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Formulation and evaluation of novel herbal antidiabetic nutraceutical powder dosage using edible plant components of Tripura, India

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Abstract

Background Nutritional deficiency diseases are common in India and other developing countries. Recently, herbal nutraceutical products have diminished diseases related to nutrition and improper diet. The current study aimed to develop a powdered herbal nutraceutical using certain native edible plant parts from Tripura, India, and to assess its antidiabetic activity.

Methods Plant parts were selected based on the ethnomedicinal information of healers. Nutraceutical powder was prepared by a simple mixing method using a double cone blender. Bulk density, tapped density, Hausner quotient, Carr's compressibility index, flow rate, and angle of repose were determined to evaluate the nutraceutical powder. The proximate composition was determined by The Association of Official Analytical Collaboration (AOAC) methods. Essential minerals were determined using an atomic absorption spectrophotometer (AAS). Vitamins (vit-C, vit-B9, vit-A, and vit-E) were determined using HPLC. The anti-diabetic activity of the nutraceutical powder was evaluated by the Oral Glucose Tolerant (OGTT) test.

Results All selected plants provided significant ethnomedicinal information. All physical parameters of the nutraceutical powder significantly matched the standard values. The formulated nutraceutical powder had a good caloric value (369 kcal), and a good amount of minerals and vitamins were found. Formulated nutraceutical powder shows significant antidiabetic activity.

Conclusion Based on the results, it was concluded that formulated nutraceutical powder may minimize various malnutritional diseases and control the blood glucose label.

Keywords Nutraceutical powder · Edible plant · Proximate composition · Essential minerals · Vitamins · Antidiabetic activity

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1 Introduction

Dietary supplements, called nutraceuticals, reduce diseases associated with unhealthy eating habits. The terms "nutrition" and "pharmaceutical" combine to form the phrase 'nutraceutical' [1]. Any medication developed using food components has essential nutrient benefits and reduces the risk of numerous long-lasting illnesses [2]. Plant-based ingredients with multipurpose qualities are trendy worldwide in the dietary supplements and nutritional sectors. These popularities include bolstering immunity, maintaining excellent physical condition, and protecting against short- and long-term disorders. Similarly, there is an increasing market for foodstuffs and medications traditionally used by tribal people [3].

Numerous Indian inhabitants tend to suffer from ailments that are linked to their dietary requirements. There are regions in India with far worse dietary and nutritional conditions [4]. Nobel laureate in Economics Angus Deaton claims that India's national eating habits are primarily composed of carbohydrates with little polypeptide and fat, contributing to inadequate nutrition in the country. According to World Bank data, India has one of the highest rates of malnourished children in the world [5]. Eleven percent of diseases worldwide are caused by malnutrition. Malnutrition is the root cause of many vitamin deficiency illnesses, including anemia, pellagra, scurvy, marasmus, and night blindness. In light of this, drug manufacturers are creating a variety of polyherbal nutraceutical formulations (powders, tablets, and capsules) that contribute to lowering the global rate of lack of nutrition [6]. Certain Asian nations, including China, Japan, India, South Korea, Thailand, Singapore, and Taiwan, have enormous potential for nutraceutical companies. These Asian nations are anticipated to take the forefront in manufacturing plant nutraceuticals owing to their abundant raw materials, highly qualified labor, and first-rate research and development centers [7]. One of the most affordable solid dose forms is powder, which is the most adaptable and accessible form to prescribe, mix, and give. The use of powdered plant nutraceuticals has increased in developing and developed countries [8].

Diabetes, sometimes referred to as diabetes mellitus (DM), is a chronic metabolic condition that develops when the body is unable to adequately utilize or create enough insulin [9]. Diabetes is one of the top 10 causes of death and disability worldwide. Globally, 529 million people (6.1% of the population) have diabetes as of 2021 [10]. According to projections, 77 million people in India had diabetes in 2019, and this number is predicted to reach over 134 million [11]. Many medicinal plants have been explored by natural product scientists for the treatment of diabetes mellitus. Diabetes can also be treated with a variety of herbal medications, including diasulin, pancreatic tonic 180 cp, dia-care, and epinsulin. Two crucial nutraceutical powder formulations used to treat diabetes mellitus are bitter gourd and gurmar powders [12]. Recently, in Western countries, the use of herbal medicines for the treatment of chronic diseases such as diabetes, heart disease, arthritis, and depression has increased [13].

