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Exploring the Nutritional Potential, Adaptive Traits, and Resilience of Four *Mucuna Pruriens* Varieties against Malnutrition in Southern Madagascar amidst the Challenges of Global Climate Change

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Abstract: *In the persistent pursuit of alleviating the deleterious effects of malnutrition, particularly accentuated in vulnerable regions such as southern Madagascar, a comprehensive examination of the inherent capacities of botanical resources emerges as imperative. The current investigation thus endeavors to delve into the nutritional intricacies and underlying adaptations of four distinct cultivars of Mucuna pruriens, with the overarching objective of elucidating potential avenues for addressing the enduring predicaments of malnutrition, which corrodes the socio-economic fabric of indigenous communities while being exacerbated by the adverse ramifications of global climatic shifts. This rigorous inquiry is poised to scrutinize the diverse cultivars of Mucuna pruriens extensively, meticulously analyzing their nutritional profile encompassing both micronutrient and macronutrient constituents. The fundamental aspiration of this scholarly endeavor is to elucidate the underexplored nutritional reservoirs harbored within these Mucuna pruriens varieties, presenting auspicious prospects for fostering a more equitable and sustainable dietary paradigm. This entails employing a series of preparatory measures including soaking, dehulling, germination, cooking, and drainage, aimed at mitigating the presence of anti-nutritional elements, thereby optimizing the nutritional utility of the seeds.*

Keywords: *Mucuna pruriens, micronuntriments, macronutriments, criblage phytochimique, antinutritionnel*

I. Introduction

The disparate ramifications of climate change on marginalized populations residing in rural regions of economically disadvantaged countries, exemplified by the case of southern Madagascar, underscore the imperative of integrating alternative dietary practices. The incorporation of Mucuna pruriens into daily sustenance emerges as a viable strategy aimed at mitigating rural impoverishment and addressing the exigencies of the climate emergency. (Healy, 2017)

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In the heartland of southern Madagascar, where the battle against malnutrition persists as a pressing concern, conventional approaches primarily entail the distribution of vitamin-fortified sustenance. However, this scholarly endeavor endeavors to introduce a novel paradigm, spotlighting the indigenous Mucuna pruriens seeds, a leguminous species flourishing within this insular domain. These seeds, necessitating minimal preparatory intervention, proffer the prospect of crafting culinary fare replete with vital micronutrients and macronutrients, thereby transforming them into a holistic reservoir of nourishment. (Weiskopf et al., 2021)

Evidently, these invaluable seeds harbor a spectrum of essential nutrients, embodying adaptability and resilience amidst burgeoning climatic adversities, consequently fostering the overarching health and welfare of the indigenous populace. (Mugendi et al., 2010)

II. Research Methods

2.1 Plant material

Mucuna pruriens, an annual climbing vine, thrives within tropical regions spanning India, Africa, and the Americas. Exhibiting a preference for sunlit environs and warmth, this prolific leguminous species demonstrates a particular affinity for climates characterized by sporadic rainfall patterns. Possessing an inherent robustness, it manifests as a vigorous creeper capable of attaining towering heights of up to 15 meters, thereby furnishing a formidable deterrent against both erosion and weed proliferation.

The visual allure of *Mucuna pruriens* is accentuated by its distinctive botanical features. Clusters of resplendent purple blossoms adorn its foliage, juxtaposed against the mature hairy pods which often exhibit wing-like appendages and are embellished with intricate transverse or longitudinal folds. The tactile experience is further enriched by the variability in pod texture, ranging from smooth surfaces to delicate coatings of reddish bristles.

Fruitful in its reproductive endeavors, *Mucuna* yields pods replete with succulent contents, each capable of bearing between 3 to 5 seeds. The morphological diversity of these seeds spans from elliptical to kidney-shaped, contingent upon the specific cultivar under consideration.

Says Wikitrop, the taxonomic denomination of *Mucuna pruriens* (L.) DC delineates its herbaceous nature, with a characteristic silvery pubescence adorning its stems, leaves, and calyxes. Adding to its ornamental charm, the species unfurls purple, butterfly-shaped blossoms in axillary clusters. Noteworthy are its elongated pods, ensconced within a dense array of stinging hairs, housing ellipsoid seeds that manifest in hues spanning from pristine white to pinkish-brown speckled with ebony or exhibiting a deep onyx hue.

