Millet, pulse and green vegetable based nutriformulations: Nutritional, Functional and Health perspectives - A comprehensive Review

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Abstract

Millet-pulse-preen (MPGv) nutriformulations offer a promising approach for developing nutritionally balanced, functional, and sustainable foods. Relevant literature published mainly during 2015-2026, with emphasis on 2020-2026, was retrieved from major scientific databases using terms related to millets, pulses, green leafy vegetables, nutriformulations, processing, bioactive compounds, and health benefits. This review examines nutritional and functional attributes, nutritional synergy, processing effects, health potential, and food applications of these complementary ingredients. Their combination can enhance protein quality, dietary fibre, micronutrient density, bioactive compounds, and functional properties. Such formulations may support glycaemic regulation, healthy body weight, cardiovascular and gastrointestinal health, and improved micronutrient adequacy. However, direct clinical evidence for complete formulations remains limited. Further research is needed on formulation optimization, nutrient bioavailability, standardized processing, sustainability, and human clinical validation. Overall, MPGv nutriformulations have considerable potential to contribute to sustainable nutrition, nutritional security, and public health.

Key Words: Functional foods; MPGv; Nutriformulations; Nutritional synergy.

Introduction

The increasing burden of malnutrition, micronutrient deficiencies, obesity, diabetes mellitus, cardiovascular diseases, and other non-communicable diseases (NCDs) represents a major global public health challenge [1]. Rapid urbanization, changing dietary patterns, and increased consumption of highly processed foods have contributed to reduced intake of nutrient-dense traditional foods and increasingly energy-dense but nutrient-poor diets [2]. Consequently, increasing attention has been directed toward functional foods and nutrient-rich dietary interventions that can address nutritional inadequacies while potentially supporting the prevention of diet-related chronic diseases.

Millets, pulses, and green leafy vegetables (GLVs) represent three nutritionally complementary food groups with considerable potential for the development of functional and nutrient-dense foods. Millets are recognized as climate-resilient nutri-cereals because of their adaptability to diverse environments and their contribution of dietary fibre, slowly digestible carbohydrates, minerals, vitamins, and bioactive phytochemicals [3. 4]. Their relatively favourable glycaemic characteristics, gluten-free nature, and phenolic content have increased interest in their use in functional food development. Renewed interest in millets has also been associated with efforts to promote sustainable food systems and nutritional security [5]. Pulses complement cereals nutritionally by providing substantial plant protein, lysine-rich amino acid profiles, resistant starch, dietary fibre, B-complex vitamins, and essential minerals such as iron, zinc, magnesium, and potassium [6]. Their dietary fibre, protein, and resistant starch content has been associated with favourable effects on satiety, glycaemic regulation, gut health, and cardiometabolic risk [7]. When combined with cereal grains, pulses can complement limiting amino acids and thereby improve the overall protein quality of composite diets.

Green leafy vegetables constitute another important component of balanced diets because they provide vitamins, including A, C, E, K and folate, together with minerals, dietary fibre, carotenoids, chlorophylls, flavonoids, and other bioactive phytochemicals [8]. These constituents contribute to antioxidant and other potential health-promoting activities and can help increase the dietary supply of important micronutrients, including iron, calcium, folate, and provitamin A. Their incorporation into composite food formulations may therefore enhance micronutrient density and functional value [9]. Their incorporation into composite food formulations therefore enhances both nutritional quality and functional efficacy.

The concept of nutriformulations has gained increasing attention as a strategy for designing composite foods that combine nutritionally complementary ingredients to enhance nutrient density, functional properties, and potential health benefits [10, 11]. Combining millets, pulses, and green leafy vegetables may provide complementary sources of protein, dietary fibre, micronutrients, and bioactive compounds, thereby offering a broader nutritional profile than formulations based on individual ingredients [12]. Furthermore, appropriate processing techniques such as germination, fermentation, malting, roasting, extrusion, and controlled drying can reduce anti-nutritional factors while improving digestibility, bioavailability of nutrients, sensory characteristics, and consumer acceptability [13, 14]. These advances have expanded the application of composite nutriformulations in ready-to-eat foods, bakery products, complementary foods, therapeutic diets, snacks, beverages, and other value-added functional products.

