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Ragi Revolution: Enhancing Dietary Practices through Nutritional Education and Local Food Systems Implementation

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Ragi (*Eleusine coracana*), commonly known as finger millet, is a nutrient-rich cereal that remains underutilized in modern diets despite its high calcium, iron, and dietary fiber content. This examines how ready-to-eat ragi-based supplementary foods, combined with effective nutrition education, can drive behavioral changes to incorporate ragi into daily diets and local food systems. The increasing

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availability of ready-to-eat ragi products offers an accessible solution for improving nutrition, but challenges remain in terms of consumer acceptance due to unfamiliarity and taste preferences. This paper focuses on the role of nutrition education in reshaping dietary behaviour, emphasizing case studies that demonstrate the effectiveness of targeted interventions in promoting ragi consumption. Additionally, it explores strategies for integrating ragi into public nutrition programs and sustainable food systems, highlighting the importance of community-driven efforts and public-private partnerships. The review also discusses the role of policy support and multi-stakeholder collaboration in fostering ragi's cultivation and incorporation into local food systems. By examining behavioural change strategies such as social marketing and culturally sensitive approaches, this paper presents a roadmap for promoting ragi as a key component of sustainable diets and public health interventions.

Keywords: Agricultural sustainability; dietary behaviour change; finger millet; nutrition education; public health policy; ragi.

1. INTRODUCTION

1.1 Ragi and Its Nutritional Importance

Ragi (*Eleusine coracana*), or finger millet, is an ancient grain that has served as a staple food in various regions, particularly in Africa and India, for over 4,000 years. It is highly valued for its resilience in harsh environmental conditions such as droughts and low soil fertility, making it an important crop for subsistence farming in arid and semi-arid regions [1]. Unlike modern high-input crops like rice and wheat, ragi thrive in poor soil with minimal care and can be stored for extended periods, making it a reliable source of food during famine or drought periods. While the traditional significance of ragi is notable, its nutritional attributes have garnered increased attention in modern diets, particularly in the contexts of health, nutrition, and sustainable agriculture.

Fig. 1. Ragi (*Eleusine coracana*), or finger millet

Ragi stands out due to its high nutritional content, especially in comparison to commonly consumed grains. It is rich in calcium, with 100 grams of ragi providing 344 mg of calcium, which supports bone health and can help prevent conditions like osteoporosis [2]. This makes it particularly valuable for children, pregnant women, and the elderly, who require higher calcium intake. Furthermore, the high fiber content in ragi plays a significant role in regulating blood sugar levels, making it ideal for individuals with diabetes or those at risk of developing the condition. The grain has a low glycemic index (GI), meaning it is digested slowly, leading to a more gradual release of glucose into the bloodstream, preventing sharp spikes in blood sugar levels [3]. This quality is not only important for diabetic patients but also contributes to weight management, as it promotes satiety and reduces overall calorie intake. Ragi is also noted for its impressive iron content, with 100 grams providing 3.9 mg of iron, a vital nutrient in combating iron-deficiency anemia, especially among women and children in developing countries [4]. In regions with prevalent malnutrition and anemia, incorporating ragi into regular diets could play a crucial role in addressing nutrient deficiencies. Moreover, the presence of methionine, an essential amino acid rarely found in other cereal crops, further enhances the nutritional profile of ragi [5]. Methionine is important for protein synthesis, tissue repair, and fat metabolism, making ragi an essential dietary component, particularly for vegetarians and those with limited access to diverse protein sources.

Fig. 2. Ragi flour

1.2 Nutritional Composition of Ragi

The rich nutritional composition of ragi extends to its content of polyphenols and antioxidants, which have been linked to several health benefits. Antioxidants found in ragi, such as flavonoids and phenolic acids, help protect the body against oxidative stress and chronic diseases such as heart disease and cancer [2]. These compounds play a role in neutralizing free radicals, molecules that can cause damage to cells and contribute to aging and the development of various diseases. Additionally, the anti-inflammatory properties of these antioxidants may help alleviate inflammatory conditions, contributing to the overall health-promoting effects of ragi-based diets.

Table 1. Nutritional composition of Ragi per 100 gms.

Nutritional Composition	% Value
Energy (Kilo Calories)	328
Carbohydrates (gms)	72
Proteins (gms)	7.3
Dietary Fiber (%)	15–20
Minerals (%)	2.5–3.5
Fat (%)	1–2
Calcium (mg)	344
Potassium (mg)	408
Sodium (mg)	11
Iron (mg)	3.9

Ragi is a gluten-free grain, which has become increasingly important in recent years as more people seek alternatives to gluten-containing grains due to celiac disease, gluten sensitivity, or general dietary preferences [6]. As a gluten-free whole grain, ragi provides an excellent alternative to wheat, barley, and rye for individuals who need to avoid gluten, while offering a far superior nutritional profile compared to processed gluten-free products that often lack essential nutrients. Despite these significant nutritional benefits, ragi remains underutilized in many parts of the world, largely due to changes in dietary habits and a lack of awareness about its health benefits. In regions like India, where rice and wheat dominate the daily diet, traditional grains such as ragi have seen a decline in consumption. However, recent trends toward healthier eating and the growing interest in ancient grains have started to revive ragi's popularity as a key component of nutritionally balanced diets. Integrating ragi into modern diets, especially in the form of ready-to-eat products, presents a viable solution to improving nutritional outcomes, particularly in undernourished populations. As awareness grows around the health benefits and versatility of ragi, there is potential for it to reclaim its place as a staple grain in both traditional and contemporary food systems. By promoting its inclusion in public nutrition programs and emphasizing its value through education, ragi can help address pressing nutritional challenges, such as anaemia, calcium deficiencies, and the rising incidence of lifestyle-related conditions like diabetes. With its nutrient-dense profile and adaptability to low-input farming systems, ragi is poised to play a critical role in sustainable agriculture and nutrition security in the years to come [1].

