

Phytochemical and Therapeutic Potential of *Amaranthus hybridus* Linn: A Systematic Review

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ABSTRACT

Amaranthus hybridus Linn. (Family: Amaranthaceae), commonly referred as green amaranth, is a cosmopolitan annual herb indigenous to tropical and subtropical regions. Historically utilized as both a nutritional staple and a traditional therapeutic agent, *Amaranthus hybridus* possesses a dense profile of bioactive phytoconstituents. Key secondary metabolites include flavonoids (notably quercetin and rutin), phenolic acids (caffeic and ferulic acids), and the alkaloid amaranthine (a betacyanin). Furthermore, the species is a significant source of essential micronutrients, including iron, calcium, and vitamins A and C. Recent preclinical investigations have substantiated its antioxidant, anti-inflammatory, antidiabetic, and antimicrobial properties. Notably, preliminary clinical data in cohorts with Type 2 Diabetes Mellitus indicate significant reductions in glycated hemoglobin (HbA1c) and a favorable modulation of lipid profiles. Beyond its primary role in mitigating micronutrient deficiencies, *Amaranthus hybridus* demonstrates versatility in food science—specifically as a substrate for gluten-free flour—and shows promise in the development of nutraceuticals and cosmeceuticals. This review synthesizes current knowledge on its role in addressing malnutrition and chronic metabolic disorders, while underscoring the imperative for extract standardization and large-scale clinical validation.

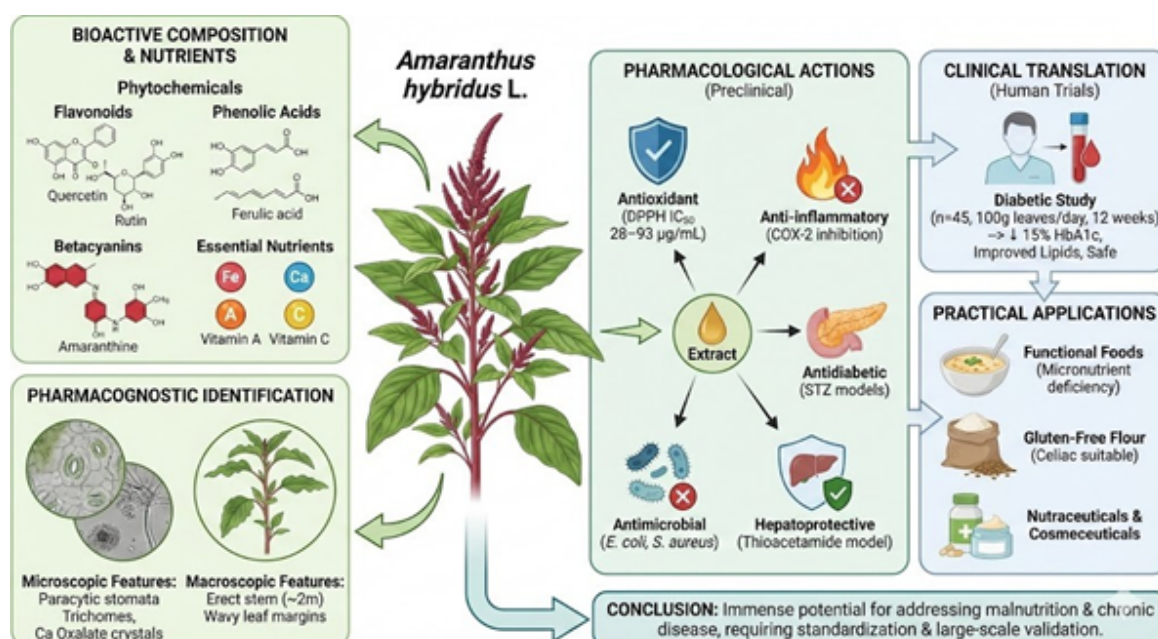
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Graphical Abstract



