Project Proposal: Smart Protein

1. Title:

"Sustainable Smart Proteins: Integrating Green Leaf Proteins with Millets & Pseudo-Cereals for Innovative RTC & RTE Foods"

2. Research Hypothesis:

The incorporation of sustainable plant-based protein sources into RTC and RTE formulations will offer a viable alternative to conventional protein sources, addressing protein-energy malnutrition while promoting environmentally sustainable food production.

Key Questions:

What is the optimal method for extracting Green Leaf Proteins (GLPs) from duckweed, moringa, amaranth, and alfalfa to maximize protein yield, digestibility, and bioavailability?

How does the bioavailability of proteins from GLP-millet blends compare to conventional protein sources (e.g., dairy, soy, or animal proteins)?

What are the best formulation strategies for integrating GLPs with millets/pseudo-cereals in RTC and RTE food products?

3. Origin of the Proposal:

India faces a dual burden of malnutrition—protein-energy deficiency among vulnerable populations and an increasing prevalence of lifestyle-related metabolic disorders. Traditional protein sources, including animal-based products, are often expensive, environmentally unsustainable, or inaccessible to a significant portion of the population. In order to satisfy the rising demand for foods high in protein worldwide, it is necessary to investigate substitute plant-based proteins that are not only affordable and nutrient-dense but also sustainable. Duckweed, moringa, amaranth, and alfalfa are the sources of Green Leaf Proteins (GLPs), which are a low-resource, high-yield substitute for traditional proteins. These leaves are a great way to fight protein-energy malnutrition (PEM) because they are high in vitamins, antioxidants, and essential amino acids. Furthermore, GLPs can be grown hydroponically, which drastically lowers the need for energy, water, and land when compared to traditional agriculture, which makes them scalable and climate resilient. At the same time, millets and pseudo-cereals like buckwheat (kuttu), amaranth (ramdana), barnyard millet (jhangora), and

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finger millet (mandua) have become more well-known due to their high nutritional content and climate change adaptability. They are great functional foods that can help with deficiencies in both macronutrients and micronutrients because they are naturally gluten-free, high in dietary fiber, important micronutrients, and complex carbohydrates. When combined with millets and pseudo-cereals, GLPs provide a well-balanced plant-based protein matrix that can promote immunological response, metabolic health, and muscle growth. For nutritionally vulnerable populations, including children, pregnant women, the elderly, and athletes, the combination of leaf proteins and grain-based proteins improves protein quality, digestibility, and bioavailability.

This proposal seeks to create clean-label foods by combining GLPs, millets, and pseudo-cereals into Ready-to-Cook (RTC) and Ready-to-Eat (RTE) food products. These food formulations will be made to satisfy a wide range of consumer tastes while maintaining a high protein content, enhanced digestibility, and extended shelf life. Convenience, affordability, and sustainability will be the main points of emphasis, ensuring that both urban and rural populations can use these products. The DBT-BIRAC BioE3 Policy, which encourages the development of alternative proteins and high-performance biomanufacturing, the Sustainable Development Goals (SDGs), and India's National Nutrition Mission are all in line with the project. Additionally, it backs government efforts to promote millet, especially in view of the International Year of Millets (2023) and the growing global movement for indigenous, climate-resilient crops.

4. Background & Rationale:

The challenge of global malnutrition, particularly protein-energy malnutrition (PEM), has prompted extensive research into alternative protein sources (Nightingale et al., 2023). Protein-energy malnutrition (PEM) remains a critical public health challenge in India, particularly among children, pregnant women, and elderly populations (Swaminathan et al., 2021). The Indian diet, primarily cereal-based, often lacks adequate protein quality and essential amino acids (Longvah et al., 2017). While animal-based proteins provide high-quality amino acids, their production is resource-intensive, contributing to environmental degradation and raising concerns about affordability and accessibility (Poore & Nemecek, 2018). Green Leaf Proteins (GLPs) are emerging as a viable alternative due to their high protein content, rich amino acid profile, and low environmental footprint (Verma et al., 2022). Leaves like duckweed, moringa, amaranth, and alfalfa have been recognized for their high protein digestibility and bioavailability, making them suitable for addressing protein deficiencies sustainably (Georgiev et al., 2020). Millets and pseudo-cereals such as finger millet (Eleusine coracana), barnyard millet (Echinochloa crus-galli), amaranth (Amaranthus spp.), and buckwheat (Fagopyrum esculentum) are increasingly gaining attention for their nutritional density and climate resilience (Saleh et al., 2013). They are rich in dietary fiber, micronutrients (iron, zinc, calcium), and bioactive compounds, offering multiple health benefits, including improved metabolic health and gut microbiome support (Devi et al., 2014).