A tiny highland province called Tripura is located in northeastern India's southernmost region. It is located at latitudes of 22° 56′–24° 32′ and longitudes of 91° 10′–92° 21′ [14]. The state receives annual rainfall of 2400–2500 mm, relative humidity of 70–85%, and temperatures between 10 and 35 °C. It experiences humid–mild tropical weather [15]. In Tripura, 379 tree species, 320 bush, 581 herbs, 165 creepers, 16 creeper shrubs, 35 dense bushes, and 45 aerophytes have already been documented [16]. Nineteen tribes, including the Jamatia, Chakma, Halam, Kuki, Chaimal, Uchoi, Magh, Garo, Lushai, Bhutia, Lepcha, Bhil, Munda, Oraon, Mog, Santhal, Murasing, Reang, and Tripuri, belong to the province of Tripura. Their food habits are different from those of the general community. They consumed various plant-related foods to maintain their diet. Surprisingly, the tribal communities of Tripura are much healthier than the general community [17]. The current study aimed to develop a powdered herbal nutraceutical using certain native edible plant parts from Tripura, India, and to assess its antidiabetic activity.

2 Methodology

2.1 Collection of plant materials and gathered the ethnomedicinal information

Plant samples were collected following the Plant Conservation Roundtable Conservation Guidelines. Fresh leaves of *Moringa oleifera* Lam were collected in June 2022 and seeds of *Lablab purpureus* (L.) Sweet were collected in September 2022 from Killa, Udaipur, Gomati district of Tripura. The fruits of *Musa paradisiaca* L. and frond of *Diplazium esculentum* (Retz.) Sw. were collected in July 2022 from Golaghati, Bishalgarh, Sepahijala district of Tripura. The collected

plant species were identified by a plant taxonomist, Prof. B. K. Datta, Department of Botany, Tripura Central University, Suryamaninagar, Agartala, India. After confirming the plant species, we have gathered ethnomedicinal information.

The Institutional Human Ethical Committee of Tripura University granted ethical approval and permission. Ethnomedicinal information about four edible plant parts (*Moringa oleifera* Lam (leaf), *Lablab purpureus* (L.) Sweet (seed), *Musa paradisiaca* L. (fruit), *Diplazium esculentum* (Retz.) Sw. (frond) was collected from face-to-face verbal discussions with the common healers of three ethnic communities (Debbarma, Koloi, and Garo) of Tripura. The common healers were well informed and given a proper explanation about the study procedure, and informed consent was collected from them. All the interacting persons of the three ethnic communities are adults at least 40 years old [18].

2.2 Processing of the plant's materials

After proof of identity, the plant parts were cleaned carefully with purified water and air-dried. The dried samples were then crushed again to obtain a fine powder. The powder material was packed in a closed vessel and well-preserved at room temperature for future research [18].

2.3 Experimental animals

Adult Swiss-albino mice (18–25 g) both sexes were used for acute toxicity test. Male ob/ob mice (type II diabetes mice) (weighing 50–55 g, age 12-week) were used for the anti-diabetic activity test. The animals were obtained from the animal house of Tripura University (A Central University). The Temperature (20 °C) and humidity (53%) of the animal house were controlled and maintained under a 12 h/12 h light/dark cycle. Food and water were available during the fasting period. National Institutes of Health regulations were followed for the care and handling of the animals. The Institutional Ethics Committee (No. 1667/GO/a/12/CPCSEA) approved the study protocol [19].

2.4 Formulation of nutraceutical powder doses

A new herbal anti-diabetic nutraceutical powder was prepared by mixing the powdered samples from different plants. A specified amount (Table 1) of previously processed plant materials (leaves of *Moringa oleifera* Lam, seed of *Lablab purpureus* (L.) Sweet, fruit of *Musa paradisiaca* L., frond of *Diplazium esculentum* (Retz.) Sw.) were placed in a double-cone blender (AISI 316) to properly mix the whole sample. The mixed powder samples were collected and kept in a closed container with proper labeling [20].

2.5 Evaluation of formulated powder

The powder was evaluated using the method of Chime et al. [22] with some modifications. The bulk density, tapped density, Hausner quotient, Carr's compressibility index, flow rate, and angle of repose of the powder were determined to evaluate the nutraceutical powder.

2.6 Acute toxicity test

Acute toxicity tests of the formulated nutraceutical powder samples were performed using the Lorke [23] method with some modifications. Swiss-albino mice of both sexes (18–25 g) were divided into different groups (one control group and six test groups). Each group contained ten animals. The control group received only distilled water, whereas the six different treated groups received different doses (10, 50, 300, 800, and 1200, 2000 mg/kg body weight) of the powder sample orally. Mice were then kept under observation for up to 72 h for any mortality and symptoms of toxicity [23].