Fig. 3. Ragi seeds

2. READY-TO-EAT RAGI-BASED SUPPLEMENTARY FOODS: TYPES AND BENEFITS

Ragi, or finger millet (*Eleusine coracana*), has gained increasing attention as a highly nutritious and versatile grain that can be used in various forms of ready-to-eat supplementary foods. These products cater to the growing demand for convenient, healthy, and easy-to-consume options, particularly in a world where busy lifestyles often prevent people from preparing nutrient-dense meals from scratch. Ready-to-eat (RTE) ragi-based foods offer significant health benefits and are becoming more popular as awareness of ragi's nutritional properties increases. The introduction of RTE products is an essential step toward mainstreaming ragi in urban and semi-urban populations, thus helping bridge the nutritional gap, particularly in developing countries [7].

Fig. 4. Ragi Dosa

2.1 Types of Ready-to-Eat Ragi-Based Foods

There is a wide range of RTE ragi-based foods available today, offering consumers easy and accessible options to incorporate ragi into their diets. Some of the most common types include:

Ragi flakes and porridge: Ragi flakes, similar to other breakfast cereals, are pre-processed and flattened ragi grains that can be consumed with milk or water, either hot or cold. They offer a quick and nutritious breakfast solution, especially for working individuals and school-going children. These flakes can also be used to prepare porridge, which has traditionally been a popular form of ragi consumption in many rural households. Ragi porridge is highly beneficial for infants and elderly people due to its digestibility and rich nutrient profile [8].

Fig. 5. Ragi flakes

Fig. 6. Ragi biscuits

Ragi biscuits and cookies: Biscuits and cookies made from ragi flour are increasingly common in the market, catering to health-conscious consumers looking for alternatives to refined wheat products. These products often combine ragi with other healthy ingredients like oats, nuts, and seeds, further enhancing their nutritional value. Ragi biscuits are a particularly popular snack for children, providing them with essential nutrients such as calcium and iron without the need for added sugar or preservatives [9].

Fig. 7. Ragi cakes

Ragi-based energy bars: Energy bars made from ragi, combined with ingredients like dates, nuts, and seeds, have become a preferred choice for people seeking convenient, on-the-go snacks. These bars are often marketed to athletes, fitness enthusiasts, and individuals needing a quick energy boost. In addition to being high in dietary fiber, ragi-based energy bars provide a good balance of carbohydrates and proteins, making them a suitable option for sustained energy release during physical activities [10].

Ragi malted drinks: Ragi malt, made from sprouted ragi grains, is another popular ready-to-eat product that can be consumed as a drink. Sprouting ragi increases its bioavailability of nutrients, particularly calcium and iron, making malted ragi drinks highly nutritious. These drinks are frequently fortified with additional vitamins and minerals, making them an ideal supplementary food for children and those recovering from illness [11].

Fig. 8. Ragi malted drinks

2.2 Nutritional and Health Benefits of Ready-to-Eat Ragi-Based Foods

Ready-to-eat ragi-based foods are not just convenient but also pack a wealth of nutritional

benefits that make them an ideal addition to any diet. Key health advantages include:

High in calcium and iron: One of the standout nutritional qualities of ragi is its exceptionally high calcium content, which makes it particularly beneficial for bone health. RTE ragi products such as flakes, biscuits, and malted drinks retain these benefits, making them an excellent choice for children, pregnant women, and the elderly. Additionally, ragi's iron content helps in combating anemia, a condition prevalent in many developing regions [5].

Gluten-free and easily digestible: As ragi is naturally gluten-free, it is an excellent option for individuals suffering from gluten intolerance or celiac disease. Many ready-to-eat ragi-based products are now being developed for this specific consumer demographic, providing a nutrient-rich alternative to typical gluten-free products made from rice or corn [1]. Moreover, the digestibility of ragi is enhanced during the processing of these RTE foods, particularly in malted or flaked forms, making it a suitable option for infants and elderly individuals with sensitive digestive systems.

Ideal for weight management: Ragi is high in dietary fiber, particularly soluble fiber, which aids in digestion and promotes a feeling of fullness. This makes RTE ragi-based foods an excellent option for people looking to manage their weight. Products like ragi flakes, biscuits, and energy bars help control hunger pangs and prevent overeating by promoting satiety [3]. The low glycemic index of ragi ensures that it releases glucose into the bloodstream gradually, helping maintain stable energy levels and preventing spikes in blood sugar levels.

Rich in antioxidants and polyphenols: Ragi is rich in antioxidants, including polyphenols and flavonoids, which help combat oxidative stress in the body. Oxidative stress has been linked to several chronic conditions such as cardiovascular diseases, diabetes, and certain types of cancer [2]. Incorporating RTE ragi-based foods into the diet can contribute to overall health by reducing inflammation and preventing the onset of these conditions. The rise in popularity of RTE ragi-based foods offers a promising opportunity to incorporate this highly nutritious grain into modern diets. These products not only provide convenience but also address several health concerns, from bone health to diabetes management. With increasing consumer awareness about the benefits of ragi, the development of RTE products will likely continue to grow, making ragi a staple grain in many households.

Fig. 9. Key health benefits of Ragi (Finger Millet)

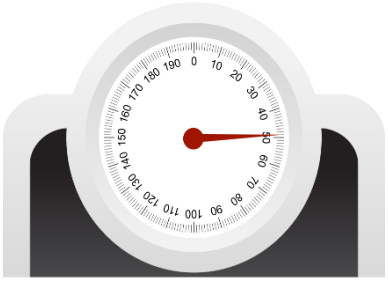

Fig. 10. Ideal for weight management

3. CURRENT CONSUMPTION TRENDS AND CHALLENGES IN INCORPORATING RAGI

Ragi, despite its rich nutritional profile and numerous health benefits, has seen fluctuating levels of consumption in both rural and urban populations. Historically, ragi was a staple food in regions like South India and parts of Africa, where it was grown extensively due to its drought-resistant nature and adaptability to harsh environmental conditions. However, with the Green Revolution and the subsequent emphasis on high-yielding cereals like rice and wheat, ragi's consumption has significantly declined in favor of these more commercially viable grains (Devi et al., 2014). In recent years, however, there has been a renewed interest in ragi consumption, particularly among health-conscious urban populations and those seeking to diversify their diets with ancient grains. Nevertheless, significant challenges remain in fully incorporating ragi into the mainstream food systems.