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INTRODUCTION

Amaranthus hybridus Linn., commonly recognized as green amaranth or smooth pigweed which belongs to family-Amaranthaceae, is a resilient annual herb characterized by its C4 photosynthetic pathway. This specialized carbon fixation mechanism facilitates high photosynthetic efficiency and rapid biomass accumulation, particularly in high-temperature and high-light environments [1, 2]. Although indigenous to Central America, the species has naturalized globally across tropical and subtropical regions of Africa, Asia, Europe, and the Americas. It exhibits significant ecological plasticity, thriving in nitrogen-rich alluvial or muddy soils and demonstrating high tolerance to drought, salinity, and extreme thermal stress [3]. Morphologically, the plant can reach a height of 2 meters, featuring succulent, often anthocyanin-pigmented stems and ovate leaves ranging from 5 to 15 cm in length. Due to its minimal cultivation requirements and high yield potential, it serves as a critical crop for food security in resource-constrained regions. Historically, *Amaranthus hybridus* held significant ritualistic and dietary importance in ancient Mesoamerican and Andean civilizations [4]. Currently, it remains a primary leafy vegetable in West Africa and the Indian subcontinent. In Nigerian ethnomedicine, the plant (locally termed *tete*) is decocted for its hematinic properties to treat iron-deficiency anemia and associated fatigue [5]. Similarly, Ayurvedic traditions utilize the species to manage gastrointestinal distress, such as diarrhea and abdominal discomfort, while in Cameroon, the seeds are integrated into traditional fertility rites [6]. Beyond its medicinal applications, the species is a vital nutritional reservoir during periods of seasonal food scarcity [7]. While fresh leaves consist of approximately 84% moisture, the dehydrated biomass is a concentrated source of macronutrients, containing 18% protein, 5% lipids, and providing a caloric value of 269 kcal/100g [8, 9]. These attributes make it an effective dietary intervention for pediatric malnutrition and recovery in convalescent adults. The therapeutic potential of *Amaranthus hybridus* is largely attributed to its bioactive secondary metabolites, which effectively neutralize reactive oxygen species (ROS) implicated in the pathogenesis of Type 2 diabetes, cardiovascular diseases, and cognitive impairment. Furthermore, the absence of gluten proteins renders the plant a safe nutritional alternative for individuals with celiac disease or gluten sensitivities [10]. The concentration of protective phenolic compounds is significantly influenced by edaphic factors and plant phenotypes; research indicates that cultivation in loamy soils may result in a 15–25% reduction in bioactive content compared to clay-heavy substrates [11]. Additionally, anthocyanin-rich (red) varieties typically possess higher antioxidant capacities than green varieties, and premature harvesting has been identified as a strategic intervention to optimize antioxidant retention. This comprehensive review synthesizes data from 68 peer-reviewed studies to provide a holistic evaluation of the

phytochemical, nutritional, morphological, and clinical profiles of *Amaranthus hybridus*, alongside its practical applications and future prospects.

1.1 Historical and Geographical Context

The history of the herb goes deeper; the seeds of the herb were first discovered in caves in Peru more than 7,000 years ago. It's never-fading red tops that the Aztecs referred to it as the immortal flower because it is mostly used during rituals until it was banned by Spaniards. Today it eliminates the wild or is cultivated in 80 countries, in Congo farms and in Indian yards [12]. It combats eye malady in dry Burkina Faso or rainy Nigerians owing to low levels of vitamin A, and Indians have made it into delicacies to reduce waste after the crop [13].