Table 1 Formulation chart of the herbal nutraceutical powder

Herbal ingredients	Quantity taken for 100 g	Reference
Moringa oleifera Lam leaf powder	30 g	[21]
Lablab purpureus (L.) Sweet seed powder	40 g	
Diplazium esculentum (Retz.) Sw. frond powder	20 g	
Musa paradisiaca L. unripe fruit powder	10 g	

2.7 Estimation of proximate composition

Total moisture, total carbohydrate, complete protein, total fat, total ash, and total caloric value of the nutraceutical powder were determined by the method of Goswami and Manna [24] with some modifications. The total dietary fiber of the nutraceutical powder was determined using the method of Ozolića et al. [25] with some changes.

2.8 Determination of minerals

Manna et al.'s [26] method, with some modifications, was used to determine the mineral content of the formulated powder. Mineral concentrations were determined by atomic absorption spectrophotometry (AAS).

2.9 Determination of vitamins

Two water-soluble vitamins, vit-C and folic acid, were determined by the Debnath and Manna [27] method with some modifications using the RP-HPLC system.

Instrumental condition

Column: C18 BDS column (10 cm × 4.6 mm; 3 µm)
Mobile phase: A = Hexane-1-sulfonic acid sodium (5.84 mM): acetonitrile (95:5) with 0.1% triethylamine as solvent (A) at pH 2.5; B = 5.84 mM of hexane-1-sulfonic acid sodium: acetonitrile (50:50) with 0.1% triethylamine as solvent (B) at pH 2.5, pH = 3.54.
Flow rate: 1.6 ml/min.
Injected volume: 20 µl
Absorbance recorded: vitamin C = 246 nm, folic acid = 282 nm.

Two fat-soluble vitamins, vit-A and vit-E, were determined by the Debnath and Manna [27] method using an RP-HPLC system with some modifications.

Instrumental condition

Column: dC18 column (particle diameter 5 µm, 150 × 4.6 mm i.d.)
Mobile phase: methanol:water = 98:2.
Flow rate: 1.00 ml/min
Injected volume: 10 µl
Absorbance recorded: vitamin E = 230 nm, vitamin A = 265 nm.

2.10 Anti-diabetic activity

2.10.1 Experimental design

The animals were randomly divided into three groups for testing. Each group contained six animals. Group I: vehicle control group treated with 0.5% sodium carboxymethyl cellulose, Group II: positive control group treated with 200 mg/kg metformin via gavage, and Group III: test group treated with 200 mg/kg herbal nutraceutical powder via gavage. The experiment was continued for 4 weeks. At the end of the investigation, all animals were fasted overnight, and blood samples were collected from the tail vein. Before blood collection, the animals were administered pentobarbital (i.v.) as an anesthetic agent [28].

2.10.2 Oral glucose tolerance test (OGTT)

After 4 weeks of treatment with the formulated nutraceutical powder, the animals were fasted overnight, and glucose solution (2 g/kg of body weight) was administered orally. Blood samples were collected at time intervals of 0, 30, 60, 90, and 120 min. Blood glucose was measured using a glucose meter (i-QARE DS-W®) [28].

3 Statistical analysis

For analysis of the physical evaluation test, proximate compositions, minerals, and vitamin data of the formulated nutraceutical powder were expressed as mean ± SDs. For the evaluation of antidiabetic activity in ob/ob mice, data are expressed as mean ± S.E.M. All statistical analyses were performed using SPSS 17.0 software.

4 Result

4.1 Ethnomedicinal information of plant

The ethnomedical information of the plant samples is presented in Table 2.

4.2 Evaluation of nutraceutical powder

The evaluated parameters of the nutraceutical powder are presented in Table 3. All the parameter values showed satisfactorily.

4.3 Acute toxicity study

The results indicated that at the highest dose of 2000 mg/kg body weight, the formulated nutraceutical powder did not show any changes in behavior, and no death was observed. This resolved that no lethal or toxic effect up to 2000 mg/kg b.wt. dose of the formulated nutraceutical powder.

4.4 Determination of proximate composition

The total estimated quantity of the proximate composition of herbal nutraceutical powder is represented in Table 4.

4.5 Minerals determination

The determined mineral values are presented in Table 5.

4.6 Determination of vitamins

The estimated values of water-soluble vitamins (vitamin C and folic acid) and fat-soluble vitamins (vitamin A and vitamin E) in the herbal nutraceutical powder are presented in Table 6.