3.1 Current Consumption Trends

Ragi in traditional diets: In rural areas, particularly in states like Karnataka, Tamil Nadu, and parts of Maharashtra in India, ragi continues to be a staple grain, largely because of its affordability and easy availability. In these regions, ragi is commonly consumed in traditional forms such as *ragi mudde* (ragi balls), *ragi roti*, and porridge. It is often preferred for its ability to provide sustained energy throughout the day, making it a popular choice among laborers and farmers [12]. In many African countries, ragi remains an important crop for subsistence farmers, particularly in semi-arid regions where other cereal crops fail to thrive.

Urban health-conscious consumers: In urban areas, the increasing awareness of ragi's health benefits has led to a gradual rise in its consumption. The growing trend towards healthier, whole-grain foods and the shift away from highly processed foods have contributed to the resurgence of ragi as a preferred ingredient in various products. Many companies are now marketing ready-to-eat ragi-based products like flakes, biscuits, and energy bars, targeting health-conscious consumers, athletes, and individuals seeking to manage lifestyle diseases such as diabetes and obesity [13]. This trend is also supported by the growing demand for gluten-free diets, as ragi offers a nutritious alternative to wheat-based products for those with celiac disease or gluten sensitivity [14].

Fig. 11. Urban health-conscious consumers

Ragi in public nutrition programs: Several government initiatives and nutrition programs, particularly in India, have started incorporating ragi into midday meal schemes and public distribution systems to address malnutrition and micronutrient deficiencies. For instance, in Karnataka, ragi has been reintroduced into school feeding programs to provide children with a source of calcium, iron, and fiber, helping combat common nutritional issues such as anemia and stunted growth [15]. Such programs are vital in promoting ragi consumption among younger generations, who might otherwise be more familiar with rice and wheat-based diets.

3.2 Challenges in Incorporating Ragi into Mainstream Diets

Despite the growing awareness of its health benefits, ragi faces several challenges in being fully incorporated into mainstream diets. These challenges are primarily related to cultural preferences, economic factors, and the lack of adequate promotion.

Preference for rice and wheat: One of the biggest challenges in increasing ragi consumption is the strong cultural preference for rice and wheat, particularly in urban areas. For decades, these grains have been the dominant components of Indian diets due to their affordability, availability, and versatility in cooking. The Green Revolution prioritized the mass cultivation of rice and wheat, leading to a decline in the cultivation of millets like ragi [16]. As a result, ragi is often seen as a "poor man's food" and is generally regarded as less desirable compared to polished rice and wheat products.

Lack of awareness and knowledge: While ragi is well-known in certain regions, there remains a significant knowledge gap regarding its nutritional benefits in other parts of the world. Many people are unaware of its high calcium, iron, and fiber content, which can help address major health issues such as anemia, osteoporosis, and diabetes [17]. Additionally, ragi's traditional preparation methods, which can be time-consuming, act as a deterrent for people who are unfamiliar with its culinary uses. The lack of recipe diversity and familiarity further contributes to ragi's limited appeal, particularly among younger generations who may not have grown up consuming millets.

Market availability and economic factors: Ragi's limited market availability, particularly in urban areas, is another significant challenge. Due to the focus on rice and wheat, the supply chain for millets like ragi is underdeveloped, with lower production volumes and fewer distribution channels. While the market for health foods is growing, ragi products often remain niche, with limited availability in mainstream grocery stores. Moreover, the cost of processed ragi-based products, such as biscuits and energy bars, is often higher than their wheat-based counterparts, which can discourage widespread adoption, especially in low-income households [9].

Processing and shelf life: Ragi is a more perishable grain compared to rice and wheat, primarily because of its high fat content, which makes it susceptible to rancidity. This presents challenges in terms of storage and shelf life, making large-scale distribution more difficult. Processing technologies for millets, including ragi, are still developing, and there is a need for better preservation methods and value-added processing techniques that can enhance the grain's shelf life without compromising its nutritional value [18].

Government policy and support: Although there have been efforts to reintroduce ragi in public nutrition programs, government policies still favor the mass production of rice and wheat. Farmers are provided with incentives and subsidies to grow these grains, while millets like ragi receive relatively little attention. The lack of robust support for millet farmers means that ragi cultivation remains limited, which in turn affects its market availability and affordability [19].

The challenges of incorporating ragi into mainstream diets are multifaceted, encompassing cultural, economic, and policy-related issues. Overcoming these obstacles requires concerted efforts in promoting the health benefits of ragi, developing innovative recipes and ready-to-eat products, improving market access, and providing better incentives for farmers to cultivate millets. Through targeted interventions and education, ragi can become a staple grain once more, contributing to healthier and more sustainable diets.

4. THE ROLE OF NUTRITION EDUCATION IN SHAPING DIETARY BEHAVIOUR

Nutrition education plays a critical role in shaping dietary behaviour, as it helps individuals make informed decisions about their food choices, ultimately contributing to improved health outcomes. In the context of incorporating ragi into daily diets, nutrition education can significantly impact the acceptance and sustained consumption of this highly nutritious grain. By increasing awareness about ragi's health benefits and addressing misconceptions surrounding its consumption, nutrition education serves as an essential tool in promoting healthier eating patterns, particularly in regions where rice and wheat dominate the diet. Effective nutrition education can foster behaviour change by influencing individual attitudes, beliefs, and cultural practices, while also addressing broader environmental and economic factors that impact food choices [20].

4.1 Importance of Nutrition Education

Nutrition education is important because it empowers individuals to understand the relationship between food and health. When people are educated about the nutritional content of various foods, including ragi, they are more likely to make conscious decisions about incorporating these foods into their diet. For example, when individuals learn that ragi is rich in calcium, iron, fiber, and essential amino acids, they may be more inclined to include it in their meals as a preventive measure against conditions like osteoporosis and anemia [21]. Additionally, nutrition education can dispel myths and address barriers to consuming certain foods. In the case of ragi, many urban consumers may perceive it as a "rural" or "poor man's food," a notion that can be countered through targeted education campaigns that highlight its versatility, taste, and health benefits. Furthermore, nutrition education is essential in addressing the growing

burden of non-communicable diseases (NCDs) like diabetes, hypertension, and cardiovascular diseases. These conditions are often associated with unhealthy dietary patterns, including the excessive consumption of refined carbohydrates, sugars, and processed foods. By educating individuals about the benefits of consuming whole grains like ragi, which have a low glycemic index and are rich in fiber, nutrition education can help mitigate the risk of these lifestyle diseases [22].

