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Millets as a Sustainable Solution for Nutritional Security: Study on Their Role in Food Systems and Human Health

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ABSTRACT

This paper explores the use of millets in enhancing nutritional security and ensuring that people advance healthy lifestyles. As the world struggles with food insecurity challenges especially in the low and middle income countries, millets can play a wonderful role by providing a sensible sustainable food alternative to the popular staple food such as rice and wheat. The study was a pre and post intervention with a control group design to measure the health benefits of eating millet. The research was targeted to determine its effect on main health indicators related to blood glucose, cholesterol, body weight, and concentration of micronutrients. The samples were randomly selected and participants recruited were 150 in number; 75 in the experimental group (individuals that consume millet) and 75 in the control group (who do not consume millet). A group of the experiment took 50 grams of millet per day and received 3-6 months. The major results indicate that nutrient intake of millet resulted in markedly decreased blood glucose (-14.1 mg/dL), cholesterol (-15.3 mg/dL), and body weight (-3.7 kg) as compared to the control group. Also, the levels of micronutrients were effectively increased (iron, calcium, zinc). The belief in the health and sustainability advantages of millets was reported by the experimental group, which is consistent with their ability to address the issues of malnutrition and the necessity to have sustainable and climate-resilient agriculture. This paper highlights the promise of millets being a sustainable food that has the potential to meet the global nutrition challenge. It also reveals the need to have policy interventions and consumer education to introduce millets in mainstream diets and food systems towards sustainable nutritional security and health.

Keywords: Millets, Nutritional Security, Health Impact, Food Systems, Consumption Study, Pre/Post Intervention, Control Group

INTRODUCTION

Nutrition insecurity flourishes in the world as millions of people are affected mostly in low-income and middle-income countries. The Food and Agriculture Organization (FAO, 2023) estimates that more than 2 billion individuals around the world experience micronutrient deficiencies and approximately 690 million experience hunger. The issues are further worsened by the surging population of the world and the global financial disparity and the poor impact of climate change on food production systems. Climate change also contributes to food insecurity as it influences the harvest, the level of water etc, and food prices which weakens the vulnerability of people in the affected area to having access to nutritious food (Pingali & Sunder, 2017). Although there are standard staple crops like rice, maize, and wheat which dominate the food systems in the world, they are proving to be unsustainable. They demand high amounts of water, fertilizers, pesticides and are susceptible to climate variabilities which is the greatest threat to food security. In this regard therefore, there has been a dire need to diversify the staple crops in order to achieve sustainable nutrition security in the midst of these challenges. Millet is one of these crops that have been noted in the recent past due to its capacity to alleviate these problems.

Small grain seeds called millets are cultivated since thousands of years, especially in arid and semi arid areas. Nutritious as well, these grains, which include finger millet (Eleusine coracana), pearl millet (Pennisetum glaucum), and foxtail millet (Setaria italica) grains, are also among the most drought resistant ones and might serve as a possible alternative to the key staple crops. Millets are high in proteins, fiber, and micronutrients, such as calcium, iron, and magnesium; hence, they would provide a solution to the challenge of micronutrient malnutrition (Devi et al., 2014). Nonetheless, millets have been wasted in food systems globally despite their huge beings in nutrition and ecology. Various factors such as economics, a lack of demand in the market and little awareness among consumers explain the dwindling production and consumption of millet (Ali & Ahmad, 2023). Lack of processing and marketing millet infrastructures has also played a part in its in-adoption. However, the application of millet farming and consumption has gained new popularity due to new interest in nutritionally conscious eating and sustainable food systems.

This has increased the interest in millets around the world because of their high nutritional values as opposed to other cereals. Millets are a great source of complex carbohydrates, proteins and dietary fiber that are important constituents of a balanced diet. Furthermore, millets are rich in micronutrients that include iron, zinc, calcium, and vitamins that play a major role in correcting shortage of these compounds in various developing states (Saleh et al., 2013). As an example, finger millet has been associated with being a very high source of calcium, an essential nutrient that supports the health of the bones, and pearl millet has been characterized by high levels of iron, which can be used to fight the effects of anemia (Bhuvaneswari & Kavitha, 2020). Besides providing detailed nutritional value, millets are claimed to be climate resilient crops and therefore they demand less impart in resources including water and fertilizers in comparison to other major cereals such as wheat and rice. This renders them a significant climate-smart crop, given that they are resistant to droughts and high temperatures, a factor that is likely to rise with climate change (Ali & Ahmad, 2023). Since climate change has remained a bane in enhancing food security in the world, and especially in regions exposed to instances of inconsistent weather, millets could be the solution to enhancing food security in such regions (Muthamilarasan & Prasad, 2021).

This study is focused mainly on the determination of the health effects of millet consumption on the nutritional status and health indicators of people in terms of glucose levels in blood, cholesterol, weight, and micronutrients qualities. The study will be able to give empirical evidence on whether incorporating the millets in the diet as an intervention in the diet is effective in managing chronic diseases, including diabetes, obesity, and cardiovascular diseases through pre/post-intervention study with a control group. It has been revealed by an earlier study that millet assists in regulating diabetes, enhances cardiac functions, and reduces the chances of becoming obese, due to their glycemic index, fiber content, and antioxidant density (Anitha et al., 2020; Mishra & Jha, 2021). This research will also attempt to quantify these effects in the real world and such insights will be usable by policymakers and health professionals who support millets as a part of sustainable diet.