Table 2 Ethnomedicinal use report of selected edible medicinal plant parts

Botanical name and family	Local name	Plants parts	Ethnomedicinal report
Moringa oleifera Lam (Moringaceae)	Sajana	Leaf	Anti-edema effect, anti-rheumatic effect, hepatoprotective activity, anti-diabetic activity
Lablab purpureus (L.) Sweet (Fabaceae)	Sime	Seed	Anti-microbial activity, anti-fungal activity, anti-inflammatory activity
Musa paradisiaca L. (Musaceae)	Kola	Unripe fruit	Anti-ulcer activity, anti-diabetic activity, anti-anemic activity
Diplazium esculentum (Retz.) Sw. (Athyriaceae)	Dekhi sak	Frond	anti-diabetic activity, hepatoprotective activity, anti-microbial activity

Table 3 Evaluated physical parameters of prepared nutraceutical powder

Physical parameters	Nutraceutical powder
Bulk density (g/mL)	0.44 ± 0.03*
Tapped density (g/mL)	0.45 ± 0.03*
Hausner quotient	1.1 ± 0.01*
Carr's compressibility (%)	8.08 ± 0.88*
Angle of repose (°)	32.63 ± 1.53*
Flow rate (g/s)	6.03 ± 0.56*

*Values represent mean ± SDs for three samples

Table 4 Proximate composition of herbal nutraceutical powder

Proximate compositions	Total amount (%) (mean ± SDs)
Moisture	3.68 ± 0.40*
Carbohydrate	71.27 ± 1.09*
Protein	15.9 ± 0.62*
Total fat	2.29 ± 0.12*
Ash	6.08 ± 0.28*
Dietary fibre	4.18 ± 0.34*
Energy	369 kcal

*Values represent mean ± SDs for three samples

Table 5 Minerals profile of herbal nutraceutical powder

Minerals	Total amount (mg/100 g) (mean ± SDs)
Iron	0.96 ± 0.05*
Sodium	0.16 ± 0.05*
Potassium	49.73 ± 1.47*
Calcium	11.34 ± 0.90*
Manganese	3.87 ± 0.08*
Phosphorus	10.61 ± 0.48*

*Values represent mean ± SDs for three samples

Table 6 Quantitative profiles of water-soluble and fat-soluble vitamins

Name of the vitamins	Total amount (mean ± SDs)
Ascorbic acid (vitamin C) (mg/100 g)	3.22 ± 1.13*
Folic Acid (vitamin B_9) (mcg/100 g)	20.56 ± 0.66*
Retinol (vitamin A) (mcg/100 g)	30.19 ± 1.05*
Tocopherol (vitamin E) (ng/g)	1.84 ± 0.07*

*Values represent mean ± SDs for three samples

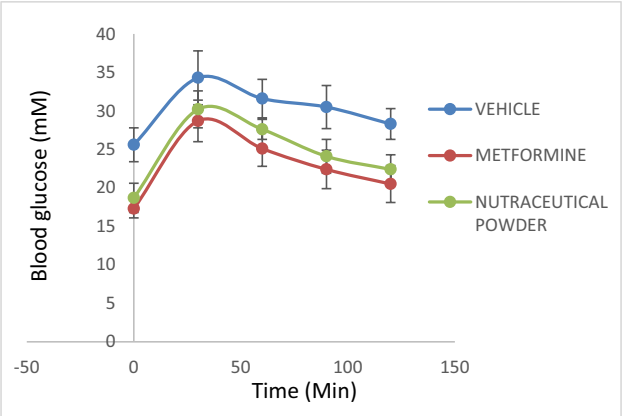

Fig. 1 Oral glucose tolerance test

4.7 Evaluation of antidiabetic activity

4.7.1 Oral glucose tolerance test (OGTT)

Blood glucose levels at different time intervals are shown in Fig. 1. From Fig. 1, it was observed that the test group (received nutraceutical powder) significantly reduced the blood glucose level compared to the control and standard groups.

5 Discussion

Ethnomedicine is an anthropological field that provides traditional health and disease-related knowledge of indigenous and ethnic communities worldwide. Ethnomedicine can also be defined as the use of plants by humans as medicines [29]. The conventional understanding of various ethnic groups has helped to build up ethnomedicinal studies [30]. In the present experiment, the ethnomedicinal report was collected from three different ethnic communities (Debbarma, Koloi, and Garo) of Tripura, India, and it was found that all the plant samples have significant ethnomedicinal importance.

Mixing is the best method for powder formulation. In ancient times, various Ayurvedic churnas were prepared using a mixing method [31]. The newly formulated nutraceutical powder was well mixed, and without lump formation. Bulk and tap densities are vital for solid dosage manufacturing and development. Bulk and tapped densities are also significant parameters for exploring the compressibility or Carr's index, Hausner ratio, and flowability of pharmaceutical powders. If the value of Carr's index is greater than 25, it means that the powder has poor flowability, and if the value is less than 15, it means that the powder has good flowability. The value of the Hausner ratio less than 1.25, indicates that the powder flow is good [32]. The angle of repose is significant for the proposal of dispensation, storage, and conveying systems for particulate materials [33]. The results (Table 3) showed that the newly formulated nutraceutical powder passed all flowability tests.

