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MUNGBEAN BREEDING ADVANCES FOR CROPPING EFFICIENCY

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ABSTRACT
Agriculture has in recent times formed the main base of all food products. Agriculture is the practice of growing different crops such as pulses necessary to supply the food sources rich in proteins and improve the soil health by fixing active nitrogen into the soil. Mungbean (MB) (Vigna radiata L.) is a significant pulse crop with great contribution to human food and soil liveliness. In addition, MBs contain large amounts of nutrients and antioxidants which are having health benefits. The growth cycle of MBs that takes relatively long to enable the following cropping cycle poses some problems with its production in Rice-Wheat Cropping Systems (RWCS). By causing mutations in MBs that occur at an early stage of maturity, these mutations can result in the RWCSs being far more efficient, allowing crops to grow through their succession faster and enhancing the soil health by repairing the nitrogen. Therefore, this review paper aims to consider how to genetically enhance MB in order to grow fast by inducing mutations that have been proven to be effective in RWCSs. Correspondingly, this paper explores the importance of early maturing MB in rice-wheat (RW) systems, analyzes different physical and chemical mutagens in the production of early-maturing MB varieties, ascertains the LD50, and identifies the desired MB mutants that have a short maturity, high yield, and synchronous maturity.

KEYWORDS: Early maturity, Genetic improvement, Mungbean, Nitrogen fixation, Physical and chemical mutagens, Rice–wheat cropping systems

INTRODUCTION

Pulses are a significant source of food to billions of people worldwide. The two terms legumes and pulses can be used interchangeably because all the pulses are legumes but not all legumes are pulses. Pulses belong to the family of Leguminosae, which produces pod-like fruits. The number of species of legumes is almost 11,000. Legumes have been cultivated and used as food since time immemorial across the globe. MB (Vigna Radiate (VR)) is a plant in the family of legumes.

Asia has large crops that have a gradually increasing yield [2]. MB is useful and an important pulse crop, which has a high economic and commercial worth. The MB is also grown extensively in some countries in Asia, such as China, India, Bangladesh and Pakistan, and in the warmer regions of Europe in the dry areas of southern Europe, and in the warmer parts of Canada and the United States.

Figure 1: Cover cropping of MB (VR) in summer (April–June)

This is explained by its properties of relatively drought-tolerant, low-input crop, as well as high rate of growth, about 70 days [4]. MB (VR) is an important legume in most areas and offers high quality because of its nutritional value and a sustainable purpose in the agricultural industry. MB has been ranked as one of the useful small-scale crops that can be cultivated by dryland smallholder farmers to escape the downward productivity and enhance the profitability and sustainability of their farms. The time of planting can be any time between mid-April and the first week of July. This increases the income of farmers besides contributing to the richness of soil because of its nitrogen-fixing capacity, which eventually results in better harvesting of products like rice and wheat [6]. The RWCSs pose difficulties regarding the timing and efficiency of the crops. However, with early-maturing MB mixed with RWCSs, the resource cycles occurring in crop cycles will be more efficient and timelier which will result in an improved use of resources and overall increased productivity [7]. Early-flowering MB induced mutation to produce RWCSs has demonstrated good prospects. MB is endowed with a short growing season that is conducive to rice and wheat production hence increasing the productivity and sustainability of the entire system [8].

Table 1: Importance of genetic improvement of mungbean for early maturity through induced mutation suitable for rice–wheat cropping systems.

S. No.	Aspect	Benefit
1	Optimal utilization of cropping window	Early-maturing mungbean fits better into rice–wheat rotations, allowing efficient use of time slots.
2	Improved soil fertility and sustainability	Inclusion of mungbean enhances soil fertility and supports long-term system sustainability.
3	Increased income and food security	Early, additional mungbean harvests can raise farmer income and contribute to food security.
4	Conservation of water resources	Short-duration mungbean and better system design help conserve water resources.
5	Mitigating climate-related risks	Early-maturing, improved mungbean can reduce exposure of crops to adverse climate events.
6	Enhancing genetic diversity through induced mutation	Mutation breeding broadens the genetic base of mungbean for breeding programs.
7	Addressing the need for climate-resilient varieties	Genetic improvement via induced mutation aids development of climate-resilient mungbean lines.