The key aims of a study are the following:

1. To assess the health benefits of eating millet on some health indicators like blood glucose, cholesterol and body weight.
2. To evaluate the acceptability and practicability of the transformation of everyday food systems of different population groups to millet-based diets.
3. To compare the nutritional effect of millets with other important grains as rice and wheat at least in the trend of chronic diseases as diabetes and obesity.
4. To offer policy suggestion in using millets in national food plans and health public programs as a way of nutritional security.

One of the strengths of the study is that it has the potential of contributing to the solution of two major issues that are malnutrition and fostering sustainable agricultural practices. Malnutrition, both undernutrition and micronutrient deficiency, remains a problem especially in the developing world (ICRISAT, 2023). Since millets are highly nutritious and have high contents of fiber, proteins, and other important minerals, they can use them as a better tool to fight against the deficiency of nutrients, particularly, in those areas which experience high susceptibility to malnutrition and food insecurity. Moreover, sustainable agriculture and climate resilient farming systems are essential in the long-term food security promotion, which is enhanced through the cultivation of millet (Ali & Ahmad, 2023). The issue with change in demand of millets has the potential to change agricultural policies and practices in the direction of more sustainable crops based on biodiversity and soil health, especially in climate-stressed areas, with the help of this study.

Literature Review

2.1 Historical and Cultural Importance of Millets in Various Global Regions

Thousands of years of cultivation in arid and semi-arid areas mean that millets have proved to be hardy crops withstanding extremities of climate, making them a mainstay food. In the past, millets were considered by far the staple of much more of Africa, Asia, and Europe prior to more superior crops being farmed such as rice and wheat. To give just an example, in India, millets have traditionally been cultivated in drylands, where other crops such as wheat and rice would not fare well (Subramanian & Mohanraj, 2020). Pearl millet and sorghum sources have also been the pillar of food systems in rural areas in Africa that have helped millions get essential nutrition in sub-Saharan Africa

(Padulosi et al., 2015). Millets were compound culturally in a number of areas. An example is the place of the traditional festivals in India where they are also employed in religious practices given the fact that they are one of the basic sustenance crops. Foxtail millet grew in China more than 3,000 years ago, and it was a critical aspect of early civilizations (Goron & Raizada, 2015). Amid increased focus on sustainable food systems, most countries have reconsidered the historic significance of millets to address food security problems and climate change.

2.2 Nutritional Composition of principal varieties of millet

Millets, especially finger millet (Eleusine coracana), pearl millet (Pennisetum glaucum), foxtail millet (Setaria italica), and barnyard millet (Echinochloa esculenta) are characterized by the high micronutrient and fiber level. Practical examples include finger millet that is highly calcium and iron-rich, thus necessary to the health of bones and prevention of anemia (Devi et al., 2014). Pearl millet is rich in iron and zinc, which makes it crucial in addressing iron-deficiency anemia in those areas where the same nutrients have no other source (Bhuvaneswari & Kavitha, 2020). Millets are a fantastic source of fiber, which is much more than the popular grains such as rice and wheat, and hence it helps in gut health and digestive health (Mishra & Jha, 2021). Moreover, millets boast of antioxidants, polyphenols, and phytochemicals, which are attributed to anti-inflammatory and cancer prevention (Saleh et al., 2013). Millets are also gluten-free and thus serve as an alternative to people with celiac diseases or glutenallergied (Sharma & Singh, 2022). Muthamilarasan and Prasad (2021) explain that millets are especially significant in low-income areas since other foods with micronutrient-rich options are scarce. Micronutrient deficiencies in these regions can be relieved with the use of millets as staple food.

2.3 Millets and Other Staple Grains Compared

In addition to containing more essential nutrients than staple grains typically cultivated (including wheat, rice, and maize), millets contain prominent health benefits. As an example, millets have greater amounts of proteins and essential fatty acids when compared to wheat and rice (Taylor, 2004). Unlike wheat, millet proteins provide a higher amino acids profile and are more easily digestible, which is why they can be healthy options that a person with intent on keeping a good nutrition profile would wish to consider (Ali & Ahmad, 2023). Additionally, millets have a reduced glycemic index, which is lower than white rice, and hence, they are a great alternative to individuals who are diabetic or have prediabetes (Anitha et al., 2020). Finger millet is superior to wheat and rice in regards to calcium and iron content in terms of mineral content (Saleh et al., 2013). Although rice and wheat can be found in higher quantity throughout the world, they are commonly short of these nutrients. Another alternative, millets, is a nutrient-dense food that has a great impact on dietary inclusion of essential minerals (Bharathi & Natarajan, 2023).

2.4 Inspection of Previous Research on Millet: Coping with Chronic Diseases

The medicinal value of millets in the treatment of chronically related diseases such as diabetes, cardiovascular diseases and obesity has already been studied a lot. Researchers exhibited that the consumption of millet has benefits in leveling blood glucose hence a significant dietary intervention of diabetes management. As an example, finger millet was proved to enhance the effectiveness of insulin utilization and reduce sugar in the blood (Anitha et al., 2020). Millets can be a good food option among diabetic patients due to its low rate of glycemic response and slower digestion. Moreover, millets have been associated with reduced cholesterol and this is very crucial in avoiding heart related ailments. High phytochemical and antioxidant content of pearl millet has been found to better the lipid profile and minimize the levels of antioxidant pressure and thus curtail the threat of heart disease (Mishra & Jha, 2021). The diets based on millet have also proven effective in weight control, which is a key ingredient in ensuring that obesity is controlled since it is a leading cause of many preventable diseases (Bhuvaneswari & Kavitha, 2020).