4.2 Behavioural Change Models in Nutrition Education

Behavioural change models are often used in nutrition education programs to promote healthier dietary behaviors. One such model is the Health Belief Model (HBM), which suggests that individuals are more likely to adopt healthy behaviors if they perceive a personal risk to their health, believe in the benefits of the behavior, and feel capable of taking action [23]. In the context of ragi consumption, educators can use this model to highlight the risks of nutrient deficiencies and lifestyle diseases, while promoting ragi as a beneficial and accessible food option. For example, if individuals perceive that their current diet puts them at risk for conditions like diabetes or anemia, and they believe that consuming ragi can reduce that risk, they are more likely to change their dietary behavior. Another useful model is the Theory of Planned Behavior (TPB), which emphasizes the role of intention in behavior change. According to TPB, individuals are more likely to engage in a specific behavior if they have a positive attitude toward it, believe that significant others support the behavior, and feel they have control over the behavior [24]. In the case of ragi, nutrition education can focus on fostering positive attitudes by promoting the grain's health benefits, while also working with communities and families to create social support for ragi consumption. Programs can also provide practical guidance, such as recipes and cooking demonstrations, to help individuals feel more confident in incorporating ragi into their meals.

4.3 The Role of Schools and Communities in Nutrition Education

Schools and community-based organizations play a pivotal role in nutrition education, particularly in shaping the dietary behaviors of children and families. School-based nutrition programs can introduce ragi into midday meals or school feeding programs, educating children from an early age about its nutritional benefits. Studies have shown that school-based nutrition education programs are effective in promoting long-term dietary changes, as children often bring the knowledge they gain into their homes, influencing family eating habits [20]. Additionally, schools can organize cooking classes, nutrition workshops, and food-tasting events that introduce students and their families to ragi-based recipes. Community-based nutrition education programs also have a significant impact, particularly in rural and low-income areas where access to information about healthy food options may be limited. These programs can involve local health workers, agricultural extension services, and community leaders in disseminating information about ragi and other healthy foods. In many cases, community gardens and farmer cooperatives can be used as platforms to promote ragi cultivation and consumption, providing both educational and practical support for incorporating ragi into local diets [25]. These programs can also help address common misconceptions and cultural barriers to ragi consumption, making it more acceptable and appealing to a broader audience.

4.4 Overcoming Challenges in Nutrition Education for Ragi Promotion

Despite its benefits, promoting ragi through nutrition education comes with challenges. One of the major challenges is the strong cultural preference for rice and wheat in many regions, which makes it difficult to convince people to shift to or include ragi in their diets. Nutrition education must therefore be tailored to local contexts, considering cultural food preferences and offering practical solutions that make it easy for individuals to adopt ragi consumption [22]. Another challenge is the perception of ragi as an inferior or "backward" food, which can act as a psychological barrier to its consumption, especially among urban and upwardly mobile populations. Overcoming this challenge requires strategic marketing and education campaigns that rebrand ragi as a modern and desirable superfood, much like how quinoa and chia seeds have been successfully marketed in Western countries [21]. This can be achieved through collaborations with health influencers, chefs, and media campaigns that highlight the versatility, taste, and health benefits of ragi in contemporary food culture. Additionally, the lack of availability of ready-to-eat ragi products in urban markets can hinder its widespread adoption. Nutrition

education efforts must therefore be coupled with policies that promote ragi cultivation, production, and distribution to ensure that consumers have access to affordable and high-quality ragi products. Government support, in the form of subsidies and public awareness campaigns, is crucial in this regard [15].

5. BEHAVIOURAL CHANGE MODELS AND THEIR APPLICATION IN RAGI PROMOTION

Promoting the adoption of healthier dietary choices often requires not only educating the population but also addressing the deeper psychological, social, and environmental factors that influence behavior. Behavioural change models offer structured approaches to understanding how people adopt new practices, such as incorporating ragi into their daily diets. Applying these models in nutrition programs helps in framing targeted interventions that can effectively promote the use of ragi and other nutritious foods. The successful promotion of ragi requires addressing cultural attitudes, individual behaviors, and broader socio-economic influences [26].

5.1 The Health Belief Model (HBM)

The Health Belief Model (HBM) is one of the most used frameworks for understanding health-related behavior change. The model is based on the idea that individuals will adopt healthy behaviors if they perceive a personal risk, understand the severity of the risk, and believe that taking a specific action will reduce that risk [23]. In the context of ragi promotion, this model can be applied by framing ragi consumption as a preventive measure against common health risks such as diabetes, anemia, and osteoporosis. For instance, educators can emphasize the risk of calcium deficiency in older adults, particularly among women, and explain how ragi's high calcium content can help prevent osteoporosis. Similarly, highlighting the rising rates of type 2 diabetes and presenting ragi as a low-glycemic alternative to high-GI grains like rice can encourage individuals at risk to make dietary changes. By providing clear and accessible information about the health benefits of ragi, the HBM can be used to shift perceptions and motivate individuals to incorporate ragi into their diets [22].

Application Example: In rural communities where nutritional education is limited, a program using the HBM can be implemented by organizing health camps that explain the risks of iron deficiency anemia and demonstrate how consuming ragi daily can address this issue. Visual aids, community health workers, and simple demonstrations of how to prepare ragi-based dishes can make the information more relatable and actionable for the target population. Additionally, personal testimonials from community members who have experienced health improvements after incorporating ragi can enhance perceived susceptibility and benefits, further driving behavior change.