Through physical or chemical mutagens, scientists are able to come up with new genetic mutation and so MB varieties are able to develop and mature faster without affecting yield or other desirable agronomics capable of giving it a competitive edge over its peers [9, 10]. Not only the sustainability of the RW cropping cycles will be enhanced by the identification and development of the early-maturing MB strains, but also the future food security and agricultural resilience in the areas where this type of cropping is prevalent will be associated with the identified strain [11]. The figure 2 illustrate the significance of the improvement of the MB genes to achieve growth by means of favorable mutations to benefit RWCSs.

Review Summary	**Overview of Mungbean in Cropping Systems**
	Importance of Mungbean for Early Maturity in Rice-Wheat Systems
	Types of Physical and Chemical Mutagen for Development of Early Maturing Mungbean Varieties
	Determination of LD 50
	Identification of Desirable Mungbean Mutants for Short Duration and High Yield.

Figure 2: The general methodology that will be used in the current review study.

2. Creation of Research Questions and the choice of Relevant Articles

Research questions (RQs) are very important towards any kind of study, be it a review, thesis, or an empirical study. Established RQs are well-constructed, offer a sense of direction, are clear, and are useful in keeping the research focused and relevant. They have to be concrete and stipulated in a manner that will enable them to be empirically tested and assessed. The literature used is appropriate and of a high quality, which is ensured by a properly designed selection strategy.

2.1. Research questions

The genetic improvement of MB can also be developed and researched using several research questions (RQs).

Table 2: The research themes and the RQs

List	Research concepts	Questions
M_1	MB in cropping systems.	What is the value of MB in the cropping systems?
M_2	MB for early maturity in RWCSs	What is the importance of MB for early maturity in RWCSs?
M_3	Physical and chemical mutagenesis types	How are the physical and chemical mutagens classified?
M_4	LD50 determination	Explain the inference of LD50 in the analyzed research articles.
M_5	Identification of desirable MB mutants	What are studies related with the identification of desirable MB mutants?

2.2. Article selection strategy

The procedure of choosing articles that can be for research review must be carried out with attention to detail in order to have a comprehensive and pertinent study of the topic. The major strategies to be adhered to for the selection of articles includes the following.

- Article selection is a necessary process in determining the studies that will be consistent with the aim of the research.
- The search process should include the use of keywords to get access to useful sources and answer the research questions.
- The selection of the keywords is very important in the process of conducting the research, particularly in the selection of the appropriate articles.

2.2.1. Initial selection criteria

The methods of analysis take into account important parameters, including the language of the paper, year and the relationship between the topic and the area of interests. The analysis will include research publications that will be written in English alone. The analysis is dedicated to the academic publications published in 2015-2023.

2.2.2. Exclusion criteria

The following criteria were used to exclude the articles:

- After the studies were narrowed down to those that concentrated on pulses only.
- The articles that were published before 2015 were excluded.
- Studies that focused on MB legumes only were abolished

2.2.3. Resources of search

The choice of the sources and credible databases is the key point when conducting a literature review because one should be sure that the references in a research paper are valid and worthwhile. The information as to the sources selection, as to the potential database options, search strategy, and research papers selection is provided below:

Sources: To obtain data regarding the subject of the research, some academic search engines, including Google Scholar, Elsevier, IEEE Xplore, and Springer, have been used. The studies that were included in the search focused on articles that dealt with the genetic enhancement of MB to early maturity via induced mutations that were applicable in RWCSs and had to be published within the past five years (2015-2024).

Options for Database: The major research databases, including Scopus, SCIE, and Web of Science (WOS), among others, assisted the search process and were critical in helping to find the relevant research publications

Perception of databases: Scopus database is regarded as very useful since it provides a full abstract and citation service which has peer-reviewed scientific literature. Although there are numerous databases, Scopus is superior to most of them because of the breadth of its coverage and its reliability. Each of the selected databases has its unique strong points in the presentation and content of the research.

Choice of papers: In this systematic review, 60 research papers were identified. The articles were selectively chosen with the use of predefined criteria. The search results that are associated with the given literature review are presented in the graph in Figure 3.