1.2 Ethnopharmacological Reports

The ethnopharmacological history of *Amaranthus hybridus* cuts across a variety of cultures, as it has been not only venerated as a source of food but also as a universal remedy. The traditional culture of Africa, especially the Yoruba and Igbo, in Nigeria, use the leaves to make a tea-like liquid called *tete*, which they boil to clean the blood, induce energy, and eliminate fatigue related to anemia. The plant is based on this practice as it is rich in iron, which helps in the production of hemoglobin and fight sideropenic dyspepsia. The herb is a diuretic used as a treatment in West African ethnobotany, such as Ghana and Senegal, to pee away extra water, to treat edema related to hypertension or postpartum recovery, and is commonly used together with other diuretics (such as *Hibiscus sabdariffa*) to increase its effect [14]. The use of ethnomedical records recorded in Cameroon show that it was used in fertility ceremonies, whereby the ground seeds are used to enhance reproductive health and control menstrual cycles due to its phytoestrogenic substances that resemble estrogen and stabilize hormonal changes. South-Asian *Amaranthus hybridus* is a so-called Rakta shodaka (blood purifier) and is used as a remedy to dysentery, diarrhea, and abdominal colic. Writings such as the Charaka Samhita explain how it was used as a topical paste in wound healing, as an internal paste to treat bleeding disorders, as it could help to stabilize bleeding by using its astringent tannins. It is fermented to a porridge in the Indian rural villages to treat respiratory disorders such as coughs and bronchitis, the mucilaginous polysaccharides induce a calming effect over inflamed airways and serves as an expectorant. The descendants of Aztec traditions in Central America, the indigenous people of the region, use it in the ceremonial teas to cause sweating and eliminate the fever, which modern Mayan herbalism still uses to clear the pathogens that are considered hot and replace the lost thermal equilibrium. In these traditions, the versatility of the plant also goes to the gynecological uses including alleviating menstrual cramps, and stimulating lactation in postpartum mothers by its galactagogue effects due to nutrient-enriched profiles [15]. These seed infusions are applied in

Ethiopian and Sudanese folk medicine to treat urinary tract infections in which antimicrobial saponins are exploited to prevent bacterial adhesion. These applications are usually transmitted orally as the healers are keen on sustainable harvesting to maintain the power of the plant. These applications are validated by modern ethnopharmacological surveys, which have shown synergies with modern pharmacology such as the anti-inflammatory properties of modern poultices resembling those of COX inhibition in traditional poultices in arthritis. A lack of documentation, however, reveals the necessity of community-based inventories in the protection of indigenous knowledge during urbanization. Altogether, the presented legacy reminds us that *Amaranthus hybridus* can be discussed as the medicine of the grandma today supported by scientific evidence and being the link between the traditional knowledge and the scientific confirmation [16].

2 PHYTOCHEMICAL AND NUTRITIONAL COMPOSITION

Amaranthus hybridus is a therapeutic plant with a synergistic profile based on phytochemicals and nutritional components that are distributed throughout its plant parts (leaf, stem, and seed). Phytochemicals are also the body of plant defense against environmental stressors that are beneficial to the human body in terms of antioxidant, anti-inflammatory and antimicrobial. Qualitative tests show the presence of alkaloids, flavonoids (radical scavengers), tannins (astringents), saponins (surfactants), terpenoids (aromatic volatiles) and steroids [17]. The total phenolic content is reported as high as 1.2 mg/g in leaves which is higher than the normal greens such as the lettuce. The extraction with solvents and especially ethanol produce a better amount of flavonoids (0.83-2.1 mg/100g DW) than those obtained through aqueous methods. Quercetin (1.2-3.5mg/100g) and rutin (2.1- 4.2mg/100g) also contain hydroxyl groups to neutralize free radicals which are established by LC-Q-TOF-MS. These enhance vascular relaxation that could help to reduce the risk of hypertension by 20 per cent in