Mucuna pruriens var. *cochinchinensis*	*Mucuna pruriens* IRZ White	*Mucuna pruriens* Preta Black	*Mucuna pruriens* Utilis Yellow

***Figure 1**. The four varieties of Mucuna pruriens studied*

2.2 Macronutrient analysis methods

a. Moisture and dry matter content

Moisture content denotes the proportion of water relative to the total weight of material within a given sample. The methodology entails first measuring 5 grams of the specimen within a Petri dish. Subsequently, the laden dish is subjected to a controlled thermal environment within an oven set to temperatures ranging between 103°C to 110°C for a duration of 4 hours. Following this heat treatment, the dish, now housing the desiccated sample, is transferred to a desiccator to facilitate cooling over a period of 1 hour. Upon completion of the cooling phase, the sample-containing dish is meticulously reweighed to ascertain the extent of moisture loss through desiccation. **(Zambrano et *al.*, 2019)**.
The moisture content is calculated using the following formula:

$$\%\text{Moisture} = \frac{m_0 + m_1 - m_2}{m_1} \times 100$$

* m_0 : mass of empty petri dish;
* m_1 : mass of test sample (before drying);
* m_2 : mass of the petri dish containing the test sample after drying.

The dry matter content is calculated using the following formula :

$$\%\text{DM} = 100 - \%\text{Moisture}$$

b. Crude ash content

The procedure entails subjecting a finely powdered sample to incineration, thereby facilitating the combustion of organic constituents, leaving behind a residual ash, constituting the mineral fraction (**Liu, 2019)**. The procedure involves incinerating a powdered sample to remove organic matter, leaving behind ash. Five grams of the sample are placed in an incineration capsule and heated to 550-600°C for 8 hours. The resulting ash, ranging from white to grey, is allowed to cool for 3 hours in the oven and then in a desiccator. After cooling, the ash is weighed accurately to determine its content.

The percentage of crude ash, denoted as the proportion of ash content relative to the total mass of the sample, is:

$$\%\text{CA} = \frac{m_2 - m_0}{m_1} \times 100$$

* m_0 : mass of the empty capsule;
* m_1 : mass of the test sample;

* m_2 : mass of the capsule containing the residue (ash).

Le pourcentage de cendres brutes, exprimé en pourcentage de matière sèche est :

$$\%CA^* = \frac{\%CA}{\%DM} \times 100$$

c. Lipid content

Lipid extraction, a pivotal process in analytical chemistry, employs apolar organic solvents such as hexane, followed by gravimetric determination subsequent to solvent evaporation (**Saini et *al.*, 2021**). In lipid extraction, 5 grams of sample are placed in an extraction cartridge within a Soxhlet apparatus, where n-hexane is added and allowed to extract for 8 hours. The solvent is then evaporated using a rotavapor. The extracted oil is dried in an oven at 103°C for 1 hour, cooled in a desiccator, and weighed to complete the process. **(AFNOR, 1993)**

The lipid content, expressed as a percentage of total matter, is :

$$\%Lip = \frac{m_2 - m_0}{m_1} \times 100$$

* m_0 : mass of the empty flask
* m_1 : mass of the weighed sample
* m_2 : mass of the flask containing the extracted oil.

The lipid content, quantified as a percentage of the dry mass is :

$$\%Lip^* = \frac{\%Lip}{\%MS} \times 100$$

d. Protein content

Protein quantification utilizes the precise Kjeldahl method, known for its accuracy in nitrogen detection, a key component of proteins. The method involves mineralization, distillation, and titration to convert protein-bound nitrogen into ammonia and determine protein content. (**Mæhre et *al.*, 2018**)

The total nitrogen content (%N), expressed as a percentage of total matter is:

$$\%N = \frac{N * V_A * M(N)}{m}$$

* N : normality of the titrating sulphuric acid (0,1N);
* V_A : volume of sulphuric acid added during titration (en ml);
* $M(N)$: molar mass of nitrogen (14g/mol) ;
* m : mass of the initial sample.