Moreover, millets and pseudo-cereals complement GLPs, as their carbohydrate and protein profiles enhance overall digestibility and amino acid balance (Nirmala et al., 2020). Blending GLPs with millets can create highly nutritious, functional foods that align with modern dietary trends, such as gluten-free, high-protein, and clean-label foods (Sethiya et al., 2021). The shift towards Ready-to-Cook (RTC) and Ready-to-Eat (RTE) foods reflects changing dietary habits and increasing consumer demand for convenience (Bhatt et al., 2022). However, most RTC and RTE products in the Indian market rely on refined cereals, artificial additives, and protein isolates rather than natural, whole-food-based protein sources. Developing Green Leaf Protein (GLP)-integrated millet-based Ready-to-Cook (RTC) and Ready-to-Eat (RTE) foods addresses multiple concerns by enhancing nutrition, sustainability, and health benefits. These formulations improve protein quality, fiber content, and micronutrient bioavailability, making them a valuable addition to diets combating malnutrition. Millets and GLPs are low-resource, climate-smart crops that require minimal inputs, ensuring sustainability and resilience against climate change. Additionally, the incorporation of GLPs enhances functional food properties, offering potential benefits for metabolic health, immunity, and gut health. The proposed research aligns with India's National Nutrition Mission (POSHAN Abhiyaan) and DBT-BIRAC's BioE3 Policy, promoting high-performance biomanufacturing and alternative protein innovations (DBT-BIRAC, 2024). Furthermore, it supports global initiatives for sustainable food systems, including the International Year of Millets (2023) and the United Nations Sustainable Development Goals (SDGs) on Zero Hunger and Sustainable Agriculture (FAO, 2023).

5. Current International and National Status:

Global Landscape

The alternative protein market has experienced significant expansion in recent years. In 2024, the global protein alternatives market is projected to be valued at approximately $15.7 billion, with expectations to reach $25.2 billion by 2029, reflecting a Compound Annual Growth Rate (CAGR) of 9.9%. Similarly, the plant-based protein sector is estimated at $14.3 billion in 2024, anticipated to grow at a CAGR of 7.5% to $20.5 billion by 2029. Long-term projections suggest that the alternative protein market could escalate to $290 billion by 2035, potentially accounting for 11% of annual global protein consumption.

Advancements in genomics and molecular biology have catalyzed the development of alternative protein sources. Notably, next-generation sequencing (NGS) technologies have facilitated genome and transcriptome sequencing of millets and pseudo-cereals, expediting the development of molecular markers for crop improvement. Additionally, comprehensive reviews highlight the nutritional profiles and functional benefits of pseudo-cereals, emphasizing their potential in food product innovation.

The plant-based food market has witnessed substantial growth, with U.S. retail sales doubling from $3.9 billion in 2017 to $8.1 billion in 2023. This surge is driven by consumer demand for sustainable, health-conscious, and ethically produced food options. However, challenges persist, including market saturation and evolving consumer preferences, leading companies like Unilever to reassess their plant-based meat ventures.

National Landscape

In India, millets and pseudo-cereals are recognized for their nutritional richness and climate resilience. Recent studies emphasize their role in ensuring food and nutritional security, advocating for their integration into mainstream agriculture. Research initiatives focus on genetic enhancement and trait mining to improve yield and nutritional profiles of these crops.

The Indian government has launched programs to promote millet cultivation, aligning with global sustainability goals. The declaration of 2023 as the "International Year of Millets" by the United Nations highlights India's commitment to these climate-resilient crops. Policies supporting the integration of millets into public distribution systems aim to enhance nutritional outcomes and increase food security.

The domestic market for plant-based proteins in India is growing, propelled by a growing middle class and increasing health awareness. The integration of green leaf proteins with millets presents opportunities for innovative product development, catering to both traditional tastes and modern convenience. However, challenges such as consumer acceptance, supply chain logistics, and competitive pricing need to be addressed to fully realize market potential.