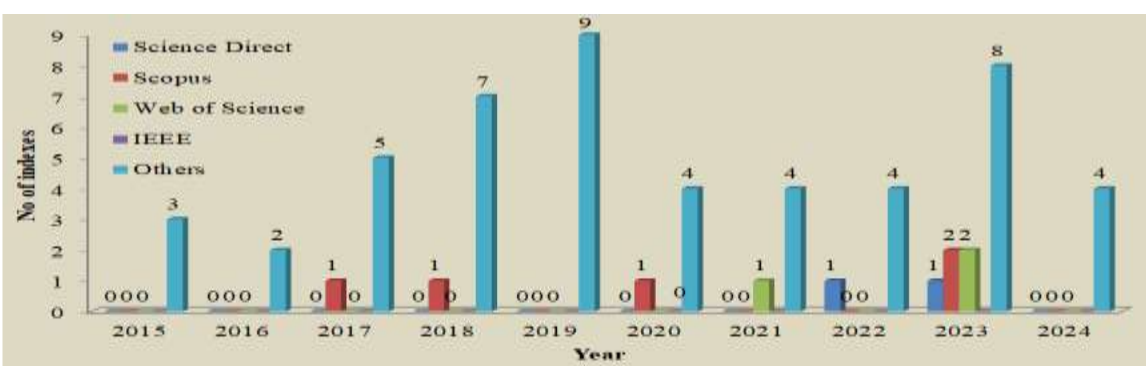

Figure 3: Graphical depiction of the results

Moreover, quantitative data may give a numerical approach to the sources that are used in the literature review. In making the list of 60 research articles, percentage distribution of publications was determined on different basis in Figure 4 also shows a pie chart that exhibited the percentage-based assessment of these publications.

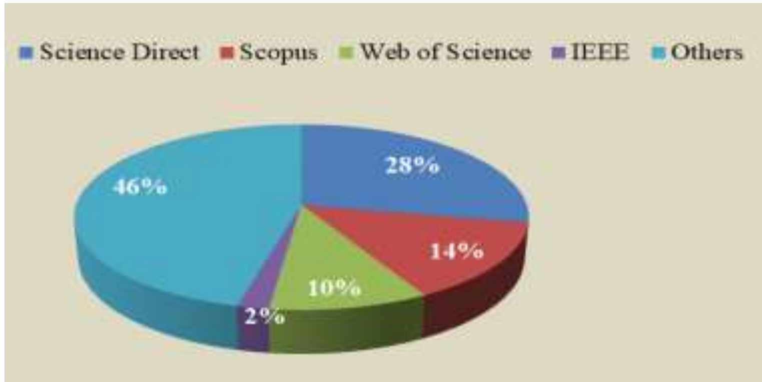

Figure 4: Pie chart of publication percentage analysis

3. LITERATURE REVIEW

It has a reason to study the genetic enhancement of MB to mature earlier with induced mutation; especially in the backdrop of RWCSs. MB contains high amounts of proteins and other nutrients. Mutation that has been induced can as well enhance resistance to pests and diseases in the MB cultivars which reduces crop losses and reduces pesticide use.

The paper will cover the MB principles in a cropping system (CSs), the need to develop early-maturity MB in a RW system, and the possibilities of using physical and chemical mutagens to create early-maturity MB. It shall also deal with the determination of LD50 and coming up with desirable MB mutants that have reduced period of time, higher yield and consistent maturity.

3.1. OVERVIEW OF MUNGBEAN IN CROPPING SYSTEMS

MB, as a nutritious food, is a significant feed, and a fodder crop across the world due to its great composition of nutrients, minerals, and vitamins [12]. MB is a multipurpose legume, which contributes greatly to CSs, especially in Asia and Africa [13]. MB is an effective element of sustainable CSs, which has numerous agronomic, environmental, and economical advantages [14]. It makes it a significant crop in bettering resilience and productivity in agriculture since it has the capacity to improve SF and integrate in various farming practices [15].

A research was done to observe the reaction of MB to various levels of fertilized soil and lime under acidic soil conditions in an alley cropping system (CS) within the Vindhyan region of India. The aim of the objective was to evaluate the efficiency of these treatments in identifying the right fertility and lime requirements of acidic soils and its effect on the productivity of MB. Maximum increase of MB yield was obtained through 100% RDF, which gave a high seed yield (524 kg/ha), straw yield (1426 kg/ha) and total biological yield (1949 kg/ha) [16].