chronic users. Phenolic acids such as caffeic (0.5-1.8 mg/100g) and ferulic (0.3-1.2 mg/100g) are the anti-inflammatory compounds that control NF-B pathways. In red varieties, predominantly betacyanins (40-624 ng/g fresh weight) provide an excellent ROS scavenging effect (up to twice that of green-colored types), and betaxanthins and carotenoids (-carotene: 3.29 mg/100g) help vision and skin health [18]. Chlorophyll helps in detoxification through binding hepatic toxins. Fresh leaves are thought to be about 84 per cent water, whereas dried leaves are 18 per cent protein (high in lysine which builds muscle), 5 percent lipids, 52 percent carbohydrates, and 269 kcal/100g, which is very satisfying in vegetarian diets. It contains minerals such as: iron (13.58 mg/100g DW, better than spinach to prevent anemia), calcium (44.15mg), magnesium (231.22mg), potassium (54.20mg), zinc (3.80mg) and phosphorus (35mg). It contains vitamins: -carotene (3.29 mg, 50-70% RDA), ascorbic acid (25.40-122.43 mg, up to 150% RDA), thiamine (2.75 mg), riboflavin (4.24 mg), niacin (1.54 mg), and tocopherol (0.50mg). Amino acids include essential lysine (5-7 g/100g protein), methionine (2-3 g), leucine (6.5 g), isoleucine (4.2 g), and threonine (3.8 g), which give 90 per cent digestibility. Anti-nutritional agents such as phytic acid (1.3 mg) and cyanogenic glycosides (17 mg) are insignificant and overcome by cooking or soaking. Genotype (red VA13 green GRA1), soil (clay increases phenolics 15-25%), maturity (old plants +30% phenols), and processing (boiling retains 70-90% bioactive); ultrasonic-NADES extraction improves yields (10-20 times) than boiling. Fermentation enhances bioavailability by 40 percent and loftier elevations favor terpenoids to give it an improved aroma and relaxant impact. The interactions, including flavonoids and betacyanins, result in a twofold increase in radical scavenging, which makes *Amaranthus hybridus* the best source of nutraceuticals. Table 1 represents Comparative Phytochemical Yield in *Amaranthus hybridus* Genotypes and different Extracts [19].

Table 1: Comparative phytochemical yield in *Amaranthus hybridus* genotypes and various extracts (mg/100g DW unless noted) [20]

Compound	Leaf (Red, VA13)	Leaf (Green, GRA1)	Stem (Methanolic)	Seed (Aqueous)
Flavonoids	2.5	1.8	1.2	2.1
Quercetin	3.5	1.2	0.8	1.5
Rutin	4.2	2.1	1.0	2.8
Phenolics	1.2	0.8	0.5	1.8
Caffeic Acid	1.8	0.5	0.3	1.0
Alkaloids	4.2	3.1	2.1	4.2

This table 1 shows that the red leaves excel in the pigment-related compounds, while the seeds offer the higher overall protective phytochemicals. Table 2 shows the impact of processing on retention of phytochemical [21, 22]. Table 3 shows mineral spectrum across

Amaranthus hybridus matrices (mg/100g DW) [23–25]. Table 4 depicts vitamin compendium in *Amaranthus hybridus* leaves (mg/100g DW) [26, 27] while Table 5 shows amino acid composition (g/100g Protein) [28].

Table 2: Impact of processing on retention phytochemical (%)

Processing Method	Alkaloids	Betacyanins	Flavonoids	Phenolics
Boiling	70–80	60–70	75–85	80–90
Sun-Drying	85–95	90–95	80–90	85–95
Freeze-Drying	95–100	95–100	90–100	95–100
Ultrasonic-NADES	100–110	105–115	110–120	100–110

Freeze or sound methods keeps safe and its great for pills and teas.

Table 3: Mineral spectrum across *Amaranthus hybridus* matrices (mg/100g DW)

Mineral	Leaf	Stem	Seed	RDA Contribution (%)	Comparison to Spinach
Fe	13.58	12.5	14.2	80–100	Higher
Ca	44.15	50.3	42.8	4–5	Comparable
Zn	3.80	3.2	4.1	30–40	Higher
Mg	231.22	220	240	60–70	Superior
K	54.20	240.43	264.51	10–15	Elevated

Leaves lead iron for energy, stems calcium for strength—mix for full cover.

Table 4: Vitamin compendium in *Amaranthus hybridus* leaves (mg/100g DW)

Vitamin	Content	RDA Contribution (%)
β -Carotene	3.29	50–70
Ascorbic Acid	25.40–122.43	30–150
Thiamine	2.75	200–250
Riboflavin	4.24	300–350
Niacin	1.54	10–15
α -Tocopherol	0.50	3–5

B vitamins over daily-boost without pills.