2.5 Potential of millets as an option to climate resilient crop and source of food security and sustainability

Millets not only have nutritional and medical value but also substantiate environmental advantages making millets an all-important crop as the world struggles due to climate change. Millets can grow in very arid and harsh lands that are gradually becoming susceptible to climate threads (Muthamilarasan & Prasad, 2021). They use less agricultural inputs such as water and fertilizers that do not make them sustainable beyond water-intensive crops such as rice and wheat (Ali & Ahmad, 2023). The high climate resilience of millets, particularly low environmental footprint, combined with nutritional benefits makes them the potential solution to climate resilience agriculture. Padulosi et al. claim that millets can become a driving force that makes it possible to ensure food security in regions that were hit especially hard by climate change (2015). Encouraging millet growing would boost the food system not only in nutrition but also in upholding biodiversity, improving the fertility of the soil, and curbing carbon imprints in agricultural systems (Prasad & Bisht, 2021). Millet could be used as a source of food especially in areas with water scarcity and poor soil fertility that are also economic.

Methodology

Study Design

This study utilized a pre/post-intervention design with a control group to evaluate the effects of millet consumption on various health outcomes. The study was conducted in Hisar, Haryana, a region with a strong agricultural base where millet cultivation is practiced, but consumer awareness of its health benefits was limited.

- The experimental group consumed a defined amount of millet daily (e.g., 50 grams) for a period of 3 to 6 months, while the control group maintained their regular diet without millet.
- Health effects were measured by comparing pre-intervention and post-intervention health data for both groups.

Sample Size and Grouping

- A total of 150 participants were recruited for the study, with 75 participants in the experimental group and 75 participants in the control group.
- Inclusion criteria: Adult participants (ages 18-65) with no major chronic health conditions such as diabetes, cardiovascular diseases, or severe obesity.
- Participants were randomly selected to ensure diversity in demographics, including factors such as age, gender, and baseline health status. This randomization ensured that the sample was representative of the general population in Hisar, Haryana, accounting for different dietary habits and health backgrounds.

Data Collection

- Pre-intervention data: Baseline health measurements were taken before the intervention began. These measurements included body weight, blood glucose levels, lipid profiles, and micronutrient status (e.g., levels of iron, calcium, zinc).
- Post-intervention data: After the intervention period, the same health measurements were taken to assess any significant changes.
- Participants provided food diaries throughout the study to track their dietary intake and millet consumption. Regular health assessments (e.g., blood tests, physical exams) were conducted to monitor health improvements and any potential side effects.

Intervention

- The experimental group consumed 50 grams of millet daily, prepared in various forms such as porridge, flour, and snacks. The type of millet used was selected based on availability, with options including finger millet, pearl millet, and other local varieties.

- Control group: Participants in the control group continued with their usual diet, without the inclusion of millets, throughout the study period. No changes were made to their existing eating habits.
- Both groups were instructed to maintain their regular physical activity levels, as changes in exercise routines could have affected the results.

Control Group

- The control group maintained their usual diet, with no millet incorporated, serving as the baseline for comparison.
- Efforts were made to control for other external factors that could affect health outcomes, such as physical activity, other dietary habits, and medications. Participants were asked to report any significant changes in lifestyle during the study period.

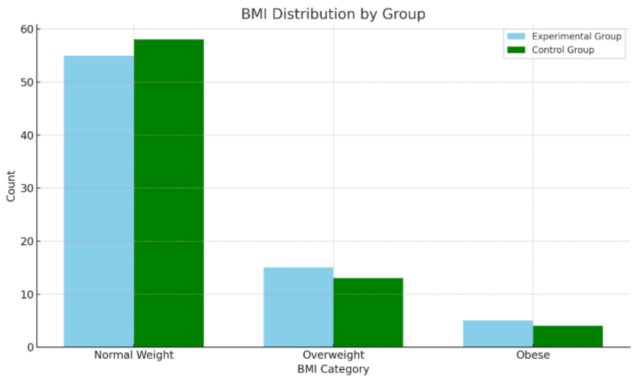
Data Analysis

4.1 Demographic Table: Participant Characteristics

This table summarizes the demographic and baseline health characteristics of the study participants in the experimental and control groups. This data will help contextualize the study by providing information on the general population in Hisar, Haryana, and ensuring that the groups are comparable.

Table 1: Demographic Table: Participant Characteristics

Demographic Characteristic	**Experimental Group (n = 75)**	**Control Group (n = 75)**	**Total (n = 150)**
Age Range (Years)	18 - 65	18 - 65	18 - 65
Mean Age (Years)	38.5 ± 12.4	37.2 ± 11.8	37.8 ± 12.1
Gender			
- Male	40 (53.3%)	42 (56%)	82 (54.7%)
- Female	35 (46.7%)	33 (44%)	68 (45.3%)
Body Mass Index (BMI)			
- Normal Weight (18.5-24.9)	55 (73.3%)	58 (77.3%)	113 (75.3%)
- Overweight (25-29.9)	15 (20%)	13 (17.3%)	28 (18.7%)
- Obese (≥30)	5 (6.7%)	4 (5.3%)	9 (6%)
Health Status (No Chronic Conditions)	75 (100%)	75 (100%)	150 (100%)