Acute toxicity tests have been used to determine the short-term adverse effects of a drug when administered as a single dose or multiple doses during short-term exposure [34]. Acute toxicity testing is required for any pharmaceutical dosage forms for initial investigation [35]. Our sample did not show any toxic effects at the highest dose level of 2000 mg/kg of body weight.

Determination of proximate composition is important because it provides an idea of the essential nutritional composition of any food product [36]. Under proximate analysis, three fundamental macronutrients (total carbohydrate, total fat, and total protein) were analyzed. The actual caloric values of any nutritional sample depend on the amount of these three macronutrients [37]. Interestingly, it was observed that our newly formulated nutraceutical powder contains a high caloric value (369 kcal). Total moisture, total ash, and total fiber are the other important parameters under proximate composition. The stability of any food supplement is directly correlated with moisture content [37]. The ash value predicts the amount of minerals within a food or food sample [38]. Fiber is essential for

Table 7 Responsible phytochemicals for antidiabetic activity of selected plant parts

Name of the plant	Used plant part	Responsible phytochemical for antidiabetic activity	References
Moringa oleifera Lam	Leaf	Chlorogenic acid, quercetin	[46]
Lablab purpureus (L.) Sweet	Seed	Trigonelline	[47]
Diplazium esculentum L.	Frond	Kaempferol and quercetin	[48]
Musa paradisiaca L.	Unripe fruit	Epicatechin, 3-*O*-rhmnosyl-glucoside, and quercetin	[49]

maintaining a healthy body in our regular diet. Recently, research has shown that high-fiber diets reduce the risk of multiple diseases, such as cardiovascular disease, type 2 diabetes, certain cancers, constipation, and diarrhea. They also maintain blood sugar and lipid levels [39]. Our sample contained a less amount of moisture contains (3.68 ± 0.40%), good amount of ash value (6.08 ± 0.28%), and dietary fiber (4.18 ± 0.34%). Essential minerals are vital components of food that help the body develop and function. They are necessary for building strong bones and teeth, controlling body fluids, and converting food into energy [40]. Our formulated nutraceutical powder contained high amounts of essential minerals (Table 5).

Ascorbic acid (AA) is a ubiquitous water-soluble vitamin present in citrus fruit. It converts cholesterol into bile acids. Vitamin C is an active source of antioxidants that promotes the development of the immune system. Vitamin C also helps control high blood pressure, collagen formation, iron absorption, and wound healing. The recommended daily amount of vitamin C for adults is 90 mg for men and 75 mg for women [41]. Folic acid is also known as vitamin B9. During pregnancy, folic acid helps to develop the neural tube. It also prevents significant birth problems in the baby's brain and spine. The production of red blood cells is another vital function of folic acid. As per the Centers for Disease Control and Prevention (CDC), the daily recommended folic acid level in an adult girl is 400 µg [42]. Vitamin A is important for healthy vision, boosting the immune system, and developing the reproductive system. Vitamin A also helps improve cardiac and lung function. Daily vitamin A requirement is 900 µg/day for men and 700 µg/day for women [43]. Vitamin E is one of the vital lipid-soluble vitamins. It has numerous biological activities, including antioxidant, anticancer, anti-arthritis, and anti-aging effects. The human body requires a small amount (15 mg/day for both men and women) of vitamin E [44]. Our formulated nutraceutical powder contains a good amount of vitamin C, vitamin A, folic acid, and vitamin E (Table 6).

Phytochemicals are natural compounds in herbal medicines that may help prevent and treat diabetes. They can act as antihyperglycemic agents and mimic insulin action [45]. Table 7 presents the names of the phytochemicals in the selected plant samples responsible for antidiabetic activity.

The oral glucose tolerance test (OGTT) determines how well the body can use and store glucose. It is one of the best tests for screening type 2 diabetes [50]. This experiment showed that the newly formulated nutraceutical powder responded well in the OGTT test compared to the standard and vehicle control groups (Fig. 1). If the blood sugar level measured in the test is above a certain level, this could be a sign that sugar is not sufficiently absorbed by the body's cells.

6 Limitations of the study

In this work, we did not perform a stability study of the formulated nutraceutical powder. In future studies, we will perform a stability study.

7 Conclusion

Based on these results, it was concluded that the formulated nutraceutical powder contained a high number of caloric values and macro-and micronutrients. This nutraceutical powder has significant anti-diabetic activity. This may minimize various malnourished diseases in children and pregnant women. In future research, a stability study of the product will be performed.

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Author contributions BD, KM and WSS designed the study. RB and AMAI performed the laboratory work and drafted the manuscript. SA literature search. LS critically edited and revised the manuscript. All authors approved the final version to be submitted manuscript.

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Data availability The data supporting the findings of this study are available upon request from the corresponding author.