Although numerous reviews have examined the nutritional and health-promoting properties of millets, pulses, and green leafy vegetables individually, comparatively limited attention has been given to their integrated use in composite nutriformulations [15,16]. Existing literature frequently focuses on individual ingredients or specific food products, with less emphasis on systematically synthesizing the nutritional synergy among these food groups, the influence of processing technologies, functional properties, mechanisms underlying potential health effects, product-development strategies, commercialization opportunities, and future research priorities [17]. This fragmented understanding limits the translation of current scientific knowledge into practical dietary interventions and functional food innovations. The proposed workflow for formulation development, product evaluation, validation, and potential commercialization of MPGv nutriformulations is illustrated in **Figure 1.**

In this review, nutriformulations refer to deliberately designed composite food formulations that combine nutritionally complementary ingredients to enhance nutrient density, functional properties, and potential health benefits. The review examines the nutritional basis and synergy of millets, pulses, and green leafy vegetables; processing technologies influencing product quality and nutrient bioavailability; functional properties and applications in value-added foods; and current evidence regarding their potential contribution to the prevention and management of lifestyle-related disorders. Particular attention is given to research gaps, technological challenges, and future opportunities for developing scientifically validated, sustainable, and consumer-acceptable nutriformulations that may contribute to improved nutritional security and public health.

Literature Search Strategy

Relevant literature was retrieved from PubMed, Scopus, Web of Science, ScienceDirect, SpringerLink, Google Scholar, and Wiley Online Library. Articles published primarily between 2015 and 2026, with emphasis on recent evidence from 2020-2026, were considered. Search terms included millets, nutri-cereals, pulses, legumes, green leafy vegetables, functional foods, nutriformulations, composite flour, bioactive compounds, processing technologies, dietary fibre, protein quality, micronutrients, health benefits, and non-communicable diseases. Reports and guidance documents from the World Health Organization (WHO), Food and Agriculture Organization (FAO), and Indian Council of Medical Research-National Institute of Nutrition (ICMR-NIN), together with other authoritative sources, were also consulted to provide current nutritional and public-health perspectives.

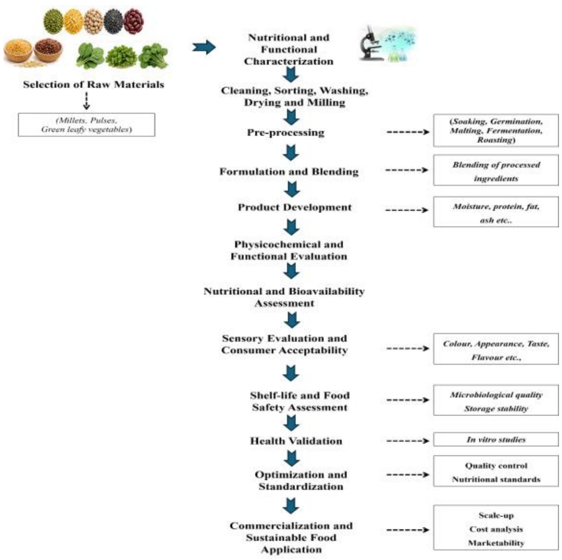

Figure 1. Integrated workflow for the development, evaluation, validation, and commercialization of MPGv nutriformulations.

Nutritional Composition and Functional Attributes of Millets

Millets are a diverse group of small-seeded cereals belonging to the family Poaceae and have been cultivated for thousands of years in Asia and Africa. Their recent resurgence in scientific and commercial interest is associated with their nutritional quality, climate resilience, and potential for functional food development [18, 19]. When consumed as whole grains, millets retain the bran, germ, and endosperm, contributing to their nutritional and functional value. India is a major producer of diverse millet species, each possessing distinct nutritional characteristics relevant to composite food development [20, 21]. Their distinct nutritional characteristics make them suitable for diverse composite nutriformulations.