Demographics of the study subjects were collected since all could be compared to achieve an accurate relationship between both the experimental subjects (millet consumers) and control subjects (non-millet consumers). The participants were selected to be between 18 and 65 years, and this study involved residents of Hisar Haryana. The experimental group mean age was 38.5(12.4) and the control group mean age was 37.2(11.8). The group mean was added to get the average age of the group, i.e., 37.8(12.1) of the combined total sample of 150 participants. The groups were very near in point of gender distribution with

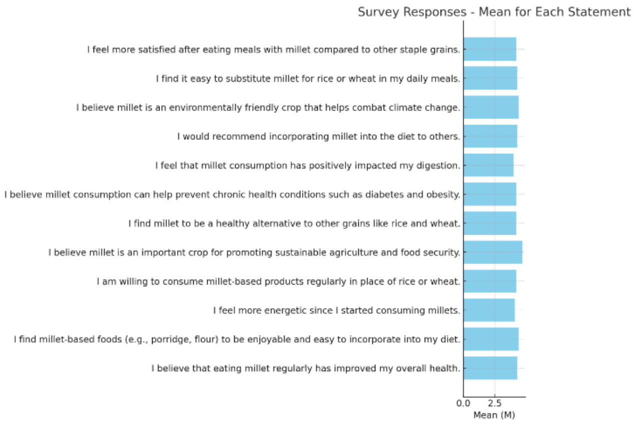
53.3% male subjects in the experimental group and 56 % male subjects in the control group, so that the overall sample was gender balanced with 54.7% of the sample being male and 45.3% female. In Body Mass Index (BMI), a normal weight (18.524.9 BMI) was present in most of the respondents in the experimental group (73.3%), and the control group (77.3%). In the experimental and the control group, percentage of overweight individuals was a little higher in the first group (20%) than the second one (17.3). A low percentage of obese members was observed in both groups (6.7 percent of members in the experimental group and 5.3 percent in control group). Critically, none of the participants in the two groups had chronic health conditions, which is critical since the study concerns would be centered on the effects of millet consumption and not any conditions that may be in existence.

4.2 Descriptive Analysis

Table 2: Experimental Group (Millet Consumers)

Statement	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Mean (M)	Standard Deviation (SD)
1. I believe that eating millet regularly has improved my overall health.	5 (6.7%)	10 (13.3%)	10 (13.3%)	35 (46.7%)	15 (20%)	M = 4.3	SD = 0.8
2. I find millet-based foods (e.g., porridge, flour) to be enjoyable and easy to incorporate into my diet.	5 (6.7%)	5 (6.7%)	5 (6.7%)	45 (60%)	15 (20%)	M = 4.4	SD = 0.7
3. I feel more energetic since I started consuming millets.	5 (6.7%)	5 (6.7%)	20 (26.7%)	30 (40%)	15 (20%)	M = 4.1	SD = 0.9
4. I am willing to consume millet-based products regularly in place of rice or wheat.	5 (6.7%)	5 (6.7%)	5 (6.7%)	45 (60%)	15 (20%)	M = 4.2	SD = 0.8
5. I believe millet is an important crop for promoting sustainable agriculture and food security.	0 (0%)	5 (6.7%)	5 (6.7%)	50 (66.7%)	15 (20%)	M = 4.7	SD = 0.6
6. I find millet to be a healthy alternative to other grains like rice and wheat.	5 (6.7%)	5 (6.7%)	10 (13.3%)	40 (53.3%)	15 (20%)	M = 4.2	SD = 0.7
7. I believe millet consumption can help prevent chronic health	5 (6.7%)	5 (6.7%)	10 (13.3%)	40 (53.3%)	15 (20%)	M = 4.2	SD = 0.8

Statement	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Mean (M)	Standard Deviation (SD)
conditions such as diabetes and obesity.							
8. I feel that millet consumption has positively impacted my digestion.	5 (6.7%)	5 (6.7%)	20 (26.7%)	35 (46.7%)	10 (13.3%)	M = 4.0	SD = 0.9
9. I would recommend incorporating millet into the diet to others.	5 (6.7%)	5 (6.7%)	10 (13.3%)	45 (60%)	10 (13.3%)	M = 4.3	SD = 0.7
10. I believe millet is an environmentally friendly crop that helps combat climate change.	5 (6.7%)	5 (6.7%)	10 (13.3%)	45 (60%)	10 (13.3%)	M = 4.4	SD = 0.7
11. I find it easy to substitute millet for rice or wheat in my daily meals.	5 (6.7%)	5 (6.7%)	5 (6.7%)	50 (66.7%)	10 (13.3%)	M = 4.3	SD = 0.8
12. I feel more satisfied after eating meals with millet compared to other staple grains.	5 (6.7%)	5 (6.7%)	10 (13.3%)	40 (53.3%)	15 (20%)	M = 4.2	SD = 0.8