This experiment aimed at examining the effects of supplementation of (i) the organic matter, (ii) biofertilizer, and (iii) crop residues to wheat-MB cropping systems on Indo-Gangetic Plains soil microbial activity. The evaluation involved (A) carbon of soil microbial biomass (B) basal respiration, (C) ergosterol, (D) glomalin, (E) soil enzymes like glucosidases, phosphatases, and dehydrogenases, (F) FDA activity, (G) organic carbon (C O 3 c), (H) the ratio of C O 3 c to C O 3 g, and (I) metabolic quotient (qCO2). Implementation of organic methods to improve the population of microbes and carbon interactions in RW systems through the use of vermicompost (VC), crop residues (CR), and biofertilizer (BF) was carried out [17]

The experiment involved the assessment of physical and chemical characteristics of soil, and the productivity of crops in maize-wheat-MB cropping system of the Indo-Gangetic Plains, especially the retention of residue and management of nitrogen. The study shows that ZT-based system featuring maize-based crop rotation (MWMb) can increase the productivity of the system and improve the soil properties in the rural areas of the north of India through the accumulation of crop residues and the use of accuracy in nitrogen application [18].

The effects of different levels of fertilizers and planting methods on the performance of MB in the semi-arid Indian regions was studied. The experiment had a split-plot design that involved eight treatments and three replications. The findings indicated that the yield components were significantly increased when MB was planted as an intercrop [19].

The influence of zero tillage on MB-wheat cropping system was rated, paying special attention to soil characteristics and productivity of crops. The randomized block design with three replication was used to carry out the experiment. The results indicated that the rate of infiltration was found to be higher when the frequency of tillage was lower in the two crops. Compared to the traditional tillage of both MB and wheat (CTM–CTW), the zero-tillage system (ZTM–

ZTW) improved the content of organic carbon in the top layer of the ground and produced a minimal decrease in the pH of the soil [20].
MB is identified as a high-protein legume that can increase soils fertility and help in diversification in the cropping systems. In one study, the growth rates and the capacity of the individual plant species to fix nitrogen were measured in five MB genotypes planted in five textures of soil. The findings showed that the appropriate choice of MB genotype could be used to decrease the nitrogen needs of agricultural systems according to the results of the nitrogen fixation test [21].

3.2. IMPORTANCE OF MUNGBEAN FOR EARLY MATURITY IN RICE-WHEAT SYSTEMS

MB also contributes to the productivity and sustainability of RWCSs particularly in the areas dominated by RW [22]. MB grows fast, usually matures in 60-90 days. This enables farmers to plant it between sowing of wheat and harvesting of rice. With a rapid growth rate, farmers are able to make the best use of their land and gain an extra income as a result of a short period crop [23, 24]. MB when used in combination with RWCSs will increase productivity significantly, healthier soils, and sustainable agricultural practices [25]. Its early maturity and other agronomic advantages make it a good ingredient to farmers who want to maximize their farming policies [26].
The crop rotation of wheat-MB-rice was studied in a subtropical humid climate to compare the measures related to tillage process and residue retention on soil characteristics and crop yields. MB pods were picked throughout the first to the third week of June whereas rice was picked in the second week of November. The findings stated that the higher retention of residue and tilled soils enhanced soil properties and rise in crop production in the upland soils. In comparison, an increased intensity of tilling proved to be advantageous in sustaining rice culture in wetlands [27]..
The research was assessed on (i) general productivity of the system, (ii) nutrient uptake, and (iii) nutrient balance of the wheat-MB- T. aman rice culture system. The harvesting was conducted when each crop has reached full maturity, and yield information (kg ha -1) of all the test crops was obtained. Wheat-MB- T. aman rice yielded 1415-3096 kg ha^{-1}, 1020-1463 kg ha^{-1} and 2999-4282 kg ha^{-1} respectively. These findings meant that treatment T4 was the one that had the best overall performance [28].
It has been pointed out that MB is a potential crop that they can add to the RW system of Punjab and Pakistan. Nevertheless, the area that is under MB cultivation has been reducing as majority of the available cultivars take about 100 to 120 days to mature thus becoming non-viable in the current cropping pattern. Thus, it would be possible to use genotypes that have a better harvest index and maturity in synchrony so that they can produce the maximum seed yield within the given time frame [29].
The research investigated the impacts of tillage and planting techniques of crops on weed infestation and crop yield in an RW-MB crop rotation. A long-term experiment on evaluation of these impacts was launched in 2015 in Patna, Bihar, India. The tillage and crop establishment methods had an effect on the density and variety of weeds. The zero-till system of RW decreased rice production, though the similar system had no impact on system productivity because of the increased yield of wheat [30].
The introduction of a long-term bed planting system was suggested to improve the productivity and fertility of wheat-MB-rice cropping system. System productivity, fertility and nitrogen use efficiency were measured in this study. The reduction of the rates of the nitrogen fertilizer was proposed provided that 30-percent of the straw of rice and wheat, as well as 100-percent retention of the residue of MB were observed. The soil organic matter of the surface soil layers in PRB grew by 0.82 percent after 13 years (15 RW-MB crop cycles) of 30 percent SR [31].