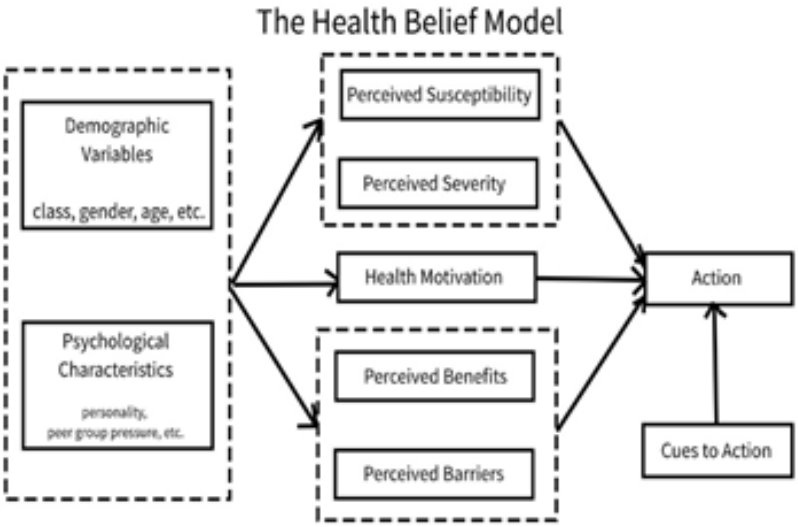

Fig. 12. Health belief model (HBM)

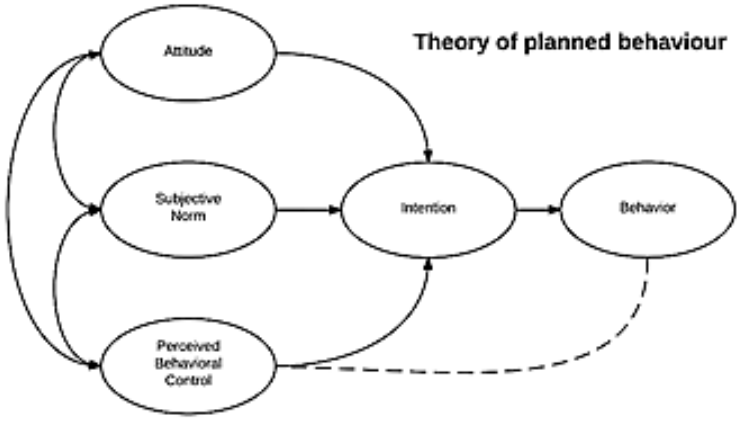

Fig. 13. Theory of planned behaviour

5.2 The Theory of Planned Behavior (TPB)

The Theory of Planned Behavior (TPB) expands on the idea that behavior is driven by intention, which is shaped by an individual's attitudes, subjective norms, and perceived behavioral control (Ajzen, 1991). This model suggests that if individuals have a positive attitude toward a behavior, believe that their peers or family support it, and feel confident in their ability to perform the behavior, they are more likely to adopt it. In the case of promoting ragi, the TPB can be useful in addressing both personal and social barriers to its consumption.

Application example: In urban areas where dietary habits are often influenced by social norms and convenience, promoting ragi through the TPB could involve community workshops that not only educate participants on the health benefits of ragi but also address perceived barriers. For instance, one common barrier is the perception that ragi is difficult to cook or lacks versatility. Cooking demonstrations that showcase easy-to-prepare, modern recipes using ragi, such as smoothies, energy bars, and baked goods, can improve perceived control. Additionally, public health campaigns that position ragi as a trendy and healthy grain, endorsed by nutritionists and fitness influencers, can create positive subjective norms that encourage wider adoption [21].

Social support in TPB: Social support plays a key role in the TPB model. If individuals see their peers and family members consuming ragi, they are more likely to follow suit. Therefore, community-driven programs that involve entire families or social groups in the promotion of ragi can be particularly effective. Schools can play an instrumental role by including ragi in midday meal programs and encouraging students to bring ragi-based snacks from home. When children discuss these meals with their families, the social norm around consuming ragi gradually shifts, making it a more accepted and desirable choice.

5.3 Social Cognitive Theory (SCT)

Social Cognitive Theory (SCT) emphasizes the role of observational learning, social reinforcement, and self-efficacy in behavior change. According to SCT, individuals learn new behaviors by observing others and modeling their actions. This theory also highlights the importance of self-efficacy—one's belief in their ability to successfully perform a behavior [27]. In promoting ragi consumption, SCT can be applied by using influential community members, media personalities, or public figures to model healthy eating behaviors that include ragi. When individuals see others consuming ragi in appealing and socially valued ways, they are more likely to follow suit.

Application Example: Incorporating ragi promotion into mainstream media, such as cooking shows, social media campaigns, or local television advertisements featuring respected figures, can significantly influence public behavior. Seeing a popular celebrity preparing or endorsing ragi-based dishes can make the grain seem more appealing, especially to younger audiences. Additionally, by providing practical tips on how to cook and incorporate ragi into everyday meals, the campaign can boost individuals' self-efficacy, helping them feel confident in making the switch [15].

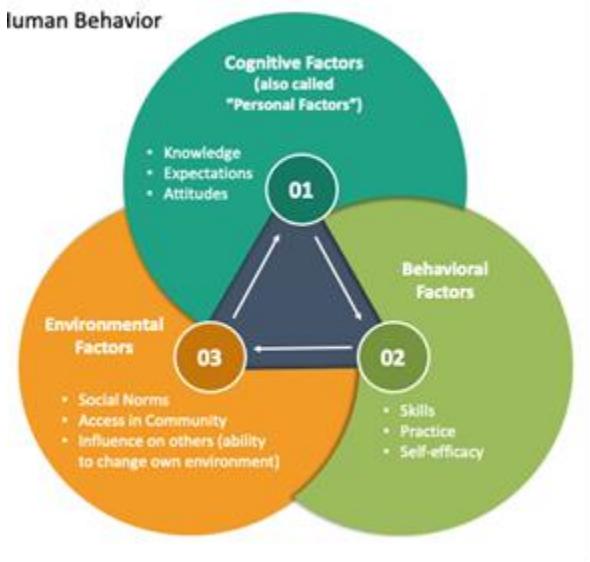

Fig. 14. Social cognitive theory (SCT)