Relevance of the Proposed Study in the Indian Context

India faces a dual burden of malnutrition, with 38% of children under five stunted and 18.7% wasted (NFHS-5, 2019-21). Additionally, 73% of Indians are protein-deficient due to low intake of high-quality proteins. The proposed study on Green Leaf Proteins (GLPs) integrated with millets and pseudo-cereals offers a nutrient-dense, sustainable, and affordable solution to combat protein-energy malnutrition (PEM) in vulnerable populations, including children, pregnant women, and the elderly. India is the largest producer of millets and pseudo-cereals such as finger millet (ragi), barnyard millet (jhangora), buckwheat (kuttu), and amaranth (chaulai). These crops are rich in proteins, fiber, and micronutrients (iron, calcium, zinc). These are climate-resilient, requiring less water and agro-inputs than wheat or rice. The proposal is aligned with India's push for mainstreaming millets under the "International Year of Millets 2023" initiative and inclusion in the Public Distribution System (PDS), mid-day meals, and POSHAN Abhiyaan programs.

The integration of GLPs with millets can further enhance protein quality, making it an ideal dietary intervention for nutritional security. India faces severe water stress and land degradation due to intensive agriculture. Traditional protein sources like livestock and soybean farming are resource-intensive and contribute to high greenhouse gas emissions. The proposed study promotes hydroponic-based Green Leaf Protein extraction (from duckweed, moringa, amaranth, and alfalfa) requiring minimal land and water, millet cultivation, which is drought-resistant and carbon-efficient and development of eco-friendly Ready-to-Cook (RTC) and Ready-to-Eat (RTE) foods, reducing reliance on animal-based proteins and supporting India's sustainability goals (SDG 2 – Zero Hunger, SDG 12 – Responsible Consumption & Production).

The alternative protein market in India is expected to grow at a CAGR of 8-10%, driven by rising urbanization and health-conscious consumers, increased demand for plant-based proteins due to lifestyle diseases (diabetes, obesity) and government support for agri-startups, millet processing industries, and bio-economy ventures under DBT-BIRAC, FSSAI, and Atmanirbhar Bharat. Developing affordable, nutritious, and culturally acceptable plant-based RTC & RTE foods can boost local economies, generate rural employment, and create export opportunities in the global functional food sector. This research aligns with multiple government initiatives, including National Nutrition Mission (POSHAN Abhiyaan), Eat Right India (FSSAI), Bio-Economy Mission (DBT-BIRAC) and PDS and ICDS Schemes.

Potential Applications in the Indian Context

The integration of Green Leaf Proteins (GLPs) with millets and pseudo-cereals has far-reaching applications across nutrition, public health, agriculture, and economic development in India. This approach caters to various consumer segments, including malnourished populations, health-conscious urban consumers, and industries focused on sustainable food production. In the realm of nutrition and public health, GLP-millet blends can play a crucial role in combating malnutrition and protein deficiency, particularly among vulnerable groups such as children, pregnant women, and the elderly. Fortified Ready-to-Cook (RTC) millet porridges can be incorporated into the Integrated Child Development Services (ICDS), while protein-enhanced Ready-to-Eat (RTE) snacks and high-protein meal supplements can support public nutrition programs targeting low-income groups. These efforts align with national initiatives like the National Nutrition Mission (POSHAN Abhiyaan) and food fortification policies. Furthermore, the application of GLP-millet blends in functional foods addresses lifestyle diseases such as diabetes, obesity, and metabolic disorders. By developing low-glycemic index formulations, gut-friendly probiotic products, and meal-replacement powders, these innovations support FSSAI's 'Eat Right India' initiative and Ayushman Bharat's preventive health strategies.

Beyond public health, the integration of GLPs into the alternative protein industry can significantly impact India's plant-based protein sector, reducing reliance on imported soy proteins. The development of GLP-based protein powders for sports and wellness nutrition, plant-based meat analogs, dairy alternatives, and infant formulas can drive market growth, which is projected to reach $450 million by 2027 with an 8-10% CAGR. Rising consumer demand for vegan, lactose-free, and high-protein foods further strengthens this sector, aligning with DBT-BIRAC's bio-economy and alternative protein policies. Additionally, the emergence of smart protein startups and MSMEs in sustainable food production can foster economic development. Millet-GLP processing hubs can produce RTC and RTE foods, while public-private partnerships (PPPs) can create affordable fortified food solutions. Export-oriented smart protein businesses can capitalize on the growing global demand for high-protein, plant-based foods, supported by government schemes like Startup India, PM Formalization of Micro Food Enterprises (PMFME), and Millet Entrepreneurship Grants.