Declarations

Ethics approval and consent to participate Animal ethical statements: this study was approved by the Institutional Ethical Committee (No. 1667/GO/a/12/CPCSEA) of Tripura University (A Central University), and all of the related facilities and experimental procedures were executed according to the Technical Standards for Testing & Assessment of Health Food (2003). Human ethical statement: the study protocol, which required human experimentation as per the Helsinki Declaration, was approved by the Institutional Human Ethical Committee of Tripura University (A Central University). Before the interviews began, the common healers provided written informed consent. To preserve their privacy, the healers' identities were kept confidential and were not included in this study.

Competing interests The authors declare no competing interests.

References

1. Aronson JK. Defining 'nutraceuticals': neither nutritious nor pharmaceutical. Br J Clin Pharmacol. 2017;83(1):8–19. https://doi.org/10.1111/bcp.12935.
2. Das L, Bhaumik E, Raychaudhuri U, Chakraborty R. Role of nutraceuticals in human health. J Food Sci Technol. 2012;49:173–83. https://doi.org/10.1007/s13197-011-0269-4.
3. Phan AD, Chaliha M, Hong HT, Tinggi U, Netzel ME, Sultanbawa Y. Nutritional value and antimicrobial activity of *Pittosporum angustifolium* (Gumby Gumby), an Australian indigenous plant. Foods. 2020;9(7):887. https://doi.org/10.3390/foods9070887.
4. Vilar-Compte M, Burrola-Méndez S, Lozano-Marrufo A, Ferré-Eguiluz I, Flores D, Gaitán-Rossi P, Teruel G, Pérez-Escamilla R. Urban poverty and nutrition challenges associated with accessibility to a healthy diet: a global systematic literature review. Int J Equity Health. 2021;20:1–9. https://doi.org/10.1186/s12939-020-01330-0.
5. Deaton A, Drèze J. Food and nutrition in India: facts and interpretations. Econ Polit Wkly. 2009;14:42–65. https://doi.org/10.2307/40278509.
6. Batool R, Butt MS, Sultan MT, Saeed F, Naz R. Protein–energy malnutrition: a risk factor for various ailments. Crit Rev Food Sci Nutr. 2015;55(2):242–53. https://doi.org/10.1080/10408398.2011.651543.
7. Jakovljevic M, Wu W, Merrick J, Cerda A, Varjacic M, Sugahara T. Asian innovation in pharmaceutical and medical device industry–beyond tomorrow. J Med Econ. 2021;24(sup1):42–50. https://doi.org/10.1080/13696998.2021.2013675.
8. Williamson EM, Liu X, Izzo AA. Trends in use, pharmacology, and clinical applications of emerging herbal nutraceuticals. Br J Pharmacol. 2020;177(6):1227–40. https://doi.org/10.1111/bph.14943.
9. Nair M. Diabetes mellitus, part 1: physiology and complications. Br J Nurs. 2007;16(3):184–8. https://doi.org/10.12968/bjon.2007.16.3.22974.
10. Bergman M, Manco M, Satman I, Chan J, Schmidt MI, Sesti G, Fiorentino TV, Abdul-Ghani M, Jagannathan R, Aravindakshan PK, Gabriel R. International diabetes federation position statement on the 1-hour post-load plasma glucose for the diagnosis of intermediate hyperglycaemia and type 2 diabetes. Diabetes Res Clin Pract. 2024;1(209): 111589. https://doi.org/10.1016/j.diabres.2024.111589.
11. Pradeepa R, Mohan V. Epidemiology of type 2 diabetes in India. Indian J Ophthalmol. 2021;69(11):2932–8. https://doi.org/10.4103/ijo.IJO_1627_21.
12. Modak M, Dixit P, Londhe J, Ghaskadbi S, Devasagayam TP. Indian herbs and herbal drugs used for the treatment of diabetes. J Clin Biochem Nutr. 2007;40(3):163–73.
13. Thomson GE. Further consideration of Asian medicinal plants in treating common chronic diseases in the West. J Med Plants Res. 2010;4(2):125–30. https://doi.org/10.5897/JMPR09.403.
14. Singh S, Das B, Das A, Majumder S, Devi HL, Godara RS, Sahoo AK, Sahoo MR. Indigenous plant protection practices of Tripura, India. J Ethnobiol Ethnomed. 2021;17(1):50. https://doi.org/10.1186/s13002-021-00476-7.
15. Shil S, Choudhury MD, Das S. Indigenous knowledge of medicinal plants used by the Reang tribe of Tripura state of India. J Ethnopharmacol. 2014;152(1):135–41. https://doi.org/10.1016/j.jep.2013.12.037.
16. Debbarma M, Pala NA, Kumar M, Bussmann RW. Traditional knowledge of medicinal plants in tribes of Tripura in northeast, India. Afr J Tradit Complement Altern Med. 2017;14(4):156–68. https://doi.org/10.21010/ajtcam.v14i4.19.
17. Alam A, Jha M, Faisal S. Traditional uses of medicinal and aromatic plants among the tribes of India. In: Medicinal and aromatic plants of India, vol. 1. Cham: Springer International Publishing; 2022. p. 107–74. https://doi.org/10.1007/978-3-030-98701-5_5.
18. Uddin MJ, Debnath B, Patari P, Nag SK, Sil SK, Manna K. Ethnomedicinal survey and determination of total alkaloids and phenolics in selected edible plants of Tripura, India. J Med Plants Stud. 2021;9(2):123–31. https://doi.org/10.22271/plants.2021.v9.i2b.1263.