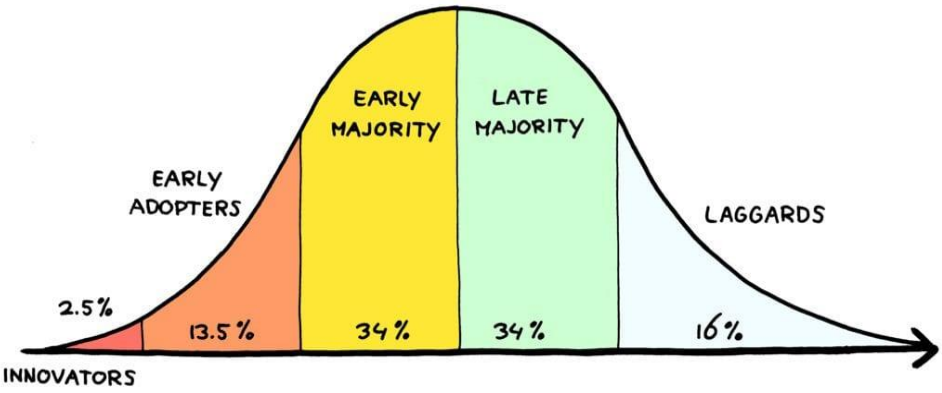

Fig. 15. Diffusion of innovations theory (DOI)

Community Modeling in SCT: Community-driven initiatives that feature local role models—such as teachers, health workers, or even successful farmers—can also reinforce the idea that ragi is a desirable and accessible food. These role models can share their personal experiences with ragi consumption, discuss its health benefits, and demonstrate how easy it is to grow, prepare, and cook. Such real-life examples are particularly powerful in rural settings, where local traditions and practices often guide food choices.

5.4 Diffusion of Innovations Theory (DOI)

The Diffusion of Innovations (DOI) theory focuses on how new ideas and practices spread within a community or society. According to this theory, the adoption of new behaviors follows a pattern where early adopters, such as innovators and opinion leaders, play a crucial role in encouraging the broader population to embrace innovation [28]. In promoting ragi consumption, DOI can be applied by targeting key influencers in both rural and urban settings to serve as champions of ragi. These influencers can introduce ragi to their social networks, which helps in spreading awareness and encouraging others to follow their example.

Application Example: Incorporating ragi into government nutrition schemes, school programs, or even high-profile public health campaigns can help create a ripple effect. When a critical mass of individuals or organizations adopt ragi, the likelihood of widespread adoption increases. For instance, if a popular restaurant chain begins offering ragi-based dishes, it signals to consumers that ragi is a desirable and mainstream choice, encouraging them to try it at

home. In rural communities, agricultural extension programs that promote ragi cultivation among smallholder farmers can help establish ragi as a viable cash crop, influencing both consumption and production patterns. By leveraging behavioral change models like HBM, TPB, SCT, and DOI, nutrition education programs can create targeted, effective interventions that not only increase awareness about ragi's benefits but also foster the social and individual changes necessary for its widespread adoption. These models provide valuable frameworks for understanding how dietary habits can evolve and how traditional foods like ragi can regain their place in modern diets.

6. STRATEGIES FOR PROMOTING RAGI-BASED FOODS AND SUSTAINABLE INTEGRATION INTO LOCAL FOOD SYSTEMS

Ragi, an ancient grain known for its nutritional richness and resilience, has great potential to address modern dietary challenges, especially in regions facing malnutrition and food insecurity. However, the widespread adoption of ragi-based foods in local diets and its sustainable integration into food systems requires a multi-faceted approach that addresses both consumer behavior and structural challenges. Strategies must encompass education, marketing, policy support, and community engagement to shift consumption patterns and establish ragi as a staple grain once more.

6.1 Strategies for Promoting Ragi-Based Foods

Promoting ragi requires not only increasing consumer awareness of its health benefits but also addressing the economic, cultural, and logistical barriers to its adoption. A well-rounded strategy for promoting ragi-based foods must involve efforts from various stakeholders, including governments, agricultural organizations, health professionals, and the food industry.

Public health campaigns and nutrition education: One of the most effective strategies for promoting ragi-based foods is through public health campaigns that emphasize their nutritional value. These campaigns should focus on educating the public about ragi's benefits, such as its high calcium, iron, and fiber content, as well as its potential to address widespread issues like anaemia and diabetes. Education efforts should include cooking demonstrations, recipe sharing, and information about how ragi can be easily incorporated into everyday meals [15]. In schools, for example, ragi can be included in midday meal programs, exposing children to the grain at an early age and promoting long-term dietary habits. This strategy also extends to urban populations, where nutrition education campaigns can position ragi as a healthy food that aligns with modern dietary trends like gluten-free and low-glycemic-index diets [14].

Marketing and rebranding of ragi-based products: Rebranding ragi as a "superfood" with numerous health benefits can help shift its perception from a rural, subsistence grain to a desirable food for health-conscious urban consumers. Marketing strategies should highlight ragi's nutritional properties and versatility in various food products, from traditional dishes to modern snacks like energy bars, smoothies, and breakfast cereals [13]. Collaborating with food influencers, chefs, and media personalities can further elevate ragi's profile and make it trendy among younger consumers. Companies can also innovate with ready-to-eat (RTE) ragi products that cater to busy lifestyles, providing convenient and nutritious options for consumers looking to improve their diets.

Policy support and government interventions: Government policy plays a crucial role in promoting ragi and integrating it into local food systems. Incentivizing farmers to grow ragi through subsidies, research support, and market access initiatives can increase production and availability. Additionally, including ragi in public distribution systems (PDS) and nutrition programs, such as the midday meal scheme and integrated child development services (ICDS), can further encourage consumption at the grassroots level [16]. Policy interventions can also ensure that ragi is accessible and affordable for all populations, particularly low-income households that may be unable to afford more expensive processed ragi products.

Building local supply chains and market access: To promote ragi-based foods sustainably, it is essential to strengthen local supply chains and create market access for smallholder farmers. Developing infrastructure for processing, packaging, and distribution will help ensure that ragi-based products reach broader markets, both rural and urban [12].