From an agricultural and sustainability perspective, GLP production through hydroponics and agricultural waste utilization presents a viable, low-input, high-protein farming approach. Cultivating protein-rich plants like duckweed, amaranth, and moringa through hydroponics, as well as extracting GLPs from agricultural waste such as leaf biomass and legume foliage, can significantly reduce land and water use compared to traditional protein sources. These

innovations align with national policies under the National Mission on Sustainable Agriculture (NMSA) and Climate-Resilient Agriculture (ICAR). Furthermore, strengthening farmer incomes through millet and GLP cultivation offers rural livelihood opportunities, enabling contract farming models and value-added supply chains that connect farmers with food-processing units. These efforts are aligned with Atmanirbhar Bharat, PM-KISAN, and government-led millet promotion initiatives. GLP-millet integration also has significant potential in government food programs, including the Mid-Day Meal (MDM) and Integrated Child Development Services (ICDS). By incorporating protein-fortified millet-GLP mixes into school meals and anganwadi centers, this initiative can help tackle protein deficiency among children, improving cognitive function and growth outcomes in alignment with the PM POSHAN scheme. Additionally, incorporating GLP-enriched millet RTC foods into the Public Distribution System (PDS) can enhance the nutritional quality of ration supplies, providing affordable protein sources for low-income groups while supporting food security initiatives under the Food Security Act and PDS fortification policies.

Beyond domestic applications, India has the opportunity to establish itself as a leader in the global plant-based protein market. With rising demand for millet-based, high-protein, gluten-free foods in North America and Europe, as well as growing trends in vegan and plant-based nutrition, India's smart protein sector can drive international exports. Government support through millet and smart protein export promotion initiatives, as well as collaboration with APEDA (Agricultural and Processed Food Products Export Development Authority), can facilitate this expansion. Despite these promising opportunities, several technological gaps need to be addressed to fully harness the potential of GLP-millet integration. Current GLP extraction methods, including juice pressing, coagulation, and filtration, suffer from low yields and high energy costs, necessitating the development of scalable and cost-effective extraction technologies suitable for diverse plant sources like duckweed, amaranth, moringa, and alfalfa. Additionally, there is a lack of scientific data on the amino acid bioavailability, digestibility, and protein quality of GLP-millet blends, highlighting the need for nutritional optimization and fortification strategies to improve protein digestibility and sensory appeal. Furthermore, there are limited RTC and RTE food formulations incorporating GLPs with desirable taste, texture, and shelf stability. Advancements in processing techniques such as extrusion, encapsulation, and fermentation can help retain the nutritional integrity of these products. Moreover, market-ready prototypes require pilot-scale validation, commercialization strategies, consumer acceptance studies, cost-benefit analysis, and regulatory approvals to ensure their success.

To bridge these gaps, several strategies can be implemented. First, developing an advanced hydroponic-based GLP extraction system with optimized low-cost enzymatic or membrane-based techniques can improve yield and purity. Second, conducting amino acid profiling, bioavailability studies, and in-vitro digestibility tests will aid in optimizing the nutritional synergy of GLP-millet blends, while incorporating natural binders, hydrocolloids, and fermentation techniques can enhance sensory appeal. Third, novel RTC and RTE prototypes can be formulated using extrusion technology for protein-rich snacks, spray-drying and encapsulation for instant protein powders, and fermentation-based enhancements for gut health benefits. Lastly, scaling up production through pilot-scale validation, regulatory approvals (FSSAI, BIRAC, NABL-certified testing), and consumer acceptance studies will pave the way for commercialization.

The expected outcomes of these efforts include the development of innovative, nutrient-dense GLP-millet RTC and RTE foods that are market-ready, high-protein, gluten-free, and climate-smart. These products will feature enhanced protein digestibility and sensory appeal for broader consumer acceptance. Additionally, optimized and scalable GLP extraction technologies will lead to cost-effective, high-yield processing systems with applications in the functional food, nutraceutical, and feed industries. Market readiness and commercialization pathways will be strengthened through pilot-scale production, startup incubation, and licensing, with potential integration into public nutrition programs such as PDS, MDM, and POSHAN Abhiyaan. Moreover, the initiative will contribute to economic and environmental sustainability by establishing a low-resource, high-impact food production system aligned with the Sustainable Development Goals (SDGs), while also increasing farmer incomes through millet-GLP-based value chains. By leveraging scientific innovation, government support, and entrepreneurial initiatives, this research can provide affordable, nutritious, and scalable solutions to address India's food security and economic growth challenges.