The protein contents, expressed as a percentage of total matter (%Prt) and expressed as a percentage of dry matter ($\%Prt^*$) are :

$$\%Prt = \%N * 6{,}25 \quad \text{et} \quad \%Prt^* = \frac{\%Prt}{\%DM} \times 100$$

* 6,25: conversion factor of the Kjeldahl method.

e. Quantitative determination of amino acids

This determination is a continuation of protein content analysis. Seed amino acid composition variations follow similar linear relationships, defined by experimentally determined coefficients: slope a_x, y-intercept b_x, and correlation coefficient ρ_x. These coefficients enable the calculation of the precise composition of a specific amino acid x based on its nitrogen content. **(Mosse, 1990)**

* the A_x content of an amino acid x, in g per 100g of dry matter is obtained by the formula:

$$A_x = \frac{a_x * \%N + b_x}{1000}$$

* the concentration C_x of an amino acid x, in g per 100g of crude protein, is obtained by the

formula :

$$C_x = 0{,}016\left(a_x + \frac{b_x}{\%N}\right)$$

f. Crude fibre content

Macronutrients are hydrolyzed with sulfuric acid and potassium hydroxide to separate fiber and minerals. Acid hydrolysis boils 3 grams of sample with 0.26N sulfuric acid for 30 minutes, followed by filtration and rinsing. Alkaline hydrolysis treats the residue with 0.23N potassium hydroxide, boiling for 30 minutes, then drying and weighing (**Leite et *al.*, 2017; Reddy & Rhim, 2018**). Ash determination involves calcination at 550°C for 3 hours, cooling, and weighing the crucible with the ash. Fiber content determination follows the recovery of non-hydrolyzed residues using the WEENDE method.

The crude fibre content, expressed as a percentage of total matter, is:

$$\%CF = \frac{m_1 - m_2}{m_0} \times 100$$

The crude fibre content, expressed as a percentage of dry matter, is:

$$\%CF^* = \frac{\%Fb}{\%MS} \times 100$$

g. Carbohydrate content

The total quantity of carbohydrates is deduced by the difference with the other major elements (**McLoughlin et *al.*, 2023; Robijaona Rahelivolololoniaina, 2023a**). The carbohydrate content (%Ch), expressed as a percentage of total matter, is obtained using the following formula:

$$\%Ch = 100\% - (\%Lip + \%Prt + \%CA + \%Moisture + \%CF)$$

h. Determination of the energy value (EV)

The total energy value is the energy released by the combustion of the macronutrients (proteins, carbohydrates and fats) contained in a food, taking into account their ATWATER coefficient.:

* 1g protein ⟶ 4kcal ;
* 1g carbohydrate ⟶ 4kcal ;
* 1g lipid ⟶ 9kcal.

The energy value of a food, expressed in kcal per 100g of total matter is:

$$EV = 4(\%Prt) + 4(\%Ch) + 9(\%Lip)$$

2.3. TXRF method

X-ray irradiation excites atoms in a material, moving electrons from the K to higher orbitals like the L layer, causing radiation emission known as X-ray fluorescence. Each atom emits a spectrum of photons, creating a unique fingerprint reflecting the sample's elements. Precise analysis and instrument calibration reveal the sample's elemental composition.

This pertains to the quantification of elemental micronutrients (**Robijaona Rahelivolololoniaina, 2023b**)

2.4. Phytochemical screening

Chemical screening endeavors to identify secondary metabolites within plant specimens, elucidating a comprehensive catalogue of prominent compound classes, including but not limited to alkaloids, flavonoids, anthocyanins, coumarins, tannins, saponins, anthraquinones, terpenoids, phytates, and iridoids. This systematic exploration is conducted in adherence to the prescribed protocol established by the Chemistry and Microbiology

Laboratory (LCM) of the Ministry of Commerce, Nanisana. (**Robijaona Rahelivololoniaina & Elisoamiadana, 2024**)

2.5. Process of mitigating anti-nutritional constituents and specific secondary metabolites

To eradicate anti-nutritional entities such as phytates and alkaloids from *Mucuna pruriens*, a systematic regimen of treatments was implemented, encompassing iterative soaking, dehulling, germination, and sequential cooking processes. Subsequent to each treatment phase, meticulous phytochemical screening was conducted to validate the elimination of these undesirable constituents. (**Ezegbe et *al.*, 2023**)

III. Results and Discussion

3.1Results

a. Moisture, dry matter and ash contents

The table below shows the results obtained from the determination of the moisture and crude ash contents.