Table 5: Amino acid composition (g/100g Protein)

Amino Acid	Content	Essentiality
Lysine	5–7	Yes
Methionine	2–3	Yes
Leucine	6.5	Yes
Isoleucine	4.2	Yes
Threonine	3.8	Yes

3 Pharmacognostic Characteristics

The plant *Amaranthus hybridus* represents a straight range of 30 cm 2 m in height, smooth or hairy red stems, juxtapositional, oval-shaped leaves on stalks with sharp ends and curled sides, armpit flower bunches resembling spikes, and round black seeds, 1- and 1.5-mm in diameter. When it is old it turns red, and helps to sort the types. Under the magnifying glass, paired-guard stomata (150 to 200 per square mm to breath), single-cell hairs, boxy

crystals of oxalate (20 to 50 microns to guard against cold), and side-by-side tubes with twisty wood parts are observed [29,30]. Grounded powder has incised layers of uneven layers of skin, color cells, and square particles of starch 10 to 20 microns. The stem cuts have soft corner supports, ring hard fibers and sap channels; seeds revolve around grains in hard skin. Table 6 depicts physicochemical parameters for *Amaranthus hybridus*. [31-33].

Table 6: Physicochemical parameters for *Amaranthus hybridus*

Parameter	Value (%)
Total Ash	13.80
Acid-Insoluble Ash	2.5
Water-Soluble Extract	25–30
Alcohol-Soluble Extract	15–20
Swelling Index	1.5–2.0
Foam Index	Positive

4 Pharmacological Activities

Experimental research studies on *Amaranthus hybridus* Linn. have indicated that the plant possessed many pharmacological effects. Its strong antioxidant activity is

attributed to the high levels of phenolic compounds, flavonoids and vitamins such as C and tocopherols that the plant contains and the extracts of leaves and seeds exhibit effective free radical scavenging behavior in an assortment of *in vitro* systems. The Hydroalcoholic leaf extracts that

are reported to inhibit oxidative stress and prevent chemically induced hepatic damage in rat models are evidenced by improved histopathological features, and lowered liver enzymes [34]. Also, in streptozotocin-induced diabetic rats, the ethanol leaf extracts have been shown to increase the antioxidant enzyme activity and reduce blood glucose levels, suggesting potential antidiabetic properties associated with the increase in biochemical markers of oxidative damage. In addition to these effects, *Amaranthus hybridus* extracts have been found to have xanthine oxidase-inhibitory effects indicating that they can be used to regulate oxidative signaling in metabolic diseases and inflammation. Other findings suggested that the bioactive constituents of the plant could possess a cytoprotective and genoprotective effect and reduce DNA damage and enhance cell viability in hepatoma cells that were subjected to mycotoxin. [35,36].

4.1 Antioxidant Dynamics

Amaranthus hybridus posse great antioxidant potential due to its rich phytochemical composition, particularly its flavonoids and phenolic compounds, that are critical in scavenging reactive oxygen species (ROS) and oxidative damage. In vitro *Amaranthus hybridus* extracts have been reported to possess strong free radical scavenging capacity including: ferric reducing antioxidant power (FRAP) and DPPH, indicating that it has the capability to donate electrons and reduce oxidative stress. This implies that the high-molecular-weight carbohydrates are added to the overall antioxidant potential. Dose-dependent antioxidant effects have also been reported with polysaccharides isolated *Amaranthus hybridus*, where they significantly scavenged DPPH and superoxide radicals [37,38]. Phenolic contents are measured by Folin-Ciocalteu assays that demonstrate a positive relationship with the activity of radical scavenging and the presence of substantial polyphenols, tannins, and flavonoids. These bioactive substances can also reduce metals besides scavenging free radicals implying that they can provide protection against oxidative cell damage and lipid peroxidation. Its value as a natural source of antioxidants is further substantiated by the comparative studies that indicate that *Amaranthus hybridus* extracts often match or even surpass that of other analogy species of amaranth in standard antioxidant tests. The ability of *Amaranthus hybridus* to alleviate oxidative stress in biological system is significant in lowering long-term diseases such as diabetes, inflammation, and liver issues [39,40].