Present TRL & Expected TRL at Project Completion

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Technology Readiness Level (TRL)	Current Status	Expected Outcome
TRL 3: Proof of Concept	- Preliminary research on GLP extraction. - Basic millet-GLP formulations in lab conditions.	- Optimized scalable GLP extraction process. - Functional characterization of GLP-millet blends.
TRL 4: Validation in Lab Conditions	- Limited RTC & RTE formulations. - Initial bioavailability and digestibility assessments.	- Prototype development of millet-GLP foods. - In-vitro and pilot-scale validation studies.
TRL 5: Validation in Relevant Environment	- No pilot-scale testing or large-scale validation.	- Pilot-scale production & sensory validation of RTC/RTE foods. - Bioavailability and digestibility studies completed. - Readiness for scale-up and regulatory compliance studies.

At the end of the study, the TRL is expected to advance from TRL 3 to TRL 5, achieving pilot-scale validation of millet-GLP food products and setting the stage for further scale-up, commercialization, and regulatory approvals.

6. Objectives:

Identification and Procurement – Identify, source, and evaluate potential green leaves, millets, and pseudo-cereals with high nutritional value, prioritizing locally available and sustainable options.
Green Protein Isolation and Characterization – Standardize an eco-friendly extraction process for GLPs, followed by a detailed characterization of their protein composition, functional properties, and digestibility.
Development of Nutritious Food Formulations – Optimize recipes and processing techniques for RTC and RTE products such as papad, rusks, soupsticks, and protein-blend powder to enhance protein bioavailability and consumer acceptance.
Comprehensive Quality Assessment – Conduct proximate analysis, sensory evaluation, and microbiological studies to ensure the nutritional adequacy, safety, and acceptability of the developed products.
Prototype Testing and Market Feasibility Study - The project will conduct prototype testing to evaluate the nutritional quality, taste, texture, and shelf life of GLP-based RTC & RTE foods. A market feasibility study will assess consumer acceptance, pricing, and commercialization potential, ensuring scalability and integration into nutrition programs.

7. Detailed Work Plan from TRL 1 to TRL 5

Detailed Work Plan from TRL 1 to TRL 5
The study follows a structured approach to advance the integration of Green Leaf Protein (GLP) with millets, progressing from basic research (TRL 1) to pilot-scale validation (TRL 5). This phased approach ensures the development of scientifically validated, nutritionally optimized, and market-ready RTC (Ready-to-Cook) and RTE (Ready-to-Eat) food products.

In Phase 1 (TRL 1: Basic Research & Concept Development, Months 1-3), the focus is on establishing a fundamental understanding of GLP extraction, composition, and compatibility with millets. This involves an extensive literature review to compile a database of GLP sources such as duckweed, moringa, amaranth, and alfalfa, alongside an assessment of their protein content, amino acid profile, and anti-nutritional factors. Initial extraction studies using juice pressing, coagulation, and filtration methods will be conducted to evaluate protein yield, purity, and efficiency. The extracted GLP will undergo proximate analysis to determine its nutritional composition and functional properties such as solubility, water-holding capacity, and emulsification, ensuring its compatibility with millet-based formulations. The key deliverables from this phase include a comprehensive GLP-millet database, preliminary extraction protocols, and an initial nutritional and functional analysis report.

In Phase 2 (TRL 2: Experimental Proof of Concept, Months 3-9), the study advances towards demonstrating the feasibility of GLP extraction, processing, and millet integration under controlled conditions. Extraction protocols will be optimized by comparing mechanical,

enzymatic, and membrane-based methods to maximize protein yield while minimizing anti-nutritional factors such as phytates, tannins, and oxalates. Small-scale formulations of GLP-millet blends will be developed with varying GLP concentrations (5-30%), followed by an evaluation of protein solubility, mixability, and shelf stability. The expected outcomes from this phase include an optimized GLP extraction protocol, prototype GLP-millet formulations, and a report on bioavailability and functional characteristics.