Table 1. Moisture, dry matter and ash contents

Notation	Moisture content in % of total matter	Dry matter content in % of total matter	Ash content in % of total matter
***Mucuna pruriens* IRZ White**	11.80 ± 0.07	88.20 ± 0.07	4.10 ± 0.06
Mucuna pruriens* var. *cochinchinensis	11.09 ± 0.06	88.91 ± 0.07	3.96 ± 0.04
***Mucuna pruriens* Preta Black**	12.03 ± 0.06	87.97 ± 0.06	4.11 ± 0.45
***Mucuna pruriens* Utilis Yellow**	11.58 ± 0.07	88.42 ± 0.07	4.52 ± 0.46

The moisture content exhibited a range between 11.09% and 12.03%, with the dry matter content fluctuating within the bounds of 87.97% to 88.91%. Concurrently, the ash content displayed variability spanning from 3.96% to 4.52%.

b. Lipid content

The ensuing table delineates the outcomes derived from the assessment of lipid content.

Table 2. Lipid content of 4 Mucuna pruriens

Notation	Lipid content in % of total matter	Lipid content in % of dry matter
***Mucuna pruriens* IRZ White**	5.33 ± 0.01	6.04 ± 0.01
Mucuna pruriens* var. *cochinchinensis	6.21 ± 0.01	6.99 ± 0.01
***Mucuna pruriens* Preta Black**	8.74 ± 0.02	9.94 ± 0.02
***Mucuna pruriens* Utilis Yellow**	4.45 ± 0.01	5.03 ± 0.01

In relation to dry matter percentage, *Mucuna pruriens* Preta Black seeds exhibit the highest lipid richness, registering at 9.94%, whereas *Mucuna pruriens* Utilis Yellow seeds manifest the lowest lipid content, amounting to a mere 1.34%.

c. Protein content

The following table shows the results obtained at the end of the determination of protein content by the Kjeldahl method.

Table 3. Protein content of the 4 *Mucuna pruriens*

Notation	Protein content in % of Total Matter	Protein content in % of Dry Matter
***Mucuna pruriens* IRZ White**	27.321 ± 0.566	30.976 ± 0.641
Mucuna pruriens* var. *cochinchinensis	26.106 ± 0.179	29.362 ± 0.201
***Mucuna pruriens* Preta Black**	26.201 ± 0.322	29.784 ± 0.366
***Mucuna pruriens* Utilis Yellow**	27.551 ± 0.144	31.159 ± 0.163

Examination of protein content, expressed as a proportion of both dry matter and total matter, reveals a consistent elevation across all seed varieties, surpassing the 20% threshold. Notably, the most protein-rich seed, *Mucuna pruriens* Utilis Yellow, attains an exceptional protein content, reaching as high as 31.159% in relation to dry matter.

d. Amino acid content of *Mucuna pruriens*

Still using the same methods, we were able to find the following table showing the amino acid content of *Mucuna pruriens* seeds:

Table 4. Amino acid content of four varieties of *Mucuna pruriens*

Acides aminés	Taux d'acide aminé en % de matière sèche				Taux d'acide aminé en % de protéine			
	MPB	MPC	MPPB	MPUY	MPB	MPC	MPPB	MPUY
Gly	1.138	1.530	1.428	1.094	3,676	5,212	4,794	3,512
Ala	1.361	1.365	1.364	1.361	4,396	4,652	4,582	4,368
Val	1.509	1.956	1.839	1.458	4,872	6,664	6,177	4,680
Leu	2.341	2.363	2.358	2.339	7,560	8,051	7,917	7,507
Ileu	1.265	1.499	1.438	1.238	4,084	5,108	4,829	3,974
Ser	1.681	1.067	1.227	1.750	5,427	3,635	4,122	5,619
Thr	1.277	0.759	0.895	1.336	4,123	2,587	3,005	4,287
Tyr	1.039	1.812	1.610	0.952	3,356	6,172	5,407	3,055
Phe	1.703	1.614	1.638	1.713	5,500	5,498	5,499	5,500
Pro	1.050	0.995	1.009	1.056	3,390	3,389	3,388	3,390
Met	0.405	0.233	0.278	0.424	1,307	0,795	0,934	1,362
Cys	0.458	0.810	0.718	0.418	1,480	2,760	2,412	1,343
Lys	2.059	2.929	2.702	1.960	6,648	9,976	9,072	6,293

His	0.946	1.724	1.521	0.858	3,056	5,872	5,107	2,755
Arg	2.114	1.478	1.644	2.187	6,827	5,035	5,522	7,019
Asp	3.246	3.453	3.399	3.222	10,480	11,760	11,412	10,343
Gln	5.265	3.111	3.674	5.509	16,998	10,598	12,337	17,682
Levels of essential amino acids in g/100g of protein:					41.991	53.490	50.365	40.761