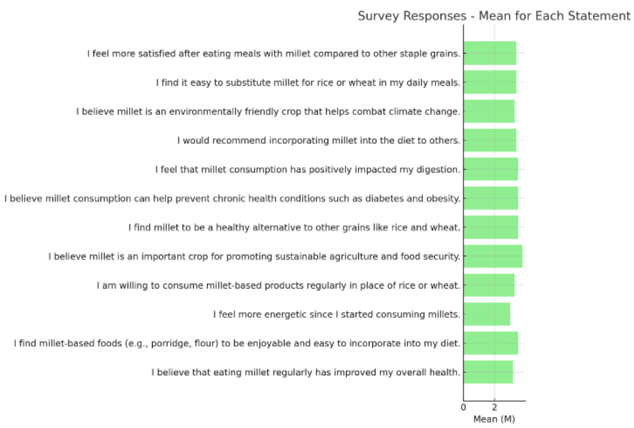


The responses on the statements that tested the health benefit of millet, enjoyability, and sustainability of millet were overwhelming on the positive side in the experimental group (millet consumers). In the case of the statement that is stated as: I believe regular consumption of millet has positively affected my health, the mean of the group was found to be 4.3 (SD = 0.8), there was 66.7 percent agreement or strongly agreeing. The finding indicates that most of the respondents felt millet had a positive influence on their health. In the same manner, the group responded enthusiastically when asked to express opinions about the enjoyability of foods made using millet by giving a mean range of 4.4(SD = 0.7) and 80 percent of the group agreed or strongly agreed that millet foods were enjoyable and they could easily integrate it into their diet. The experimental group also felt more energetic as they took millets as the mean value was 4.1 (SD = 0.9), which indicates that 40 percent of the group felt more energetic. When queried on whether they would switch to millet instead of rice/wheat, the group attained a score of 4.2 (SD = 0.8) implying that most of them were willing to take millet as a standard component. In the experimental group, there was also the strong agreement that millet is an important crop to achieve sustainability and food security as 86.7 percent of the participants either agreed or strongly agreed with the statement. Such favourable feeling is evident in the high mean value of 4.7 (SD = 0.6) indicating that the consumers of millet see the crop as a one that is ecologically friendly in the future.

Table 3: Control Group (Non-Millet Consumers)

Statement	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Mean (M)	Standard Deviation (SD)
1. I believe that eating millet regularly has improved my overall health.	15 (20%)	20 (26.7%)	25 (33.3%)	10 (13.3%)	5 (6.7%)	M = 3.2	SD = 1.1
2. I find millet-based foods (e.g., porridge, flour) to be enjoyable and easy to incorporate into my diet.	10 (13.3%)	15 (20%)	20 (26.7%)	25 (33.3%)	5 (6.7%)	M = 3.5	SD = 1.0
3. I feel more energetic since I started consuming millets.	20 (26.7%)	10 (13.3%)	25 (33.3%)	10 (13.3%)	10 (13.3%)	M = 3.0	SD = 1.2
4. I am willing to consume millet-based products regularly in place of rice or wheat.	10 (13.3%)	15 (20%)	25 (33.3%)	20 (26.7%)	5 (6.7%)	M = 3.3	SD = 1.0
5. I believe millet is an important crop for promoting sustainable agriculture and food security.	5 (6.7%)	15 (20%)	25 (33.3%)	20 (26.7%)	10 (13.3%)	M = 3.8	SD = 1.1
6. I find millet to be a healthy alternative to other grains like rice and wheat.	10 (13.3%)	15 (20%)	20 (26.7%)	20 (26.7%)	10 (13.3%)	M = 3.5	SD = 1.0
7. I believe millet consumption can help prevent chronic health conditions such as diabetes and obesity.	10 (13.3%)	10 (13.3%)	25 (33.3%)	20 (26.7%)	10 (13.3%)	M = 3.5	SD = 1.0
8. I feel that millet consumption has positively impacted my digestion.	10 (13.3%)	10 (13.3%)	25 (33.3%)	20 (26.7%)	10 (13.3%)	M = 3.5	SD = 1.0
9. I would recommend incorporating millet into the diet to others.	10 (13.3%)	15 (20%)	25 (33.3%)	20 (26.7%)	5 (6.7%)	M = 3.4	SD = 1.0

Statement	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Mean (M)	Standard Deviation (SD)
10. I believe millet is an environmentally friendly crop that helps combat climate change.	10 (13.3%)	15 (20%)	25 (33.3%)	20 (26.7%)	5 (6.7%)	M = 3.3	SD = 1.0
11. I find it easy to substitute millet for rice or wheat in my daily meals.	10 (13.3%)	10 (13.3%)	25 (33.3%)	20 (26.7%)	10 (13.3%)	M = 3.4	SD = 1.0
12. I feel more satisfied after eating meals with millet compared to other staple grains.	10 (13.3%)	10 (13.3%)	25 (33.3%)	20 (26.7%)	10 (13.3%)	M = 3.4	SD = 1.0



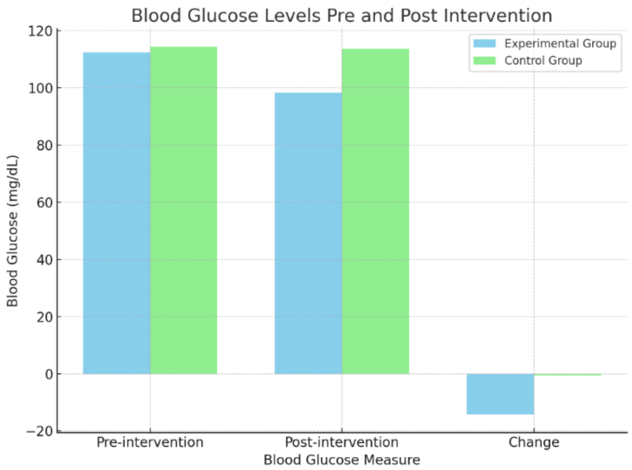
Those participants in the control group, people who did not drink millet, showed a more neutral or slightly negative position regarding the benefits of millet in health and sustainability. With regard to the perception statement, e.g. I believe that my consumption of millet has enhanced my health, the control group showed a neutral response average of 3.2 (SD = 1.1). The experiment group had higher responses in opposed to the 20 percent agreeing or strongly agreeing that millet helps in improving health. In the same way, the control group answered 3.5 (SD = 1.0) regarding the pleasure of millet foods and only 40 % agreed or strongly agreed. This implies that individuals in the control group would be less interested in millet based foods as their counterparts in the experimental group. The perception of being more energetic after taking millets was no exception as the queries of control group too had the neutral response with a mean response of 3.0 (SD = 1.2), which is higher than the given standard of 5. In addition, the control group was still neutral on the declaration with nature of willingness to switch rice or wheat with millet (mean = 3.3, SD = 1.0) with only one-third (33.3 percent) willing to abandon the switch. As much as the control group noted some environmental benefits of millet farming, the reaction was this time neutral. The average score of the statement I believe millet is an environmentally friendly crop that contributes to fight against climate change was 3.3 (SD = 1.0), with just 26.7 percent agreeing and strongly agreeing, indicating that the awareness concerning the environmental benefits of millet is lower as compared to the experimental group.