Millets are nutrient-dense cereals containing complex carbohydrates, dietary fibre, proteins, lipids, vitamins, minerals, and bioactive phytochemicals [22, 23]. Depending on species, they generally contain approximately 60-75% carbohydrates, 7-13% protein, 2-7% lipids, and 7-15% dietary fibre. Compared with refined cereals, millets generally provide appreciable amounts of calcium, iron, magnesium, phosphorus, potassium, zinc, and B-complex vitamins [24, 25]. Finger millet is particularly rich in calcium, whereas pearl millet provides comparatively higher iron and zinc. The nutritional composition and selected bioactive attributes of major millet species are summarized in **Table 1.**

Although millet proteins are nutritionally valuable, lysine is generally the limiting amino acid, whereas sulfur-containing amino acids such as methionine and cysteine are present in appreciable amounts [26, 27]. Combining millets with lysine-rich pulses can therefore improve amino-acid balance and overall protein quality in composite nutriformulations [28]. Dietary fibre is another important attribute of millets. Soluble and insoluble fibre, resistant starch, and non-starch polysaccharides may contribute to satiety, bowel function, postprandial glucose regulation, and beneficial modulation of the gut microbiota [29, 30]. These properties support the potential use of millet-based foods in nutriformulations targeting metabolic and gastrointestinal health.

Millets also contain bioactive compounds such as phenolic acids, flavonoids, tannins, lignans, phytosterols, and carotenoids, which contribute to their antioxidant potential [31]. Their concentrations vary according to species, genotype, growing conditions, and processing. Millets also contain anti-nutritional factors, including phytates, tannins, oxalates, and enzyme inhibitors, which may affect nutrient bioavailability [32]. Processing methods such as soaking, germination, fermentation, malting, decortication, and extrusion can reduce these compounds and improve digestibility, mineral availability, and sensory properties [33].

Millet flours also possess useful functional characteristics, including water and oil absorption, gelatinization, pasting, and rheological properties, which influence texture and product quality [34]. These properties support their incorporation into bakery products, extruded foods, breakfast cereals, noodles, complementary foods, and gluten-free products. Blending millet flour with pulse proteins and green leafy vegetable powders can further enhance nutritional density and functional value [33] (Nanje Gowda et al., 2022). Millets are also recognized as climate-resilient crops because of their relatively low water requirements, drought tolerance, and adaptability to marginal soils [35]. Their incorporation into composite nutriformulations can therefore contribute to nutritional improvement while supporting sustainable agriculture and food security [36]. Overall, their nutritional composition, bioactive compounds, functional properties, and environmental resilience make millets important components of millet - pulse - green vegetable nutriformulations.

Pulses: Nutritional and Functional Attributes

Pulses such as chickpea, lentil, pigeon pea, mung bean, black gram, cowpea, and field pea are important sources of plant-based protein, dietary fibre, complex carbohydrates, vitamins, minerals, and bioactive compounds [37]. Their nutrient-rich composition makes them valuable ingredients for developing functional and nutrient-dense foods. Pulses are relatively rich in lysine compared with cereals, whereas sulfur-containing amino acids, particularly methionine, are generally limiting [38].

Table 1. Nutritional composition, bioactive compounds, and selected health attributes of major millet species per 100 g edible portion.

Millet	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)	Dietary Fiber (g)	Calcium (mg)	Iron (mg)	Zinc (mg)	Magnesium (mg)	Bioactive Compounds	Health Benefits
Finger millet (*Eleusine coracana*)	336	7.3	1.5	72.0	11.5	364	4.6	2.3	137	Phenolic acids Flavonoids	Bone health, diabetes antioxidant activity
Pearl millet (*Pennisetum glaucum*)	361	11.6	5.0	67.5	11.3	42	8.0	3.1	137	Phenolics phytosterols	Iron supplementation, cardiovascular health
Foxtail millet (*Setaria italica*)	331	12.3	4.3	60.9	8.0	31	2.8	2.4	81	Polyphenols Carotenoids	Glycaemic control, antioxidant activity
Little millet (*Panicum sumatrense*)	341	9.7	4.7	67.0	7.6	17	9.3	3.7	114	Phenolics Flavonoids	Weight management, gut health
Kodo millet (*Paspalum scrobiculatum*)	353	8.3	3.6	65.9	9.0	27	0.5	1.6	130	Polyphenols Tannins	Anti-diabetic, antioxidant properties
Barnyard millet (*Echinochloa frumentacea*)	307	11.2	3.9	55.0	10.1	20	5.0	3.0	82	Phenolics Dietary fibre	Low glycaemic index, digestive health

Proso millet (*Panicum miliaceum*)	356	12.5	1.1	70.4	8.5	14	2.9	1.7	153	Ferulic acid Flavonoids	Gluten-free nutrition, cardiovascular health
Browntop millet (*Urochloa ramosa*)	338	11.5	3.5	67.0	12.5	28	6.1	2.5	120	Polyphenols Dietary fibre	Antioxidant potential, metabolic health

Source: Indian Food Composition Table (IFCT 2017)

Thus, combining pulses with millets can provide complementary amino-acid profiles and improve the overall protein quality of composite nutriformulations. Their soluble and insoluble fibre, along with resistant starch, may promote satiety, bowel health, glycaemic regulation, and beneficial gut microbial activity [39]. The nutritional composition of selected commonly consumed pulses is presented in **Table 2**.