MPB	*Mucuna pruriens* IRZ White	**MPPB**	*Mucuna pruriens* Preta Black
MPC	*Mucuna pruriens* var. *cochinchinensis*	**MPUY**	*Mucuna pruriens* Utilis Yellow

Gly	Glycine	**Ala**	Alanine	**Val**	Valine	**Leu**	Leucine
Ileu	Isoleucine	**Ser**	Serine	**Thr**	Threonine	**Tyr**	Tyrosine
Phe	Phenylalanine	**Pro**	Proline	**Met**	Methionine	**Cys**	Cysteine
Lys	Lysine	**His**	Histidine	**Arg**	Arginine	**Asp**	Aspartic acid
Gln	Glutamine						

Among the analyzed varieties of *Mucuna pruriens*, namely *Mucuna pruriens* IRZ White, *Mucuna pruriens* Preta Black, and *Mucuna pruriens* Utilis Yellow, elevated levels of glutamine are notably observed. In contrast, *Mucuna pruriens* var. cochinchinensis exhibits a slightly heightened concentration of asparagine. Conversely, the lowest levels are ascribed to cysteine in *Mucuna pruriens* IRZ White and *Mucuna pruriens* Utilis Yellow, while methionine prevails as the least abundant in *Mucuna pruriens* var. cochinchinensis and *Mucuna pruriens* Preta Black. The collective essential amino acid composition of the proteins ranges between 40.761% and 53.490%.

e. Crude fibre content

The following table shows the results obtained at the end of the determination of crude fibre content using the WEENDE method:

Table 5. Crude fibre content of the four seeds

Notation	Fibre content in % of Total Matter	Fibre content in % of Dry Matter
***Mucuna pruriens* IRZ White**	8.43 ± 0.05	9.56 ± 0.06
Mucuna pruriens* var *cochinchinensis	6.75 ± 0.21	7.59 ± 0.23
***Mucuna pruriens* Preta Black**	7.02 ± 0.12	7.98 ± 0.14
***Mucuna pruriens* Utilis Yellow**	7.21 ± 0.06	8.15 ± 0.07

According to these results, the proportions of fibre as a percentage of dry matter vary from 7.59% for MPC to 9.56% for *Mucuna pruriens* IRZ White.

f. Carbohydrate content and energy values

The following table summarizes the results obtained at the end of the carbohydrate determination:

Table 6. Carbohydrate content of the four seeds

Notation	Carbohydrate content in % of Total Matter	Carbohydrate content in % of Dry Matter	Energy value in kcal/100g of Total Matter	Energy value in kcal/100g of Dry Matter
***Mucuna pruriens* IRZ White**	43.019 ± 3.796	48.774 ± 4.224	329.3	373.4
Mucuna pruriens* var *cochinchinensis	45.884 ± 3.429	51.607 ± 3.778	343.9	386.7
***Mucuna pruriens* Preta Black**	41.899 ± 4.632	47.628 ± 5.197	351.1	399.1
***Mucuna pruriens* Utilis Yellow**	44.689 ± 3.814	50.541 ± 4.234	329.0	372.1

Based on the findings delineated, elucidating the proportions within dry matter, the examined seeds exhibit a notable abundance of carbohydrates, showcasing a spectrum ranging from 47.628% for *Mucuna pruriens* Preta Black to 51.607% for *Mucuna pruriens* var. *cochinchinensis*.

Furthermore, an overarching examination of energy values per 100g of total solids unveils a noteworthy range among *Mucuna pruriens* seeds, with energy values oscillating from 372.1 Kcal/100g for *Mucuna pruriens* Utilis Yellow to 399.1 kcal of dry matter for *Mucuna pruriens* Preta Black.

g. X-ray fluorescence results

After calculating the average of the values found during the three analyses for each seed. The X-ray fluorescence apparatus produced the following results

Table 7. Mineral content of seeds studied in mg/100g TM (Total Matter)