Establishing cooperatives and farmer producer organizations (FPOs) that focus on ragi cultivation and marketing can empower farmers to pool resources, access better prices, and negotiate with larger buyers. Local markets and food fairs can also serve as platforms for promoting ragi-based products, allowing consumers to directly interact with producers and learn more about the grain's benefits.

6.2 Sustainable Integration of Ragi into Local Food Systems

While promoting ragi-based foods is crucial, ensuring the sustainable integration of ragi into local food systems is equally important. This involves promoting agricultural practices that protect the environment, supporting local economies, and ensuring food security. Ragi's resilience to harsh climatic conditions, low water requirements, and ability to grow in poor soils make it an ideal crop for regions vulnerable to climate change and water scarcity. Sustainable integration focuses on the long-term viability of ragi cultivation and its contribution to ecological health and economic stability.

Promoting agroecological practices: Sustainable ragi cultivation can be achieved through agroecological practices that enhance biodiversity, conserve water, and maintain soil fertility. Intercropping ragi with legumes, for instance, can improve soil health and reduce the need for chemical inputs, thereby minimizing environmental impact. Additionally, using organic farming techniques in ragi cultivation can appeal to health-conscious consumers who prefer pesticide-free, natural products. Governments and NGOs can provide training and technical support to farmers, encouraging the adoption of sustainable practices that increase ragi yields while preserving ecological balance [1].

Ensuring climate resilience and food security: Given the increasing frequency of droughts and extreme weather events due to climate change, ragi's drought-resistant nature makes it a critical crop for ensuring food security. By promoting ragi cultivation in arid and semi-arid regions, countries can reduce their reliance on water-intensive crops like rice and wheat, making their food systems more resilient to climate shocks [29]. Integrating ragi into local food systems through climate-smart agricultural practices can ensure a stable food supply even in the face of unpredictable weather patterns, thereby protecting vulnerable populations from food shortages.

Supporting smallholder farmers and local economies: Sustainably integrating ragi into local food systems requires supporting the farmers who grow it, many of whom are smallholders in rural areas. Encouraging ragi production through subsidies, credit access, and market linkages can provide farmers with economic stability and reduce their dependence on less sustainable cash crops. Local processing units and value-added production initiatives, such as creating ragi flour, snacks, or ready-to-eat products, can further enhance the economic viability of ragi cultivation. These initiatives create jobs and stimulate local economies, contributing to overall rural development [15].

Encouraging community-led initiatives: Community involvement is critical to the sustainable integration of ragi into food systems. Farmer cooperatives, women's self-help groups, and local NGOs can play a pivotal role in promoting ragi cultivation, processing, and marketing. By fostering a sense of ownership and local pride in ragi, these groups can drive long-term adoption and create sustainable livelihoods. Additionally, community-led initiatives, such as organizing seed banks or collective farming projects, can ensure that traditional knowledge about ragi cultivation is preserved and passed down to future generations [14].

6.3 Challenges in Sustainable Integration

Despite the clear benefits of promoting ragi and integrating it into local food systems, several challenges must be addressed. These include limited consumer demand, inadequate market infrastructure, and the perception of ragi as an "inferior" grain compared to rice and wheat. Overcoming these challenges requires concerted efforts from all stakeholders, including governments, private industry, and civil society, to build awareness, improve market conditions, and create a supportive policy environment that encourages sustainable ragi cultivation and consumption.

7. IMPACT OF RAGI-BASED DIETS ON PUBLIC HEALTH AND NUTRITION

Ragi (*Eleusine coracana*), also known as finger millet, has been traditionally recognized as a nutrient-dense grain that provides a wide range

of health benefits. As awareness of the value of ancient grains grows, ragi has started to regain prominence in various health-conscious diets. Its unique nutritional profile, which includes high levels of calcium, iron, dietary fiber, and antioxidants, makes it particularly relevant in addressing public health concerns related to nutrient deficiencies and lifestyle diseases. The integration of ragi-based diets into daily consumption patterns can have profound impacts on public health, especially in regions where malnutrition, anemia, diabetes, and cardiovascular diseases are prevalent. This section will explore the potential health benefits of ragi-based diets and their broader implications for improving public health and nutrition.

7.1 Addressing Micronutrient Deficiencies

One of the most significant impacts of ragi-based diets is their potential to combat widespread micronutrient deficiencies, particularly in regions with high rates of anemia and malnutrition. Ragi is a rich source of iron, making it a valuable addition to the diets of populations vulnerable to iron-deficiency anemia, particularly women, children, and the elderly. A 100-gram serving of ragi provides approximately 3.9 mg of iron, which is crucial for increasing hemoglobin levels and improving the oxygen-carrying capacity of the blood [4]. Including ragi in public feeding programs, such as school meals and maternal nutrition schemes, can significantly contribute to reducing the incidence of anemia in populations at risk [5].

In addition to its iron content, ragi is one of the best plant-based sources of calcium, with 100 grams providing around 344 mg of calcium. This makes it an excellent dietary choice for improving bone health, especially in children, pregnant women, and post-menopausal women who are at risk of osteoporosis [2]. Public health campaigns that promote ragi-based diets as a preventive measure against bone-related disorders can significantly improve long-term health outcomes in these demographic groups.

7.2 Managing Lifestyle Diseases: Diabetes and Cardiovascular Health

Ragi is increasingly recognized for its role in managing and preventing lifestyle diseases, such as diabetes and cardiovascular conditions, which are growing public health concerns worldwide. One of the key properties of ragi is its low glycemic index (GI), which means it is digested and absorbed slowly, leading to a gradual increase in blood sugar levels. This makes ragi an ideal food for individuals with diabetes or those at risk of developing the disease, as it helps in maintaining stable glucose levels throughout the day [3]. Replacing high-GI foods like rice and wheat with ragi in daily meals can contribute to better glycemic control and reduce the risk of insulin resistance. Moreover, ragi's high fiber content is beneficial for cardiovascular health. Dietary fiber helps reduce levels of "bad" LDL cholesterol while promoting the production of "good" HDL cholesterol, which is essential for maintaining a healthy heart [29]. The polyphenols and antioxidants present in ragi also play a role in preventing oxidative stress and reducing inflammation, both of which are risk factors for cardiovascular disease. Therefore, incorporating ragi-based foods into the diet can lower the risk of heart attacks, strokes, and other cardiovascular complications, which are leading causes of mortality in both developed and developing countries.