Phase 3 (TRL 3: Prototype Development & Initial Validation, Months 6-12) focuses on developing functional RTC and RTE products while validating processing techniques at the laboratory scale. This includes the formulation of GLP-millet-based RTC porridges, RTE snacks, and protein powders, with optimization through extrusion, spray-drying, and fermentation techniques. Shelf stability, texture retention, and sensory attributes will be evaluated through small-scale consumer panels, incorporating feedback to refine formulations. Further validation of protein bioavailability studies will compare these products with existing plant proteins such as soy and pea. By the end of this phase, the study will deliver functional RTC and RTE prototypes, a sensory evaluation report, and nutritional validation data.

In Phase 4 (TRL 4: Process Scale-Up & Pilot-Scale Testing, Months 13-18), the study moves towards pilot-scale production to ensure reproducibility and regulatory compliance. Optimized GLP extraction and blending techniques will be scaled up, establishing batch processing parameters for RTC and RTE products. Comprehensive safety and quality compliance studies, including microbial analysis, heavy metal screening, and anti-nutrient profiling, will be conducted to meet FSSAI and WHO food safety standards. Consumer trials will be expanded across urban and rural markets, assessing pricing feasibility and business models for commercialization. The deliverables include pilot-scale production of RTC and RTE foods, a regulatory compliance report, and a market readiness assessment.

Finally, in Phase 5 (TRL 5: Pilot-Scale Validation in Relevant Environment, Months 18-24), RTC and RTE products will be validated in real-world settings such as mid-day meal programs, Public Distribution System (PDS), and retail markets. The scalability of production and distribution will be evaluated, ensuring cost-effectiveness and optimizing formulations based on consumer acceptance and pricing strategies. A commercialization roadmap will be finalized, identifying potential industry partners, startups, and farmer producer organizations (FPOs) for B2B and B2C market expansion. The study will also explore funding and licensing approvals to facilitate large-scale commercialization. The key deliverables from this phase include pilot-scale validation of RTC and RTE products in real-world conditions, a scalable production model, and a commercialization roadmap.

Upon completion of the project, the TRL will advance from TRL 1 to TRL 5, leading to validated, market-ready smart protein foods that can be further scaled to TRL 6-7 through industry collaborations and government programs. The study will result in an optimized and cost-

effective GLP extraction technology, regulatory-approved formulations, and a sustainable business model that aligns with India's food security and nutrition policies.

8. Expected Outcomes:

The project will lead to the development of affordable and sustainable Ready-to-Cook (RTC) and Ready-to-Eat (RTE) food products that incorporate Green Leaf Proteins (GLPs) with millets and pseudo-cereals. These formulations will be designed to enhance protein bioavailability, ensuring improved nutrition for vulnerable populations such as children, pregnant women, and individuals suffering from protein-energy malnutrition. A scalable and optimized process for Smart Green Protein Blends will be established, integrating efficient GLP extraction with millet-based formulations. The developed process will ensure high protein recovery, improved functional properties, and cost-effective scalability, making it suitable for commercial food production and public nutrition programs. The project will also focus on validating the nutritional benefits and market potential of these food products. This will be achieved through nutritional analysis, bioavailability studies, and consumer acceptance trials, ensuring that the formulations meet regulatory standards, taste preferences, and affordability criteria for large-scale adoption.

9. Impact & Significance:

The integration of Green Leaf Proteins (GLPs) with millets and pseudo-cereals supports India's National Nutrition Mission (POSHAN Abhiyaan) and aligns with the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 12 (Sustainable Consumption and Production). By offering a nutrient-dense, plant-based protein source, this initiative addresses widespread protein-energy malnutrition while promoting dietary diversity. Additionally, GLPs provide a sustainable alternative to conventional protein sources, requiring significantly lower land, water, and energy inputs compared to animal-derived proteins, making them an environmentally responsible solution to food security challenges. The project also fosters the development of innovative, functional food products that can be integrated into public nutrition programs, mid-day meals, and commercial food sectors, ensuring broad accessibility and impact. By leveraging scientific advancements in protein extraction, formulation, and functional food development, this initiative has the potential to transform nutrition, enhance food security, and create sustainable economic opportunities in the plant-based protein sector.

10. Timeline:

Phase 1: Raw Material Selection and Procurement (Months 1-3)

Phase 2: Process Standardization for GLP Extraction (Months 4-6)

Phase 3: Development of RTC and RTE Formulations (Months 7-12)

Phase 4: Quality Assessment and Validation (Months 13-18)

Phase 5: Prototype Testing and Market Feasibility Study (Months 19-24)

11. Conclusion: This project aims to establish Smart Green Protein Blends as a viable solution for sustainable nutrition. By utilizing GLPs and nutrient-dense pseudo-cereals and millets, the proposed RTC and RTE food products will contribute significantly to addressing malnutrition while promoting eco-friendly food innovations.