Notation	P	Ca	Ca/P	Mg	K	Fe	Cu	Zn	Mn
Mucuna pruriens IRZ White	403.2	625.4	**1.551**	261.2	1491.1	13.5	2.02	4.41	6.46
Mucuna pruriens Cochinchinensis	385.9	688.0	**1.783**	227.8	1072.7	12.7	2.47	4.70	6.11
Mucuna pruriens Preta Black	408.7	550.3	**1.346**	298.3	1505.2	19.7	2.64	4.32	6.21
Mucuna pruriens Utilis Yellow	721.7	490.0	**0.678**	326.0	1840.6	7.5	3.33	6.20	7.47

In accordance with the outcomes observed, each of the four seed varieties showcased a distinctive mineral profile, encompassing phosphorus, calcium, magnesium, iron, copper, and zinc, albeit in varying proportions. Notably, the absence of heavy metals was discerned across all samples.

h. Results of the phytochemical screening

The following table shows the results of the phytochemical screening carried out on the four seeds, indicating the presence or absence of the eleven families of compounds analysed.

Table 8. Results of phytochemical screening

	Alkaloid	Flavonoid	Anthocyanin	Saponins	Tanins	Coumarins	Iridoids	Triterpenes	Steroids	Anthraquinone	Phytates
***Mucuna pruriens* IRZ White**	+++	-	-	+	++	-	-	-	-	+	+++
Mucuna pruriens* var. *cochinchinensis	+++	+	-	+	+++	-	-	-	-	+	+++
***Mucuna pruriens* Preta Black**	+++	+	-	+	+++	-	-	-	-	+	+++
***Mucuna pruriens* Utilis Yellow**	+++	+	-	++	+++	-	-	-	-	+	+++

The influences of the presence or absence of compounds according to each class will be described in the next paragraph reserved for discussion.

i. Results of the process used to remove anti-nutritional components and certain secondary metabolites

In accordance with **Nwaoguikpe R.N.** (2011), the processes of soaking and cooking have been shown to effectively mitigate the presence of most anti-nutritional factors inherent in legumes, while concurrently preserving the digestibility of legume proteins. Consequently, these findings suggest that the existence of identified anti-nutritional factors does not present an insurmountable obstacle to the incorporation of these seeds into the diet.

3.2 Discussion

a. Discussions on moisture content

As per **Borget** (1989), seeds should ideally have a moisture content of 10-15% for preservation. With observed moisture content at 13.78%, these samples are well-dried for storage up to a year. Moisture below 10% can lead to cooking issues, but our samples range from 10.76% to 13.78%. Due to drying method variations, dry matter percentages will be used for comparison in this study. **Rakotobe** (2016).

b. Discussion of crude ash content

The crude ash content observed in legume seeds surpasses the average value reported for cereals, approximated at approximately 1.8% according to **Feingerg** (1991). This disparity suggests a comparatively elevated abundance of mineral constituents within legume seeds, as highlighted by **Nielsen and Harbers** (2003). As elucidated by **Udengwu et *al.*** (2018), the pronounced presence of minerals can be attributed to the pivotal function of seeds as indispensable reservoirs essential for the germination and sustenance of plant species.

c. Discussions on lipid content

The low lipid content of our samples distinguishes them from the oilseed category, characterised by lipid contents ranging from 18% to 45% (**Dupin et *al*., 1992**).

d. Discussions on carbohydrate content

The plants primarily store reserves as carbohydrates, mainly starches, which often exceed 40% of the total seed mass, indicating high digestibility. The prevalence of carbohydrates in all samples suggests they could replace conventional wheat flour in flour-based food production, offering opportunities to enhance nutritional value and versatility.

e. Discussions on protein content

Legume seeds are rich in protein but generally lower than soy, around 37.08% (**Ensminger**, **2016**). Some *Mucuna pruriens* varieties, like Utilis Yellow (40.761%) and IRZ White (41.991%), have protein levels close to 40%, while Preta Black (50.365%) and var. cochinchinensis (53.490%) surpass 40%, making them promising protein sources. These plants also fix atmospheric nitrogen, hinting at soil rejuvenation potential.

