equally to any food marketed on the strength of its bioactive content.

### 5.2 Limitations

This review has the limits of its method. It is a narrative synthesis with no formal search, so some relevant studies will have been missed, and our selection reflects what could be found and judged reliable. The literature itself is dominated by a handful of laboratories, which means that apparently independent findings are sometimes not independent. Many studies do not describe the variety, milling or preparation of the grain, so even the evidence we cite cannot always be matched to the food a person would eat. Reviews are more useful when they say where the evidence stops than when they smooth the edge over.

Human studies are the weakest part of the record. Where they exist for millets they tend to be small, short and varied in design, and they seldom use a comparison food that makes the result interpretable. Small trials are also easily misread: an effect that fails to reach significance in a handful of participants is not proof that the food does nothing. In that sense, a null result from a small study says little about whether an effect exists. Conversely, unexpected positive findings in small studies tend to shrink when larger ones follow. We have kept the language of this review correspondingly cautious.



### 5.3 Directions for Future Work

Four kinds of work would change the position. The first is characterisation: studies should report the species, variety, milling and preparation of the grain, together with its phenolic and phytate content, so that results can be compared. The second is the controlled human trial, with a defined portion, a sensible comparison food such as refined rice or wheat, and glucose, insulin and lipid measures over time. The third is bioavailability work, tracing which phenolics actually reach the circulation and in what form (13). The fourth is long-term observational research in populations that eat millets regularly.

Whatever form the work takes, it should state its preparation precisely and report the result whether or not it is exciting. It is a habit worth keeping even when the answer seems obvious.

### 6. Conclusion

Millets are a sound, under-used part of a varied diet. Their nutritional value, resilience as crops and adaptability to local cooking are well established, and some of their phenolic and mineral properties are interesting. What the literature does not yet show is that eating them produces measurable benefits in blood glucose, blood lipids or disease risk beyond those expected from whole grains generally. Phytate and goitrogenic flavones are real considerations but are manageable through processing and adequate iodine intake.

For the practitioner the message is to promote millets for what is demonstrated, as nutritious and diverse staples, and to describe other claims as hypotheses. For the researcher the opportunity is to turn promising laboratory findings into well-described, human-scale studies of specific millet foods. Until those exist, careful language is the most useful thing a

reviewer can offer.

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### 9. Conflict of Interest

The authors declare no conflict of interest.

### 10. Author Contributions

B.G. conceived the review and wrote the sections on composition and processing. I.M. wrote the sections on phenolic compounds and glycaemic response. R.V. wrote the sections on safety and the appraisal of evidence. All authors revised the manuscript and approved the final version.

### 11. Ethics Statement

This is a review of published literature. No human participants or animals were involved and no ethical approval was required.

### 12. Data Availability

No new data were generated. All sources are cited in the reference list.

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