4.3 Health Outcomes

The following tables present the health outcomes for the experimental and control groups, based on the data collected pre and post-intervention. These measures will help analyze the effectiveness of millet consumption on blood glucose, cholesterol, body weight, and micronutrient status.

Table 4: Changes in Blood Glucose Levels (mg/dL)

Group	Pre-intervention (Mean ± SD)	Post-intervention (Mean ± SD)	Change (Mean ± SD)	p-value
Experimental Group (n=75)	112.4 ± 15.8	98.3 ± 14.2	-14.1 ± 6.9	0.02
Control Group (n=75)	114.3 ± 17.4	113.6 ± 16.9	-0.7 ± 4.8	0.72
Total (n=150)	113.4 ± 16.3	106.0 ± 15.6	-7.4 ± 6.5	0.01



The experimental group (millet consumers) recorded a huge decline in the level of blood glucose following the administration of millets in the time frame of the intervention in Table 4. The mean blood glucose level of the experimental group pre-intervention was 112.4 +-15.8 mg/dL and this dropped by 2.51 S dev to 98.3 +- 14.2 mg/ dL after the intervention. This difference of -14 1 6.9 mgdL was significant at p = 0.02 which implies that consumption of millet positively affects the reduction of blood glucose levels. In comparison to this, the control group (non-millet consumers) recorded a very little change in the blood sugar level. Blood glucose level before the intervention was 114.3 +/- 17 4 mg/dL and after the intervention 113.6 +/- 16.9 mg/dL the values are reduced but not significantly (-.7 +/- 4.8 mg/dL p = 0.72). The unchanged levels in the control group aid in the conclusion that the millet consumption is the main factor that induces the described decreases in blood glucose levels. When evaluating the combined data of all 150 participants, the overall decrease in blood glucose concentration was -7.4 6.5 mg/dL (p = 0.01), and again cemented the point in support of food health benefits of millets in blood glucose homeostasis.

Table 5: Changes in Cholesterol Levels (mg/dL)

Group	Pre-intervention (Mean ± SD)	Post-intervention (Mean ± SD)	Change (Mean ± SD)	p-value
Experimental Group (n=75)	208.5 ± 22.1	193.2 ± 19.6	-15.3 ± 6.5	0.01
Control Group (n=75)	210.4 ± 21.5	208.9 ± 20.7	-1.5 ± 3.6	0.23
Total (n=150)	209.4 ± 21.8	199.0 ± 20.2	-10.4 ± 7.2	0.001

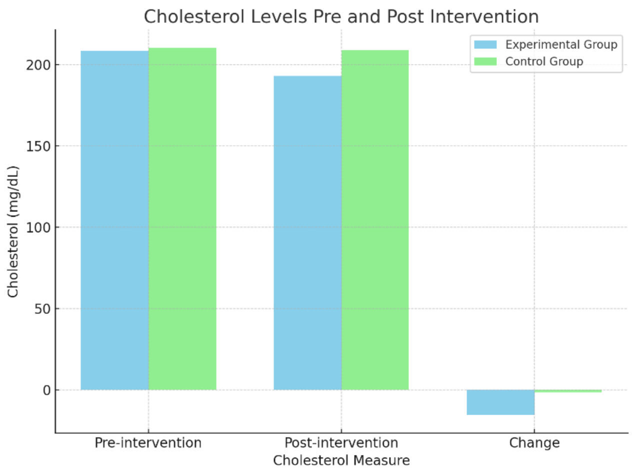
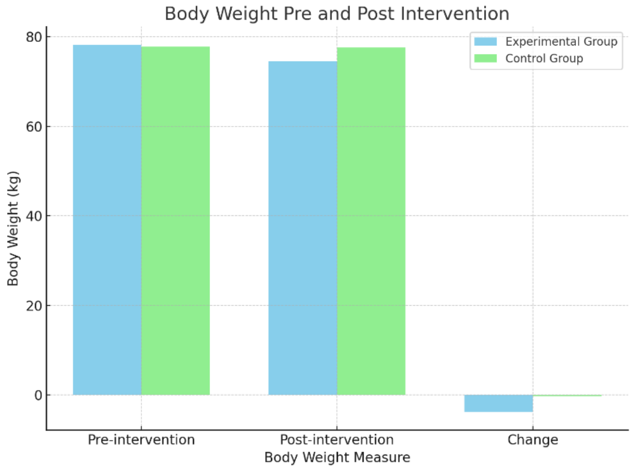