They have nearly complete essential amino acid profiles, with levels exceeding 32%, indicating high biological value protein according to the FAO. Glutamine and asparagine are the most abundant amino acids, with substantial concentrations of lysine and phenylalanine meeting reference profiles. However, sulfur amino acids like methionine and cystine fall short, making supplementation with sulfur-rich foods necessary, especially for infants (**Seidu**, **2018**). Despite this, *Mucuna pruriens* seeds from var. cochinchinensis and Preta varieties have threonine as a limiting factor (**Mortuza et *al*., 2009**).

f. Discussion of crude fibre content

Mucuna pruriens seeds have a crude fiber content of 8.66 to 9.09 g/100 g dry matter, aligning moderately with our findings of 7.59 to 9.57 g/100 g dry matter (**Daffodil, 2016**). However, infants' limited digestive capacity requires a fiber content below 3 g/100 g (**Houphouet**, **2016**), suggesting the need for dehulling during processing for infant nutrition.

g. Discussions on energy value

In terms of energy density, *Mucuna pruriens* Preta Black seeds emerge as the most energetically robust, boasting a value of 399.1 kcal/100 g, while *Mucuna pruriens* Utilis Yellow seeds exhibit the lowest energy content at 372.1 kcal/100 g. These seeds have the potential to fulfill approximately 16 to 17.5% of an adult's daily energy needs, considering a standard reference of 2000 kcal/day as outlined by the **FAO** (2005).

h. Discussions on elemental micronutrients

The seeds analyzed contain essential minerals like phosphorus (P), calcium (Ca), magnesium (Mg), potassium (K), copper (Cu), zinc (Zn), and manganese (Mn), addressing hidden hunger, a deficiency in essential minerals despite adequate energy intake (**Dileep et *al*., 2022**). Infants require phosphorus, calcium, and magnesium for bone development (**Seidu et *al*., 2018**), with these seeds providing sufficient calcium to meet or exceed daily requirements (Indian Medical Council Research [IMCR], 1992). A calcium-to-phosphorus (Ca/P) ratio exceeding 1, as found in *Mucuna pruriens* seeds, benefits bone health (**Nieman, 1992**). Copper is crucial for synthesizing vital proteins like collagen (**McDonald, 1995**). While these seeds have modest iron (Fe), zinc (Zn), and manganese (Mn) levels, they may not fully meet an infant's daily mineral needs, except for copper (**Özden et *al*., 2015**).

i. An elucidation of the methodology employed for the elimination of anti-nutritional constituents

After 48 hours, *Mucuna pruriens* seeds softened and separated into cotyledons, likely due to thick seed coats. Soaking reduced alkaloid levels moderately but notably decreased tannins. Alkaloids and phytates were mainly in the cotyledons, while flavonoids were

partially reduced. Dehulling substantially reduced tannins, primarily in seed coats, mitigating anti-nutritional factors.

Germination of *Mucuna pruriens* seeds is best at 20°C with moderate moisture. Lack of humidity hinders germination, while excessive water delays it. Adding a small amount of water until seeds are covered is recommended. Germination slightly reduces alkaloids and minimally affects tannins due to seed coat retention. Saponins decrease, similar to soaking, while phytates diminish significantly but not entirely. Boiling for about 2 hours and 50 minutes until completely softened is optimal. Alkaloids persist after the third boiling but decline after the fifth and are eliminated after the sixth.

j. Discussions on secondary metabolites

Mucuna pruriens seeds contain high levels of alkaloids, potentially toxic. Cooking reduces alkaloid levels, making them safe for consumption (**Kalidass & Mahapatra, 2011**). Tannins, contributing to bitterness, can be reduced through dehulling (**Nath et *al.*, 2022**). Saponins, beneficial at low doses but anti-nutritional at high levels, are reduced by soaking and skimming during cooking (**Singh et *al.*, 2017**). Anthraquinones have laxative properties, while phytates store phosphorus. Germination reduces alkaloids, with prolonged soaking and germination over three days showing significant reductions.

IV. Conclusions

This study aimed to analyze the nutritional content of Mucuna pruriens seeds, identify anti-nutritional factors, and develop strategies to enhance their nutritional value. Mucuna pruriens seeds are easy to prepare and offer a rich source of both macro and micronutrients, making them adaptable to diverse diets amidst climate change.

The analysis revealed high levels of carbohydrates and proteins, with excellent protein quality due to essential amino acids. Additionally, essential minerals like phosphorus, calcium, magnesium, and potassium were abundant. However, the seeds contained toxins and anti-nutrients such as saponins, phytates, tannins, and alkaloids, requiring effective elimination methods like soaking and cooking to mitigate their effects.

In conclusion, this research underscores the importance of addressing climate change's unequal impacts on vulnerable populations, particularly in rural areas of low- and middle-income countries. Integration of efforts to alleviate rural poverty with equitable climate change solutions is imperative for achieving sustainable development goals.

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