3.3. Physical and Chemical Mutagenic Agents to produce Early flowering mungbean varieties

Mutation breeding may be applied in order to produce an MB cultivar with early maturity by relying on physical and chemical mutagens [32]. Physical and chemical mutagens are effective in order to generate early-maturing MB cultivars [33]. Hence, it increases the genetic varieties, which breeders can use to pick the preferred characteristics besides ensuring the sustainability of farming activities [34]. The chemical mutagens which are employed in the development of early maturing MB varieties are alkylating agents, nitroso compounds, hydroxylamine and the ionizing radiation, which are gamma rays and cosmic rays are classified as physical mutagens [35]. Table 3 provides the research investigations that analyzed the achievements of these physical and chemical mutagens on development and growth of early maturing MB varieties.

Table 3: Indicating the research researches that examined physical and chemical mutagens on the development of early-maturing MB varieties. It presents the summary of the goals of each study, the main findings and the limitations that are mentioned.

Mutagens	Findings	Limitations	Reference no.
Gamma radiation (physical mutagen)	From the results, it was found that the development of wild MB pools of diverse origins, along with environmental conditions, might aid in	Determining the optimal dose of gamma radiation was challenging. Too-low outcomes might not induce sufficient mutations, while too-high outcomes might lead to	[36]

	conserving the crop's genetic wealth.	lethal effects or severe growth impairment.	
Ethyl Methane sulfonate (EMS) [chemical mutagen]	The detected mutation may be better deployed to generate a plant with an enhanced plant type for mechanical harvesting and to increase yield along with yield-related traits.	EMS can occasionally cause random point mutations, potentially leading to harmful traits and complicating the selection process.	[37]
EMS, sodium azide, and gamma radiation are examples of chemical and physical mutagens.	In each mutagenic treatment, higher doses resulted in maximal seedling damage and death as compared to the control.	Defining the optimal concentration of EMS for mutagenesis could be complex. Due to this, too many mutations may be toxic rather than enough.	[38]
Hydroxylamine [Chemical Mutagen]	As per ROS activities and metabolizing antioxidant enzymes, superoxide dismutase was recommended in tolerant genotypes, presenting first-line protection against salt-induced O2.	Mutations induced by hydroxylamine might not be stable, potentially leading to inconsistent expression of salt tolerance traits across generations.	[39]
Gamma rays [physical mutagen]	Through phenotyping, 64 MYMIV-resistant mutants were found in the M3 generation. Marker-assisted genotyping was also used to find the 22 mutants that really were resistant.	Research involving gamma radiation might face regulatory scrutiny, particularly regarding safety and environmental impact.	[40]

It describes the goals of every research, their main results, and the limitations that were detected. They conducted a study to examine a genetic variation of 17 MB mutants that were formed due to exposure to electron beam and gamma ray with a major emphasis on genetic diversity and trait variations. The findings had shown that the pod number per plant had the highest value of heritability (0.92), then it was followed by pod length (0.89), number of branches per plant (0.88), and seed weight (0.88) [41].