Pulses also supply important micronutrients, including iron, zinc, magnesium, potassium, phosphorus, calcium, folate, and B-group vitamins [40]. Bioactive constituents such as phenolic compounds, flavonoids, saponins, phytosterols, and bioactive peptides may contribute to antioxidant and other health-promoting effects. However, phytates, tannins, trypsin inhibitors, and lectins can reduce nutrient bioavailability [41]. Processing methods such as soaking, germination, fermentation, cooking, dehulling, and extrusion can reduce these anti-nutritional factors and improve digestibility. Pulse flours and proteins also exhibit water- and oil-holding, emulsifying, foaming, and gel-forming properties, supporting their use in bakery products, snacks, beverages, complementary foods, and other functional formulations [38].

In MPGv nutriformulations, pulses primarily contribute protein and dietary fibre while complementing the micronutrients, phytochemicals, and functional properties provided by millets and green vegetables [42, 43]. Their inclusion can therefore enhance the overall nutritional value, protein quality, functionality, and health potential of composite foods.

Green Leafy Vegetables: Nutritional and Functional Attributes

Green leafy vegetables (GLVs), including spinach, amaranth, fenugreek, moringa, drumstick leaves, and other edible leafy species, are nutrient-dense foods rich in vitamins, minerals, dietary fibre, pigments, and bioactive phytochemicals [44]. Their incorporation into nutriformulations can enhance micronutrient density and functional value. GLVs provide provitamin A carotenoids, vitamins C, K, E, and folate, along with minerals such as iron, calcium, magnesium, potassium, and zinc [45]. They also contain chlorophylls, carotenoids, phenolic compounds, and flavonoids that may contribute to antioxidant and anti-inflammatory activities [46].

The dietary fibre in GLVs supports intestinal function, satiety, and healthy glucose and lipid metabolism, while their phytochemicals may help protect against oxidative stress and inflammation [47]. However, their nutrient composition varies with species, variety, growing conditions, maturity, and processing. Some GLVs contain oxalates, phytates, tannins, and other compounds that can reduce mineral bioavailability. Processing methods such as blanching, cooking, drying, and fermentation can help reduce these factors while retaining important nutrients and bioactive compounds [48].

In MPGv nutriformulations, GLVs complement the energy- and fibre-rich millets and protein-rich pulses by contributing vitamins, minerals, carotenoids, and phytochemicals [49]. The nutritional profiles of selected GLVs and their contributions to protein, fibre, calcium, and iron are presented in **Table 3**. Their incorporation can enhance micronutrient density, antioxidant potential, colour, and overall functionality of composite foods [50].

Table 2. Nutritional composition of selected pulses and their contribution to protein, dietary fibre, and mineral intake.

Pulse	Scientific name	Energy (kcal)	Protein (g)	Carbohydrate (g)	Fat (g)	Dietary Fibre (g)	Calcium (mg)	Iron (mg)
Chickpea	*Cicer arietinum*	360	20.0	61.0	5.0	4.0	202	5.0
Black gram	*Vigna mungo*	347	24.0	60.0	1.0	1.0	154	4.0
Green gram	*Vigna radiata*	334	24.0	57.0	1.0	4.0	124	4.0
Pigeon pea	*Cajanus cajan*	335	22.0	58.0	2.0	1.0	73	3.0
Lentil	*Lens culinaris*	343	25.0	59.0	1.0	1.0	69	7.0
Cowpea	*Vigna unguiculata*	323	24.0	54.0	1.0	3.0	77	9.0
Horse gram	*Macrotyloma uniflorum*	321	22.0	57.0	0.0	5.0	287	7.0
Dry pea	*Pisum sativum*	315	20.0	56.0	1.0	4.0	75	7.0

Sources: IFCT 2017, FAO Food Composition Database

Nutritional Synergy in Composite Nutriformulations

The combination of millets, pulses, and green leafy vegetables (GLVs) provides a complementary nutritional profile that can offer greater benefits than individual ingredients alone [51]. Millets contribute complex carbohydrates, dietary fibre, minerals, and phytochemicals, while pulses provide substantial protein, lysine, resistant starch, and essential minerals [52]. GLVs further enrich the formulation with vitamins, carotenoids, minerals, fibre, and antioxidant phytochemicals. A key advantage of cereal-pulse combinations is protein complementation [53]. The relatively lower lysine content of millet proteins can be complemented by the lysine-rich proteins of pulses, resulting in a more balanced amino-acid profile and improved protein quality [54, 55]. The inclusion of GLVs further broadens the micronutrient and phytochemical profile.