19. Bikash D, Kuntal M. Formulating anti-diabetic nutraceutical tablets based on edible plants from Tripura, India. Foods Raw Mater. 2022;10(2):227–34. https://doi.org/10.21603/2308-4057-2022-2-532.
20. Byeon JC, Ahn JB, Jang WS, Lee SE, Choi JS, Park JS. Recent formulation approaches to oral delivery of herbal medicines. J Pharm Investig. 2019;15(49):17–26. https://doi.org/10.1007/s40005-018-0394-4.
21. National formulary of India, 6th edition. Indian Pharmacopoeia Commission, Government of India, Ministry of Health and Family Welfare; 2021.
22. Chime SA, Ugwuoke EC, Onyishi IV, Brown SA, Onunkwo GC. Formulation and evaluation of *Alstonia boonei* stem bark powder tablets. Indian J Pharm Sci. 2013;75(2):226. https://doi.org/10.4103/0250-474X.115493.
23. Lorke D. A new approach to practical acute toxicity testing. Arch Toxicol. 1983;54:275–87. https://doi.org/10.1007/BF01234480.
24. Goswami S, Manna K. Nutritional analysis and overall diet quality of fresh and processed (sun-dried and fermented) *Puntius sophore*. Curr Res Nutr Food Sci. 2019;7(2):360–8. https://doi.org/10.12944/CRNFSJ.7.2.06.
25. Ozoliņa V, Grāmatiņa I, Kunkulberga D. Methodology of dietary fibre determination in grain products. 2009. p. 115–9.
26. Manna K, Debnath B, Ikbal AM, Paul K, Rajkhowa A, Majumder R. Determination of phytochemicals, minerals, and evaluation of antioxidant, antidiabetic activities of young fronds of *Diplazium esculentum*: a vegetable of Tripura, India. J Sci Res. 2023;15(2):547–57. https://doi.org/10.3329/jsr.v15i2.62193.
27. Debnath B, Manna K. Ethnomedicinal information and high-performance liquid chromatography analysis of water soluble vitamins (C, B1, B3, B6, folic acid) and fat soluble vitamins (A, D3, E) of three consumable parts of *Musa paradisiaca*: cultivated in Tripura, India. Food Sci Eng. 2021;28:31–7. https://doi.org/10.37256/fse.212021580.
28. Zhang X, Jin Y, Wu Y, Zhang C, Jin D, Zheng Q, Li Y. Anti-hyperglycemic and anti-hyperlipidemia effects of the alkaloid-rich extract from barks of *Litsea glutinosa* in ob/ob mice. Sci Rep. 2018;8(1):12646. https://doi.org/10.1038/s41598-018-30823-w.
29. Staub PO, Geck MS, Weckerle CS, Casu L, Leonti M. Classifying diseases and remedies in ethnomedicine and ethnopharmacology. J Ethnopharmacol. 2015;4(174):514–9. https://doi.org/10.1016/j.jep.2015.08.051.
30. Taek MM, Banilodu L, Neonbasu G, Watu YV, Bambang Prajogo EW, Agil M. Ethnomedicine of Tetun ethnic people in West Timor Indonesia: philosophy and practice in the treatment of malaria. Integr Med Res. 2019;8(3):139–44. https://doi.org/10.1016/j.imr.2019.05.005.
31. Yatish MR, Mitti JG, Sharma VS. Review on churna kalpana. Int J Med Pharm Sci. 2021;11(2):127–36.
32. Akseli I, Hilden J, Katz JM, Kelly RC, Kramer TT, Mao C, Osei-Yeboah F, Strong JC. Reproducibility of the measurement of bulk/tapped density of pharmaceutical powders between pharmaceutical laboratories. J Pharm Sci. 2019;108(3):1081–4. https://doi.org/10.1016/j.xphs.2018.10.009.
33. Shah RB, Tawakkul MA, Khan MA. Comparative evaluation of flow for pharmaceutical powders and granules. AAPS PharmSciTech. 2008;9:250–8. https://doi.org/10.1208/s12249-008-9046-8.
34. Bhardwaj S, Gupta D. Study of acute, sub acute and chronic toxicity test. Int J Adv Res Pharm Bio Sci. 2012;1(3):103–30.