7.3 Weight Management and Digestive Health

Ragi is particularly effective for individuals looking to manage their weight, due to its high fiber and low-calorie content. The high dietary fiber in ragi not only aids digestion but also promotes a feeling of fullness, which helps in reducing overall calorie intake and prevents overeating. Studies have shown that fiber-rich foods like ragi can help control appetite by delaying the release of hunger hormones, making it easier for individuals to adhere to a weight-loss regimen [13]. In addition, the slow digestion of ragi contributes to sustained energy release, preventing spikes and crashes in blood sugar levels that often lead to unhealthy snacking. For digestive health, ragi’s fiber content improves bowel movements and helps prevent constipation, reducing the risk of gastrointestinal disorders such as irritable bowel syndrome (IBS) and diverticulitis [18]. Promoting ragi as a staple grain in public health campaigns can therefore contribute to better digestive health and overall well-being, reducing the burden of common digestive complaints in both urban and rural populations.

7.4 Supporting Maternal and Child Health

Ragi is an especially important grain for maternal and child health. Its high calcium content

supports the development of strong bones and teeth in children, while its iron and folic acid content helps in preventing anemia in pregnant women and nursing mothers [2]. During pregnancy, adequate calcium intake is critical for fetal bone development, and the consumption of ragi can help meet the increased calcium demands of pregnancy without relying on dairy products, which may be inaccessible or unaffordable for many women in low-income communities. Additionally, the iron in ragi helps in preventing maternal anemia, which is a major cause of complications during pregnancy and childbirth in developing countries. For children, ragi is often used as a weaning food due to its digestibility and nutrient density. Porridge made from ragi is easily absorbed by the body and provides essential nutrients that support growth and development during the crucial early years of life. Public nutrition programs that incorporate ragi into the diets of mothers and young children can significantly improve health outcomes and reduce malnutrition and stunting [9].

7.5 Ragi and Public Nutrition Programs

Given the vast public health benefits of ragi, integrating it into national nutrition programs is a promising strategy for improving public health outcomes. Several states in India, including Karnataka and Tamil Nadu, have already introduced ragi into public distribution systems (PDS) and midday meal schemes, ensuring that children, pregnant women, and low-income families have access to this highly nutritious grain [15]. Expanding such initiatives to other regions can enhance the overall dietary quality of vulnerable populations, helping to address both undernutrition and overnutrition. Furthermore, promoting ragi through food fortification programs can provide additional health benefits. For instance, fortifying ragi with vitamins and minerals such as vitamin D, zinc, and iodine can further enhance its nutritional profile and address multiple nutrient deficiencies simultaneously. Such initiatives are especially relevant in countries where both undernutrition and micronutrient deficiencies coexist with rising rates of obesity and lifestyle diseases [16].

7.6 Addressing Socioeconomic Disparities through Ragi-Based Diets

Ragi-based diets have the potential to address socioeconomic disparities in access to nutritious food. As a drought-resistant crop, ragi can be grown in marginal environments where other crops fail, providing food security for rural populations that rely on subsistence farming. Encouraging ragi cultivation and consumption in low-income communities can improve both dietary diversity and economic resilience, as it supports local agriculture while reducing dependency on more expensive, less nutritious imported grains [12]. By promoting ragi in public nutrition programs, governments can ensure that even the most vulnerable populations benefit from its health-promoting properties [30].

8. CONCLUSION

Ragi, with its vast nutritional benefits, offers a promising solution to many of the public health challenges faced today, particularly in regions where malnutrition, anaemia, and non-communicable diseases are prevalent. Its high content of essential nutrients such as calcium, iron, fiber, and antioxidants position it as an excellent grain for enhancing the overall health and well-being of populations. Despite its historical roots as a staple food in many parts of India and Africa, ragi has gradually lost prominence due to the rising dominance of more commercialized grains like rice and wheat. However, with increasing global awareness of healthy eating habits and the resurgence of interest in ancient grains, ragi is slowly regaining its status as a significant dietary component.

One of the primary advantages of ragi lies in its ability to address nutrient deficiencies, particularly those related to iron and calcium. Populations that suffer from anaemia, such as women and children in rural regions, can significantly benefit from incorporating ragi into their diets. In addition, its high calcium content makes it ideal for populations at risk of osteoporosis, including post-menopausal women and the elderly. Governments and health organizations that have introduced ragi into public distribution systems and school meal programs have witnessed improvements in the nutritional status of vulnerable populations. This highlights the grain's potential in combating widespread malnutrition and micronutrient deficiencies, which are still critical issues in many developing nations. Ragi’s low glycemic index is another of its standout characteristics, especially in the fight against diabetes. Given the global rise in diabetes cases, promoting low-GI foods like ragi can help manage blood sugar levels more effectively. This quality, combined with its high fiber content, also makes ragi a valuable asset in weight management and cardiovascular health.

By lowering cholesterol levels and improving digestion, ragi-based diets can contribute to reducing the prevalence of heart disease, which remains one of the leading causes of death worldwide.

Despite its benefits, the integration of ragi into modern diets faces challenges due to its stigma as a "poor man's food," especially in urban areas where refined grains dominate. Rebranding ragi as a superfood and promoting its health benefits through strategic marketing, collaborations, and innovative products can shift perceptions. Strengthening local supply chains, supporting small farmers, and enhancing production through subsidies and policies are essential for increasing ragi's availability and appeal.

Ragi's sustainability is vital in modern food systems due to its resilience in drought-prone areas and low resource needs compared to crops like rice. As a climate-resilient crop, it conserves water and soil, benefiting smallholder farmers impacted by climate change. To fully integrate ragi, a multi-faceted approach is needed, including public health campaigns, supportive policies, and innovative marketing to highlight its nutritional and environmental benefits, making it both a sustainable and health-boosting staple.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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