Together, these ingredients may enhance dietary fibre intake, antioxidant capacity, glycaemic regulation, and gut health [56]. Processing methods such as soaking, germination, fermentation, cooking, and drying can further improve nutrient availability and reduce selected anti-nutritional factors. Thus, appropriately formulated MPGv products offer potential for developing nutrient-dense, functional, affordable, and sustainable foods [57]. This nutritional synergy provides a strong basis for composite nutriformulations aimed at improving dietary quality and addressing protein and micronutrient deficiencies. The proposed nutritional synergy and potential mechanisms underlying the health effects of MPGv nutriformulations are summarized in **Figure 2**.

Processing Technologies and Their Impact

Processing plays an important role in determining the nutritional, functional, and sensory quality of MPGv nutriformulations. Appropriate processing can improve digestibility, nutrient bioavailability, stability, and consumer acceptability while reducing anti-nutritional factors. Traditional methods such as soaking, germination, malting, fermentation, roasting, cooking, and drying can reduce phytates, tannins, enzyme inhibitors, and other undesirable compounds [58]. Germination and fermentation may further improve protein and mineral availability and modify bioactive compounds [14]. Thermal processing can enhance palatability and digestibility, although excessive heating may cause losses of heat-sensitive vitamins and phytochemicals [59].

Modern technologies, including extrusion, controlled dehydration, milling, and blending, enable the production of stable and convenient products such as composite flours, snacks, bakery products, beverages, and complementary foods [60]. Processing conditions should be optimized to balance nutrient retention, reduction of anti-nutritional factors, functional properties, shelf stability, and sensory quality [61]. This is particularly important for MPGv formulations because millets, pulses, and GLVs differ in moisture sensitivity, nutrient stability, texture, and processing requirements. An optimized processing strategy can therefore improve the overall nutritional, functional, and sensory quality of the final product.

Table 3. Nutritional profile of selected green leafy vegetables and their contribution to dietary protein, fibre, calcium, and iron.

Green leafy vegetable	Scientific name	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)	Fibre (g)	Calcium (mg)	Iron (mg)
Amaranth leaves	*Amaranthus gangeticus*	45	4.0	0.5	6.1	2.0	397	3.5
Spinach	*Spinacia oleracea*	26	2.0	0.7	2.9	2.0	73	1.1
Fenugreek leaves	*Trigonella foenum-graecum*	49	4.4	0.9	6.0	1.1	395	1.9
Drumstick leaves	*Moringa oleifera*	38	6.7	1.7	4.1	2.0	440	0.9
Bathua leaves	*Chenopodium album*	48	1.6	0.2	10.8	0.8	438	1.4

Coriander leaves	*Coriandrum sativum*	44	3.3	0.6	6.3	1.2	184	1.4
Agathi leaves	*Sesbania grandiflora*	97	8.0	1.0	12.0	2.0	1130	4.0
Basella leaves	*Basella alba*	153	1.3	0.6	37.3	1.5	337	0.4

Source: Compiled from ICMR-NIN Indian Food Composition Tables and Indian food-composition data.