12. Roles and Responsibilities of PI & CO-PI:

As the Principal Investigator (PI), Dr. Smita Dimri will provide scientific and technical leadership, ensuring the project's successful execution from TRL 1 to TRL 5. She will oversee identification, procurement, and selection of nutrient-rich green leaf proteins (GLPs), millets, and pseudo-cereals, leveraging her expertise in nutritional wellness, therapeutic food processing, freeze-drying, and packaging. Her role includes guiding the standardization of protein extraction processes, optimizing food formulations, and ensuring quality control and safety assessments. She will also facilitate regulatory compliance with FSSAI and DBT-BIRAC standards, overseeing intellectual property (IP) management, patent filing, and technology transfer for large-scale commercialization.

Dr. Dimri will coordinate interdisciplinary collaborations between food scientists, biotechnologists, and industry partners, leveraging her experience with NCL Pune, CAZRI Jodhpur, Flex Foods Ltd., and Parag Dugdh Utpadak Sahakari Sangh. She will lead prototype testing, consumer trials, and sensory evaluations to refine product acceptability, ensuring market integration through feasibility studies and government nutrition programs (PDS & MDM). Additionally, she will manage funding, resource allocation, and stakeholder reporting, ensuring cost-effective project execution while disseminating research findings through scientific publications and industry outreach. Her extensive experience in food technology, industry collaborations, and regulatory oversight will be instrumental in bringing innovative, protein-rich RTC & RTE foods to market.

Dr. Aarti will contribute her expertise in tissue culture and controlled environment agriculture to support the selection, propagation, and optimization of high-yield green leafy plants suitable for nutrient-rich protein extraction. She will oversee the standardization of cultivation protocols, ensuring optimal growth conditions, nutrient composition, and biomass productivity for selected plant species. Additionally, she will assist in developing sustainable and scalable plant production techniques, integrating hydroponic advancements for future expansion of the project. Her role will also include collaborating on quality assessment, monitoring plant health, and supporting technology validation to enhance the efficiency and sustainability of the raw material supply chain for GLP-based RTC & RTE food formulations.

Dr. Sanjay Gupta will serve as an expert advisor on process engineering, contributing to the optimization of protein extraction, bioavailability enhancement, and food formulation techniques. He will guide the development of eco-friendly, scalable processes to improve nutritional quality, digestibility, and functional properties of Green Leaf Proteins (GLPs) and millet-based RTC & RTE foods. Using his expertise, he will assist in process standardization, pilot-scale validation, and technology transfer, ensuring efficiency and sustainability. Additionally, he will support quality assessment, regulatory compliance, and industry collaborations, helping to integrate bioprocess innovations into the project's food production strategies.

Dr. Nikku will lead the clinical evaluation (in later phase) of Green Leaf Protein (GLP)-based RTC & RTE foods, ensuring their safety, bioavailability, and efficacy in improving nutritional status. She will design and oversee clinical trials, including participant selection, protocol development, ethical approvals, and data collection, to assess the impact of these food formulations on protein intake, digestion, and overall health. Additionally, she will analyze biomarkers, metabolic responses, and consumer acceptability, ensuring compliance with clinical and regulatory standards. Her expertise will be crucial in generating scientific evidence for product validation, supporting regulatory approvals, and facilitating policy integration into public health nutrition programs.

Dr. Bindu Dey, with her rich and noteworthy experience down the line, will serve as the overall project coordinator, leveraging her extensive experience in R&D, technology development, IP management, and commercialization to ensure the smooth execution of the project. She will provide strategic oversight, facilitate industry-academia collaborations, and support investment and funding opportunities to scale the developed technologies. With her background in biotechnology and clinical trials, she will guide regulatory compliance and translational research, ensuring that the Green Leaf Protein (GLP)-based RTC & RTE foods meet industry standards and have commercialization potential. Her leadership will be instrumental in aligning the project with national initiatives like Atmanirbhar Bharat and Make-in-India, fostering innovation-driven solutions for nutritional security. Additionally, she will contribute to establishing partnerships with national and international organizations, ensuring that the project benefits from cutting-edge advancements in food sciences, biotechnology, and public health.