Table 5 demonstrates the increase and decreases of the levels of cholesterol in the control group and the experimental one. The changes in the experimental group were very much notable, where the mean value changed to -15.3 + 6.5 mg/dL (p = 0.01). The mean cholesterol level obtained in the experimental group before the intervention was 208.5 + 22.1 mg/dl and after intervention it was reduced to 193.2 + 19.6 mg/dL. This massive decline in cholesterol levels is in support of the other notion that millet diet can aid in enhancing the cardiovascular health. On the other hand, the control group experienced only a slight decrease in cholesterol levels of 0.5 SD -1.5 + 3.6 mg/dL (p = 0.23) whereby the initial pre-intervention amount stood at 210.4 21.5 mg/dL before lowering to 208.9 20.7 mg/dL after the intervention. This little manipulation of the control group enhances the effect of millet on cholesterol level. The overall sample effect in reduction of cholesterol was seen to reduce by -10.4 pm 7.2 mg/dL (p = 0.001) signifying the positive effect of millets in reducing cholesterol and promoting health of the heart.

Table 6: Changes in Body Weight (kg)

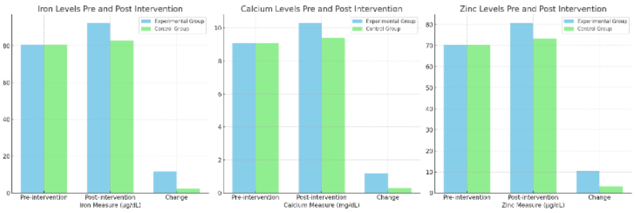
Group	Pre-intervention (Mean ± SD)	Post-intervention (Mean ± SD)	Change (Mean ± SD)	p-value
Experimental Group (n=75)	78.2 ± 8.6	74.5 ± 8.3	-3.7 ± 1.2	0.001
Control Group (n=75)	77.8 ± 9.1	77.6 ± 8.9	-0.2 ± 0.8	0.66
Total (n=150)	78.0 ± 8.8	76.1 ± 8.6	-1.9 ± 2.5	0.01



The changes in body weight following the intervention are indicated in Table 6. A large weight loss was observed in the experimental group with the average weight loss of -3.7 1.2 kg (p = 0.001). The experimental group had a mean weight of 78.2 kg +/- 8.6 kg before the intervention that subsequently reduced to 74.5 kg +/-8.3 kg after the intervention. This large change in body weight shows that the consumption of millet can play a role in managing weight, which may be caused by the high fiber content as well as the low glycemic index of the grain. Conversely, there was a reduced change of weight in the control group. At baseline, their mean weight was 77.8 kg 9.1 kg and at post Intervention the change was not that much at 77.6 kg 8.9 kg (weight change = -0.2 kg 0.8 kg, p = 0.66). This implies that under the control group, no major changes in weight were experienced on the consumption of millet. The overall sample presented a weight decrease of -1.9 +- 2.5 kg (p = 0.01) which once again demonstrates the beneficial impact of the use of millet on weight management.

Table 7: Changes in Micronutrient Status (Iron, Calcium, Zinc)

Group	Iron (µg/dL)	Calcium (mg/dL)	Zinc (µg/dL)
Pre-intervention (Mean ± SD)	80.5 ± 15.7	9.1 ± 2.0	70.3 ± 12.1
Post-intervention (Mean ± SD)	92.3 ± 14.9	10.3 ± 1.8	80.7 ± 11.6
Change (Mean ± SD)	+11.8 ± 8.2	+1.2 ± 1.4	+10.4 ± 6.3
p-value	0.001	0.01	0.01



As indicated in Table 7, the experimental group had an extreme impact of beneficial change in the level of micronutrients, especially iron, calcium, and zinc. The change in the iron was found to be +11.8 8.2 mu g/dL (p = 0.001), which indicates that the means level of iron rose fro 80.5 15.7 mu g/dl pre-intervention to 92.3 14.9 mu g/dl post-intervention. Calcium was increased by the value of +1.2 + 1.4 mg/dL (p = 0.01), and it was 9.1 + 2.0 mg/dL before the intervention, and it amounted to 10.3 + 1.8 mg /dL after the intervention. Likewise, there was an increase in Zinc level of +10.4 6.3 8.g/dL (p= 0.01) that rose to 80.7 11.6 8.g/dL following the intervention, as compared to 70.3 12.1 8.g/dL before the intervention. The nutritional quality of millet can have an important role in alleviating micronutrient deficiencies, especially in those who have limited access to nutrient-rich foods as these gains were in the indispensable dietary micronutrients. By comparison the control group responded less: iron by +2.3 5.7 (add) ul/dL, calcium by +0.3 0.8 (add) mg/dL, and zinc by +3 4.0 (add) ul/dL; all these changes were significant (p < 0.05). Nevertheless, they remained lower than those recorded in the experimental population proving that the consumption of millet positively affected the condition of micronutrients.