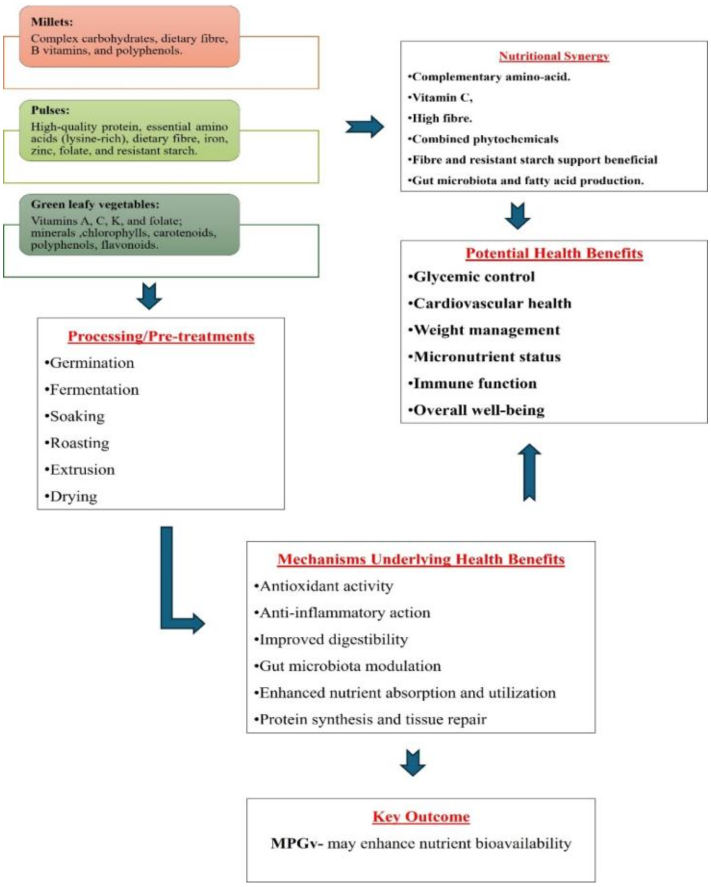

Figure 2. Nutritional synergy and potential health-promoting mechanisms of MPGv nutriformulations.

Functional Properties of Nutriformulations

MPGv nutriformulations exhibit diverse functional properties arising from their complementary proteins, carbohydrates, dietary fibre, minerals, and bioactive compounds [62]. These characteristics are influenced by ingredient proportions, particle size, processing conditions, and storage [63]. Composite formulations may show improved water- and oil-holding capacity, swelling, emulsification, foaming, pasting, and textural properties compared with individual ingredients [64]. Pulse proteins contribute to solubility, emulsification, and gel formation, while millet starch and fibre influence viscosity, structure, and energy release [65]. Green vegetable powders further contribute fibre, pigments, minerals, and antioxidant compounds.

Dietary fibre, resistant starch, phenolics, flavonoids, carotenoids, and other bioactive constituents may enhance the antioxidant and functional potential of these formulations [66]. Processing can modify these properties by altering starch structure, protein functionality, fibre characteristics, and phytochemical availability. Sensory attributes, including colour, flavour, aroma, texture, and overall acceptability, are also critical for successful product development [67]. Excessive vegetable-powder incorporation or intensive processing may adversely affect sensory quality; therefore, ingredient ratios and processing conditions require careful optimization [68, 69]. Overall, these properties support the use of MPGv formulations in composite flours, bakery products, snacks, beverages, complementary foods, and other value-added products.

Health Perspectives

MPGv nutriformulations provide complementary complex carbohydrates, plant protein, dietary fibre, micronutrients, and bioactive compounds that may support the prevention and management of diet-related disorders, including type 2 diabetes, obesity, cardiovascular diseases, hypertension, micronutrient deficiencies, and gastrointestinal disorders [70]. Their fibre, resistant starch, and relatively low-glycaemic carbohydrate profile may support postprandial glucose regulation, while protein and fibre can enhance satiety and contribute to healthy weight management [71].

Dietary fibre, plant proteins, magnesium, potassium, and antioxidant phytochemicals may also support lipid metabolism, blood-pressure regulation, and cardiovascular health [72]. Soluble fibre, resistant starch, and fermentable carbohydrates can promote beneficial gut microorganisms and intestinal function [73, 74]. Pulses and GLVs provide iron, folate, calcium, zinc, and magnesium, while millets contribute additional minerals and B-group vitamins, potentially helping to address micronutrient deficiencies [75]. Their vitamins, minerals, carotenoids, phenolics, and other phytochemicals may further support antioxidant defence and normal immune function [76].

Overall, the potential health effects of MPGv formulations are likely to result from the combined action of protein, fibre, micronutrients, and diverse bioactive compounds rather than any single ingredient. However, direct clinical evidence for complete MPGv formulations remains limited, highlighting the need for well-designed human studies to establish their efficacy, bioavailability, and optimal formulation ratios. Major health benefits and supporting evidence are summarized in **Table 4** and illustrated in **Figure 3**.