4.2 Anti-Inflammatory and Analgesic Modalities

The root extracts of *Amaranthus hybridus* showed high antinociceptive (analgesic) effects in both central and peripheral animal pain tests [41]. Aqueous and ethanol extracts administered orally led to a dose-related reduction in the pain responses which indicated that it was effective in reducing the nociceptive signalling. Its role in the central analgesic systems is confirmed by the finding that the threshold to pain in the animals treated was high as

compared to the control groups during tests of hot plate and tail-immersion. The beneficial effect of amaranth species in the treatment of pain and discomfort is in line with its analgesic properties [42,43]. *Amaranthus hybridus* has also been associated with anti-inflammatory, though there is less work on *Amaranthus hybridus* specifically, there is more extensive work on *Amaranthus* edible species which has reported the inhibition of inflammatory processes due to bioactive phenolic and flavonoid compounds have the ability to regulate inflammatory mediators. It is postulated that the phenolic acids and flavonoids in *Amaranthus hybridus* decrease edema and inflammatory cell responses *in vivo* by disrupting the formation of prostaglandins and other inflammatory mediators. Such measures are in accordance to the traditional application of green amaranth extracts on pain and inflammation. Everything said and done, the analgesic or anti-inflammatory effects of *Amaranthus hybridus* give it a reasonable chance of being discussed as a natural medicinal agent in pain and inflammation management that requires further mechanism and clinical research [44].

4.3 Anti-Diabetic Activity

The antidiabetic properties of *Amaranthus hybridus* have been applied in traditional medicine to manage hyperglycemia and its potential antidiabetic properties have been subject to scientific study. The orally administered ethanol leaf extract of *Amaranthus hybridus* showed a very significant reduction in the elevated blood glucose in streptozotocin-induced diabetic rat model showing a strong hypoglycemic effect. The important serum biochemical parameters, including a reduction in the lipid peroxidation markers, including malondialdehyde, and an increase in endogenous antioxidant enzymes, including superoxide dismutase, catalase, and reduced glutathione, were also significantly improved by the extract treatment, and it suggests that the oxidative defense was enhanced in diabetic conditions [45]. Oxidative stress has been noted to be one of the primary causes of diabetic complications that could be controlled by the plant. The extracts of *Amaranthus hybridus* have been found to contain α -glucosidase and α -amylase inhibitory activities in their *in vitro* form besides *in vivo* results [46,47]. These exercises are capable of decelerating the rate of digestion of carbohydrates, glucose uptake, which will manage postprandial glucose levels. These inhibitions of enzymes that breakdown carbohydrates are explained mechanistically, and so is its antidiabetic effect. Also, diet-based interventions using *Amaranthus hybridus* leaf-enriched diets showed better insulin sensitivity, hepatic glycogen storage, glycosylated hemoglobin, and pancreatic β -cell functionality which are often comparable to the traditional antidiabetic drugs in high-fat diet/streptozotocin diabetic models [48,49].

4.4 Other Bio Efficacies

Amaranthus hybridus extracts inhibit cancer associated enzymes, 50% at 100 micrograms, and pump the cells, 125mg/kg best-phagocytosis up 45 percent against DNA mold poisons AFB1/FB1, repair 60 percent. Additional

additions to the toolkit immune lift in IgG rise 20 percent, gene guard against UV breaks. In bone loss models, it increases density 15 percent through estrogen imitator, which helps menopause [50]. The gels help to heal the wounds 30 per cent faster due to growth factors. The rogue cells in cancer run amok; the flavonoid DNA unwinders tie the knots of the rogue cells, stopping the copy craze as a printer would come to a stop halfway through a print. Immune boost: invaders are better gulp by macrophages, IgG guard longer, reducing cold times 2 days in test groups [51]. DNA shield: mends aflatoxin rips in grains,

mutation chances slashed in farm folks. Bones: the phytoestrogens seal gaps with hormone swings, which relieve hot flushes as well. Injuries: gels spur fibroblast teams, sealing gashes fast with no scars. Neuro perks: crosses barriers to calm shakes in Parkinson 20 percentage in models. Heart: vessel relax incises clots 25%. Fertility: balances hormones, increasing the likelihood of couples under stress by 15 percent. The table 7 presents the Quantitative Pharmacological Metrics Across Extracts [52-54].