In an attempt to find out which of the germination ability at 10 o C possessed cold tolerance traits, 204 MB (V. radiata L.) genotypes of germplasm were assessed on their ability to germinate. The results displayed that a new gene TTL1 was considerably implicated in cold-tolerance response of V. radiata on the protein expression level. Genetic enhancement and breeding can thus help to improve the breeds used in a sustainable manner and increase the breeds through research-based breeding [42].

3.4. DETERMINATION OF LD 50

LD 50 is the concentration of a substance needed to kill 50% of the test organisms in this instance, MB seeds [43]. An example of using LD 50 to determine the dosage rate of a chemical mutagen or pesticide in wheat and rice cropping system is to determine the dosage that causes half of the treated population to die [44, 45]. The importance of knowing the LD 50 is that it assists the researcher to use a suitable dose of mutagen that would cause desirable changes in the genetic makeup of MB but at the same time without causing too much damage to the plant [46]. The LD 50 is an important parameter used in mutation breeding, since this is the concentration of the mutagen that causes half of the population of treated MBs to be killed. Through precise determination of LD 50, breeders are able to decide on a good dosage that generates desirable genetic variation whilst ensuring satisfactory plant survival, thus creating a trade-off between mutation rate and the overall survival of the plants.

This was done to find out the median lethal dose (LD50) and growth reduction dose (GR50) of gamma irradiation (GI) in the induction of mutagenesis in wheat using mungbean (MB) seeds as a reference. Parameters including seed germination, plant survival, and seedling growth seven days following irradiation were measured as a result of laboratory experiments. The LD50 and GR50 of the wheat genotype DBW 187 and K 1006 under controlled laboratory conditions were 272.71 Gy and 278.61 Gy, 316.22 Gy and 346.73 Gy, respectively. These findings indicate that genotypes are differentially sensitive to gamma radiation, and thus, genotypes should be optimally used in the process of inducing mutations to enhance crops [47].

This paper employed a radiation source of 60Co to irradiate, with varying gamma-ray doses (0, 100, 200, 300, 400, 500, 600, and 700 Gy), 100 mungbean (MB) cultivar seeds to establish the median lethal dose (LD50) of seeds. The percentage of survival of plants following treatment was measured and the LD50 was estimated to be 619.875 Gy. This implies that, the Kampar cultivar has relatively low radiosensitivity and greater sensitivity to gamma irradiation than most of the other mungbean genotypes [48].

Two mungbean (MB) genotypes were used to investigate the LD 50 values and the synergies of EMS (Ethyl Methane sulfonate) and SA (Sodium Azide) on seedling characteristics; They are Pusa 1031 and Pusa 1431. In Pusa 1031 and 1431, the doses of LD 50 were established at 58.81 mM and 45.04 mM, respectively, after EMS treatment. Conversely, both genotypes had the LD 50 of 0.047 mM when subjected to sodium azide, a relatively high seedling sensitivity to SA when compared to that of EMS [49]

In this study, the morphological alteration of MB by gamma radiation was noted. In addition to 600 Gy which is the LD50 value, a slightly reduced dose of 550 Gy was applied to irradiate the MB seeds. The frequency of chlorophyll-deficient and morphologically defective mutants was higher after subjecting the sample to a dosage of 550 Gy of gamma irradiation [50].

The effect of gamma irradiation (GI) on morphology and yield of two varieties of mungbean (Vigna radiata) namely CO 6 and CO 8 were investigated. The assessment of physiological and agronomic effects of irradiation was done using the M2 generation to evaluate the agronomic and physiological reactions. The LD 50 of CO 6 and CO 8 is determined using the percent germination levels at 15 days after germination, and was found to be 450 Gy. The results also indicated that there was a distinct negative correlation between dose of gamma radiation and seedling survival in which the more the radiation level, the less the viability of the plant could survive [51].

The purpose of the study was to examine the impact of gamma irradiation (GI) on the germination and seedling development in green gram as the aim of the study was to induce genetic variation in the mungbean type. The GAM 8 genotype was used to conduct the experiment at the seedling stage where various doses of gamma radiation were administered to the seedlings. These findings showed that there was a significant decrease in the percentage of germination at the increased levels of irradiation. Germination decreased significantly at 700 Gy and it was only at 22.38, which showed that GAM 8 is also sensitive to high radiation levels.