Table 4. Health benefits of MPGv -based nutriformulations supported by experimental, nutritional, and clinical evidence.

Health benefits	Major components	Evidence	Benefits
Glycaemic control	Millets, pulses, dietary fibre, resistant starch	Clinical trials and systematic reviews	Reduced postprandial and fasting glucose; possible improvement in HbA1c
Obesity and weight management	Fibre, protein, slowly digestible carbohydrates	Experimental and clinical evidence	Increased satiety and potential support for body-weight control

Cardiovascular health	Millets, pulses, fibre, minerals and phytochemicals	Clinical and epidemiological evidence	Improved lipid profile and potential reduction in cardiometabolic risk
Blood pressure regulation	Potassium, magnesium, fibre and phytochemicals	Clinical and observational evidence	Potential improvement in blood-pressure-related risk factors
Gut health	Dietary fibre, resistant starch and fermentable carbohydrates	Experimental and emerging human evidence	Support for beneficial gut microbiota and intestinal function
Micronutrient status	Green leafy vegetables, pulses and millets	Nutritional and intervention studies	Increased intake of iron, calcium, folate, zinc and other essential micronutrients
Antioxidant defence	Phenolics, flavonoids, carotenoids and other phytochemicals	Experimental studies	Reduction of oxidative stress and enhancement of antioxidant capacity
Inflammation	Polyphenols, carotenoids and dietary fibre	Predominantly experimental evidence	Potential modulation of inflammatory pathways
Protein nutrition	Pulses + millets	Nutritional and formulation studies	Improved amino-acid complementarity and protein quality
Overall metabolic health	Millet–pulse–vegetable combination	Limited direct clinical evidence	Potential combined benefits through complementary nutrients and bioactive compounds

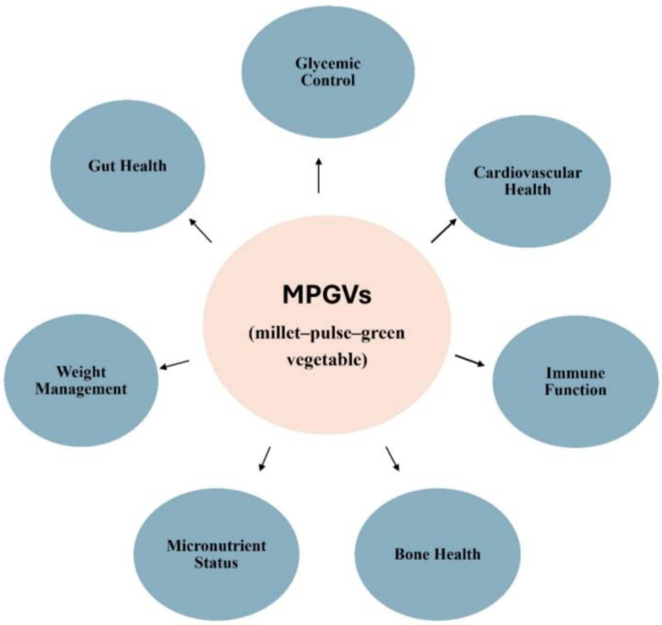

Figure 3. Multifaceted health outcomes associated with MPGv composite nutriformulations.

Commercial Products and Future Market Potential

Growing demand for nutritious, convenient, and sustainable foods has created opportunities for millet-, pulse-, and vegetable-based nutriformulations [77]. Recent studies on their nutritional and functional potential are summarized in **Table 5**. These ingredients can be incorporated into composite flours, bakery products, extruded snacks, breakfast foods, instant mixes, beverages, complementary foods, and ready-to-eat products [70]. Their nutritional diversity and compatibility with plant-based food systems make them attractive for both conventional and functional food markets [78]. MPGv combinations are particularly promising for affordable, nutrient-dense products targeting children, adults, older populations, and consumers seeking healthier dietary options [79, 80]. Enhanced protein quality, dietary fibre, micronutrient density, and antioxidant potential may provide additional value over conventional cereal-based foods.

Table 5. Recent studies on MPGv based composite nutriformulations and their nutritional and functional significance.