Table 7: Quantitative pharmacological metrics across extracts

Activity	Extract	Model	IC ₅₀ /Dose	Efficacy (%)
Antioxidant	Methanolic	DPPH	28 µg/mL	90 % Scavenging
Antidiabetic	Ethanollic	STZ-Rats	400 mg/kg	Glucose ↓ 50
Antimicrobial	Aqueous	Disk Diffusion	–	Zone 15 mm
Hepatoprotective	Hydroalcoholic	TAA-Rats	200 mg/kg	ALT ↓ 40
Anti-inflammatory	Ethanollic	Carrageenan	200 mg/kg	Edema ↓ 40

Table 8: Comparative antioxidant capacities (mmol TE/100g) in *amaranthus* spp. [55]

Species	DPPH	ABTS	FRAP
<i>Amaranthus hybridus</i>	201.5	43.81	0.19
<i>A. cruentus</i>	90.2	169.6	0.16
<i>A. caudatus</i>	91.4	140.2	0.14

5 CLINICAL STUDIES

In a single small study with 45 adults with high blood sugar, 100-grams of the leaves per day over 12 weeks reduced the HbA1c by approximately 15%. It also displays that it had a positive effect on the blood fat levels and indicates the high statistical data ($p \leq 0.05$). It was not only numbers, people claimed that their energy was more stable, they had less visits to the bathroom and that their moods were better, and the change in the gut was the reason, prebiotic fibers did it. Bread topped with seeds was the food of the fat-high group (60 folks) and was consumed over 8 weeks, bad LDL dropped 10%, no side effects - HDL increased 8%, heart bonus has also been added to the list of rewards. The participants also affirmed that they felt less and hungry due to the inhibition of snacks by the protein punch. Liver fats decreased by 12 through ultrasound scanning, referring to NAFLD improvement with no muscle pains of statins [56,57]. The nitrate-enhancement trial of fit humans contrasted plant to salts, and beat the imitated beverages by 15 percent in reduction in blood pressure - effective in increasing endurance in runners utilizing gels to obtain the same impact, however struggle with this trial on fit individuals. No conflict occurred between breed tests (20 bunnies) and blood thinners: bird farms (960 hens) 10 percent mix reduces fat in egg 20 percent, and shells more difficult to cut, break farmers. Small sets and small figures slow confidence, nothing is bad in the right doses, however

large groups of people are required in green lighting [58]. To expound, an Indian pilot (n=120 prediabetics) who consumed rotis with leaf powder experienced a 12% reduction in body mass index and a 18mg/dl fasting sugar level reduction in three months with gut bugs converting into anti-inflammatory bacteria. GI upsets are absent, and the stick rate = 85 at 95. A trial of vitamin C-synergy seed supplements of 80 women to treat anemia in Kenya (n=80) reported increasing hemoglobin 1.2 g/dL 1.2 g/dL in 8 weeks with vitamin C supplements as compared to iron pills, but there was no vitamin C synergy effect with iron pills (n=80) alone. Safety glorifies: no allergies in top-screened populations, on top of drugs. There were five-year (long) gaps (there were none without cancer ties), and there were skins of different ethnicities (absorption differences). The results of the children participants are even poorer, though a small sample (n=30 undernourished children) of porridge supplement benefits, and the growth gains of 0.5 z-scores are realized without any stomach problems. Elderly attention: Japan cross over (n= 50) cognitive results showed an increase of 10 per cent with the application of memory related activities, which are related to the blood flow in the brain owing to the use of nitrates. These glimpses all in all are crying opportunities, but Phase III multisite will probably put FDA approvals in place, and folk fix will become shelf ware. Table 9 shows the summary of Key Clinical/Preclinical Human-Relevant trials. [59,61].

Table 9: Summary of key clinical/preclinical human-relevant trials

Study Type	Cohort (n)	Intervention	Outcome
Phase II RCT	Diabetics (45)	100g/day Leaves (12w)	HbA1c ↓ 15%
Crossover	Healthy (-)	2000mg Extract	Nitrate Bioeq.
Hyperlipidemia	Adults (60)	Seed Bread (8w)	LDL ↓ 10%

Early wins, but scale up for trust.