35. Strickland J, Clippinger AJ, Brown J, Allen D, Jacobs A, Matheson J, Lowit A, Reinke EN, Johnson MS, Quinn MJ Jr, Mattie D. Status of acute systemic toxicity testing requirements and data uses by US regulatory agencies. Regul Toxicol Pharmacol. 2018;1(94):183–96. https://doi.org/10.1016/j.yrtph.2018.01.022.
36. Igile GO, Iwara IA, Mgbeje BI, Uboh FE, Ebong PE. Phytochemical, proximate and nutrient composition of *Vernonia calvaona* Hook (Asterecea): a green-leafy vegetable in Nigeria. J Food Res. 2013;2(6):1. https://doi.org/10.5539/jfr.v2n6p1.
37. Ganogpichayagrai A, Suksaard C. Proximate composition, vitamin and mineral composition, antioxidant capacity, and anticancer activity of *Acanthopanax trifoliatus*. J Adv Pharm Technol Res. 2020;11(4):179–83. https://doi.org/10.4103/japtr.JAPTR_61_20.
38. Gul S, Safdar M. Proximate composition and mineral analysis of cinnamon. Pak J Nutr. 2009;8(9):1456–60. https://doi.org/10.3923/pjn.2009.1456.1460.
39. Lattimer JM, Haub MD. Effects of dietary fiber and its components on metabolic health. Nutr. 2010;2(12):1266–89. https://doi.org/10.3390/nu2121266.
40. Godswill AG, Somtochukwu IV, Ikechukwu AO, Kate EC. Health benefits of micronutrients (vitamins and minerals) and their associated deficiency diseases: a systematic review. Int J Food Sci. 2020;3(1):1–32. https://doi.org/10.47604/ijf.1024.
41. Taraj K, Hasa A, Muca A. Sources and benefits of vitamin C. Technium BioChemMed. 2021;2:23–31. https://doi.org/10.47577/biochemmed.v2i1.2936.
42. Shulpekova Y, Nechaev V, Kardasheva S, Sedova A, Kurbatova A, Bueverova E, Kopylov A, Malsagova K, Dlamini JC, Ivashkin V. The concept of folic acid in health and disease. Molecules. 2021;26(12):3731. https://doi.org/10.3390/molecules26123731.
43. Kumar M, Kumar D, Sharma A, Bhadauria S, Thakur A, Bhatia A. Micronutrients throughout the life cycle: needs and functions in health and disease. Curr Nutr Food Sci. 2024;20(1):62–84. https://doi.org/10.2174/1573401319666230420094603.
44. Rizvi S, Raza ST, Ahmed F, Ahmad A, Abbas S, Mahdi F. The role of vitamin E in human health and some diseases. Sultan Qaboos Univ Med J. 2014;14(2): e157.
45. Teoh SL, Das S. Phytochemicals and their effective role in the treatment of diabetes mellitus: a short review. Phytochem Rev. 2018;17:1111–28. https://doi.org/10.1007/s11101-018-9575-z.
46. Paikra BK, Gidwani B. Phytochemistry and pharmacology of *Moringa oleifera* Lam. J Pharmacopunct. 2017;20(3):194. https://doi.org/10.3831/KPI.2017.20.022.
47. Bhat SS, Shivamallu C, Prasad KS, Prasad SK. Biomedical importance of *Lablab purpureus*: a review. Med Plants Int J Phytomed Relat Ind. 2022;14(1):20–9. https://doi.org/10.5958/0975-6892.2022.00003.X.
48. Semwal P, Painuli S, Painuli KM, Antika G, Tumer TB, Thapliyal A, Setzer WN, Martorell M, Alshehri MM, Taheri Y, Daştan SD. *Diplazium esculentum* (Retz.) Sw.: ethnomedicinal, phytochemical, and pharmacological overview of the Himalayan ferns. Oxid Med Cell Longev. 2021. https://doi.org/10.1155/2021/1917890.
49. Sidhu JS, Zafar TA. Bioactive compounds in banana fruits and their health benefits. Food Qual Saf. 2018;2(4):183–8. https://doi.org/10.1093/fqsafe/fyy019.
50. Mshelia DS, Adamu S, Gali RM. Oral glucose tolerance test (ogtt): undeniably the first choice investigation of dysglycaemia, reproducibility can be improved. In: Type 2 diabetes-from pathophysiology to cyber systems. London: IntechOpen; 2021.