Composite formulation / product	Major ingredients	Major findings / functional significance	Reference
Instant pulse–millet porridge	Chickpea, foxtail millet, roselle calyx	Improved nutritional quality and investigated iron and zinc bio accessibility; addition of bioactive plant material enhanced phenolic content.	[83]
Micronutrient-fortified pasta	Millet flour, pulse flour, green leafy vegetable powder	Composite formulations improved protein, calcium and iron contents; higher green leafy vegetable incorporation increased calcium and iron levels.	[84]
Millet–pulse–groundnut nutritional products	Sorghum, millets, pulses, groundnut	Ready-to-cook and ready-to-eat products were developed for preschool children; one-year intervention showed improvements in height, weight, MUAC and haemoglobin.	[85]
Kodo millet–chickpea functional products	Kodo millet, chickpea and conventional cereals	Products showed good acceptability, protein content, lysine content and in-vitro protein digestibility, demonstrating improved cereal–pulse protein quality.	[86]
Nutrient-enriched extruded vermicelli	Finger millet, red gram pulse flour, corn flour, semolina, carrot pomace	Composite extrusion was investigated for nutritional enhancement and development of a value-added cereal–pulse–vegetable product.	[87]
Millet–pulse–green vegetable high-fibre mix	Kodo millet, Bengal gram, drumstick leaves	Development of a high-fibre composite mix and evaluation of formulated recipes demonstrates the potential of combining all three ingredient groups.	[88]

Future market growth will depend on sensory acceptability, affordability, convenience, shelf stability, standardized processing, nutritional validation, and consumer awareness. Sustainable use of locally available millets, pulses, and green vegetables may reduce production costs while strengthening regional food systems [81]. However, successful commercialization requires standardized formulations, evidence-based health claims, scalable processing technologies, suitable packaging, and robust quality-control systems [82]. Collaboration among researchers, food industries, nutrition professionals, farmers, and policymakers can help translate nutriformulations research into commercially viable and nutritionally validated products.

Research Gaps and Future Perspectives

Despite growing interest in millet-, pulse-, and green vegetable-based foods, important research gaps remain. While individual ingredients have been extensively studied, relatively few studies have systematically evaluated integrated MPGv nutriformulations in terms of nutritional synergy, optimal ingredient ratios, nutrient bioavailability, sensory quality, shelf stability, and long-term health effects. Future research should focus on optimizing formulations and processing conditions to improve protein quality, micronutrient bioavailability, digestibility, functional properties, and consumer acceptability. Greater attention is also needed to determine how germination, fermentation, cooking, drying, and extrusion influence nutrient retention, bioactive compounds, and anti-nutritional factors. Well-designed in vivo and human clinical studies are essential to validate potential effects on glycaemic control, body weight, cardiovascular health, gut function, micronutrient status, and immune function.

Future product development should prioritize scalable processing, formulation standardization, affordability, sensory acceptability, appropriate packaging, and commercialization. Greater utilization of underused millet and pulse species and locally available green vegetables could promote dietary diversity, food security, and climate resilience. Sustainability assessments and emerging approaches such as nutrigenomics, metabolomics, and gut microbiome research may further clarify the mechanisms underlying the health effects of MPGv formulations. Overall, multidisciplinary research integrating food science, nutrition, agriculture, biotechnology, and consumer science is needed to translate the nutritional potential of MPGv nutriformulations into evidence-based, sustainable, and commercially viable food products.

Conclusion

MPGv nutriformulations offer a promising approach for developing nutritionally balanced, functional, and sustainable foods. Millets provide complex carbohydrates, dietary fibre, minerals, and phytochemicals; pulses contribute complementary plant proteins, fibre, and micronutrients; while green vegetables enrich the formulations with vitamins, minerals, carotenoids, and antioxidants. Their combination can enhance overall nutrient density, protein quality, and phytochemical diversity. Appropriate processing methods, including soaking, germination, fermentation, cooking, drying, and extrusion, can improve digestibility, nutrient availability, functional properties, and acceptability while reducing selected anti-nutritional factors. MPGv formulations have potential applications in complementary foods, snacks, bakery products, beverages, and other value-added products, with possible benefits for metabolic health, cardiovascular health, gut function, and micronutrient adequacy. However, further research is needed to optimize formulations, establish nutrient bioavailability and clinical efficacy, and assess long-term safety. Integrating nutrition, food technology, agriculture, and clinical research will support the development of affordable, acceptable, scientifically validated, and sustainable nutriformulations that can contribute to improved nutritional security and public health.

Declarations

Conflict of Interest:

The authors declare no conflict of interest.

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