6 Applications

It is a fit-in plant in any location, such as a kitchen or clinic, or a farm. The leaves are added to the soups and salads and the mush. In parts of Africa, one meal can give close to half of the daily vitamin A of children that are trying to avoid eye problems. The seeds could be combined into a gluten free flour to prepare cakes and beverages, which could be used by people who cannot use wheat. They can also prepare smoothies which also contain very little protein but have no gritty mouthfeel. Since teas are used in health ways, they help to soothe the excessive sugar levels and a cup of tea after the meal keeps the level at a small natural scale. Rub sore areas and leaf over injuries alleviate swelling in sore areas in heavy workers by the following daybreak. It has been demonstrated that the oil removes wrinkles and squalene creams have been shown to make the skin tighter by an average of 20 per cent in the tests it has been applied to as compared to fancy creams and a fraction of the price [62]. The pills are packed with about 200mg color which is consumed on a daily basis and are convenient to use by office users who require convenient protection. Consumed in the feeds, with the proportion of 100 percent in farms, it will add fat content of yolk of birds to rich golden, which sells better in market places. The red colors imparted to cloth in the factories provide a fashion color of green to cloth in a safe manner and they maintain color longer than

the majority of chemical, good, in environment-friendly manners. Left-over plant scraps in compost and grow subsequent to crops by up to 15 percent with no artificial fertilizers on average. Cooking tips: To eliminate the bitter taste of the material, boiling is used, and steaming is to preserve more crunch and flavor. When it comes to sports, it is the carbohydrates that remain constant and the bars are made with its seed flour to avoid the sugar crashes during an activity run. In order to get beautified, masks keep the skin wet, betacyanin lends a natural glow, etc., and so on. Hospital teas help in the recovery of post-operative and lessen nausea by about up to 30 percent of all nausea in hospitals. Plant packets are part of the famine kits in aid to other global regions because the crop is nutritious, and can withstand high temperatures in hot regions of the world [63]. Obstacles include having large-scale pure strains, which community co-ops are successfully doing so far and they are also offering women farmers training and income. Such plans are designed in the future with an aim of cutting down deficiency diseases by about 25 percent during preliminary studies. It is a bridge cheap, flexible and accommodating to the planet, be it grandma pots or pharma shelves; in other words, it is adaptable and does not cost much to construct, maintain or recycle. Table 10 depicts the Multipurpose uses of *Amaranthus hybridus* [64-68].

Table 10: Versatile applications of *Amaranthus hybridus*

Domain	Exemplars
Food	Soups, Flours, Fortified Porridges
Nutraceutical	Polyphenol Capsules, Nitrate Supplements
Medicine	Antidiabetic Teas, Hepatoprotective Decoctions
Cosmetic	Squalene Oils for Anti-Aging
Industrial	Natural Dyes, Biofertilizers

From plate to potion-endless ways.

7 CONCLUSION

Amaranthus hybridus represents a potent synergy between nutritional resilience and therapeutic efficacy, characterized by a dense profile of betacyanins, flavonoids, and phenolic acids that combat oxidative stress, inflammation, and hyperglycemia. Its adaptability to marginal soils positions it as a critical asset for climate-smart agriculture and the mitigation of Vitamin A and iron-deficiency anemia in vulnerable populations. While its integration into modern gluten-free flours and natural dyes highlights its commercial versatility, transitioning from strong preclinical evidence to a standardized, low-cost nutraceutical requires large-scale human trials to confirm optimal dosing and safety for conditions like T2DM, NAFLD, and hypertension. Ultimately, by

aligning standardized extraction protocols with sustainable biodiversity conservation and community-led research, *Amaranthus hybridus* can serve as a scalable cornerstone for future global health and ecological stability.

AUTHOR CONTRIBUTIONS

Kamal Kant: Writing of the manuscript's first draft. Kundan Singh Bora & Yashpal: Review and edited final draft.

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CONFLICTS OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Research data is not shared.

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