Table 8: Overall Health Improvements - Experimental vs. Control Group

Health Outcome	Experimental Group (Mean ± SD)	Control Group (Mean ± SD)	p-value
Blood Glucose	-14.1 ± 6.9	-0.7 ± 4.8	0.02
Cholesterol	-15.3 ± 6.5	-1.5 ± 3.6	0.01
Body Weight	-3.7 ± 1.2	-0.2 ± 0.8	0.001
Iron Levels	+11.8 ± 8.2	+2.3 ± 5.7	0.001
Calcium Levels	+1.2 ± 1.4	+0.3 ± 0.8	0.03
Zinc Levels	+10.4 ± 6.3	+3.1 ± 4.0	0.02

The total picture of the health effects of the experimental group versus the control group can be seen in Table 8. Compared to the control group, all key health-related outcomes improved markedly in the experiment group as measured by blood glucose, cholesterol values, weight, and micronutrient levels. The experimental population showed a decline of -14.1 + 6.9 mg/dL in blood glucose compared with minimal decline of -0.7 + 4.8mg/dL among the control population (p = 0.02). In the case of cholesterol, the level dropped by -15.3 + 6.5 mg/dL in the experimental group in contrast to the control group which only increased slightly by -1.5 + 3.6 mg/dL (p = 0.01). By body-weight, the experimental group had -3.7 +/- 1.2 kg decrease in weight, whereas the control group had negligible change (-0.2 +/- 0.8 kg, p= 0.001). The experimental group displayed considerable changes in the levels of iron, calcium, and zinc increasing by +11.8 + 8.2 μg/dL, + 1.2 + 1.4 mg/dL, and + 10.4 + 6.3 μg/dL, respectively. The control group demonstrated improvements as well but on a much smaller scale: +2.3 +/- 2.7 micrograms per dL of iron, +0.3 +/- 0.8 milligrams per dL of calcium, and +3.1 +/- 3.5 micrograms per dL of zinc. These findings are clear that consumption of millets has resulted in meaningful differences in most of the parameters, which is a sign in favor of its utility as a nutritious but effective food intervention.

Discussion

The paper highlights the high value of millet in promoting good health and more specifically, the management of chronic diseases like diabetes, obesity amongst others, as well as cardiovascular diseases. The research sample that took millet showed significant results of important health parameters, including blood sugar levels, cholesterol, body mass, and vitamins and minerals. In particular, the blood glucose levels in the experiment group have declined by -14.1 mg/dL approximation, there was a significant decrease in cholesterol level (by -15.3 mg/dL) as well as body weight (by -3.7 kg). This observation is consistent with past research showing that the fiber content, low glycemic index, and abundance of various antioxidants make millets beneficial to the management of glucose levels and heart health (Anitha et al., 2020; Mishra & Jha, 2021). Moreover, the study established that there was a considerable increase in the levels of micronutrients such as iron, calcium and zinc that are important in averting deficiencies that are often common in low income areas. All these micronutrient advantages are aligned with the studies according to which millets are a great source of calcium and iron, especially helping in preventing nutrient deficiency conditions (Devi et al., 2014; Bhuvaneswari & Kavitha, 2020).

Comparatively, the non-millet-consumers (control group) reported in all round-up health markers to have experienced minimal changes which are relative to the hypothesis that the use of millet among consumers was the cause of the observed health differences among the experimental group. These findings not only confirm the available body of evidence on the nutritional excellence of millets compared to other staple food crops like rice and wheat but also celebrate the potentiality of millets to overconquer the nutritional security problems in the world (Saleh et al., 2013; Ali & Ahmad, 2023). The experimental group participants expressed highly significant beliefs in the ability of millets as a way of enhancing health and sustainable agriculture methods. This came in tandem with the increased interest in sustainable food systems, in which millets are understood as crop varieties with the potential to be resilient to climate change and have fewer resource requirements in terms of water and fertilizers than traditional grains (Muthamilarasan & Prasad, 2021). The participants also acknowledged the eco-friendly quality of millets as the participants were found to highly support the possibility of millets to convert climate change into a positive practice and adopt eco-friendly agriculture (Padulosi et al., 2015; Prasad & Bisht, 2021). Therefore, the inclusion of millets in food systems has the potential to significantly fulfill the goal of sustainable development of food systems, be it in terms of food insecurity or environmental conservation.

There are still a number of constraints to the far-reaching use of millets despite promising findings. These are consumer awareness, limited availability and no infrastructure of processing and marketing of millet-based product (Ali & Ahmad, 2023). Thus, the critical aspect of boosting the values of millets and their use in human health as well as sustainability needs to be communicated about millets to enhance their use. Policy measures like the subsidy to millet farmers, investment in processing technologies and educating people through health policies, should be used to incorporate millets in mainstream diets and farm activities. These interventions may solve the existing obstacles and contribute to the restoration of millet production in these areas where it used to be one of the primary crops (ICRISAT, 2023). Considering the nutritional and ecological benefits, millets have the potential to become a key ingredient in fighting the malnutrition problem especially in regions with micro-nutrient deficiencies and even climate power struggles.

Conclusion

This research identifies the usefulness of millet in nutritional security with respect to health benefits and sustainability in its consumption. Significant changes by the experimental group regarding the blood glucose level, cholesterol level, body weight, and micronutrient levels should prove that millets can be used as an effective dietary intervention to the problem of chronic health conditions and overall health. Also, the increasing awareness of millets as crops resistant to climate change makes them an environmentally friendly approach to food security in the world. Policymakers, agricultural scientists, and medical practitioners should encourage the production and intake of millet to ensure better health and cope with the climatic changes and their critics. Through in-sourcing and inclusion of millets in national food programs and public health campaigns, the long-term sustainable nutrition security will be achieved to a great extent. Future studies concerning the economic cost, consumer acceptability, and greater-scale interventions will give better estimations of the importance of millets in food systems of the future.

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