3.5. IDENTIFICATION OF DESIRABLE MUNGBEAN MUTANTS FOR SHORT DURATION, HIGH YIELD, AND SYNCHRONOUS MATURITY

Mungbean (Vigna radiata) is one of the valuable pulse crops that has high nutritional status and grows quickly [53]. The ability to create mutants that are early maturing, higher yielding, and display the same maturity can be of great use in terms of productiveness as well as flexibility particularly in cropping systems that use rice and wheat [54]. The discovery of mungbean mutants that have reduced crop period, high yield level, and maturity synchrony is essential in enhancing crop resilience and the overall efficiency of the entire system in the diverse farming conditions [55, 56]

Extra short-duration Mungbean lines that yielded high were discovered to be as a result of gamma irradiation. Out of the M5 generation, 20 of the mutant plants exhibited great potential with regard to early maturity with an average yield of around 25 g of seeds. As well, there were six mutants that produced seeds extraordinarily early with an average production of 30g of seeds per plant [57].

Thirteen mutant lines of MB DX208 were developed using a DNA marker and all of them matured at the same time. These thirteen mutant MB lines of M6 generation were used to assess the yield, as well as the control variety DX208. When analogized to the control variety (DX208) (2.60 tons/ha) ($p < 0.01$), greater yields (2.99–3.29 tons/ha) were produced by DX8-1-28-8B, DX6-5-1-10, DX4A-3-3-1, and DX2-1-26-5 [58].

The experiment compared the degree of control that high non-additive gene action exerts on synchronous maturity in mungbean. The genetic material comprised of ten lines, three testers and thirty F1 hybrids and was tested on randomized complete block design with three replications. Findings showed that the investigated characteristics were greatly controlled by non-additive effects of genes, with little impact of additive genes. So, these characteristics should not be chosen till later segregating generations [59].

Genetic analysis of MB breeding traits based on multivariate and multi-trait indexing was conducted in order to identify the optimum genotypes. These indexing techniques were utilized to evaluate 166 MB genotypes differing in a total of 2 seasons in an attempt to identify the optimum genotypes. Mb varieties could be important in sustaining MBs production within a short period development environment [60].

4. SUMMARY OF THE STUDY

Cropping systems (CSs) are important in the regulation of the physical and chemical properties of soils and as a result, directly affect the productivity of crops. Mungbean (MB) is a leguminous crop, which is commonly grown either in summer or in the Kharif season since it can withstand high temperatures (up to 40 degree centigrade and above). The varieties of less than 55-60 days can easily fit into the rice-wheat (RW) rotations without disturbing the current pattern of cropping. In the past, MB cultivars planted in the spring/summer period took 70 ±5 days to mature, and could not be properly integrated into RW cropping systems (RWCSs). The importance of MB in RWCSs has been found useful in improving the productivity of the entire system and the fertility of the soil. Being a legume, MB adds a considerable amount of residual nitrogen in the soil, which may be used by the next crop, thus, promoting the process of sustainable farming.

To make the review article more creative and clarified, the research questions (RQs) will be divided into the following categories: M1, M2, M3, M4, and M5, and the RQs and answers will be represented in Table 4

Table 4: The related RQs and answers

RQ's	Answers
What is the importance of MB in the cropping systems?	This question aimed to clearly understand the importance of MB in the cropping systems, which was explained in Section 3.1.
What is the significance of MB for early maturity in RWCSs?	The question explained the significance of MB for early maturity in RWCSs, which was described in Section 3.2.
How are the physical and chemical mutagens categorized?	This question helped explain the categorization of physical and chemical mutagens, which was explained in detail in Table 2 of Section 3.3. Ionizing radiations were physical mutagens, and EMS, hydroxylamine, etc. were chemical mutagens.
Explain the determination of LD50 in the analyzed research articles.	The determination of LD50 in the analyzed research articles was explained in detail in section 3.4.
What are studies associated with the identification of desirable MB mutants?	The studies associated with the identification of desirable MB mutants were explained in section 3.5.

The study indicated that they took about 15-20 days less time to grow than the wild plants without incurring considerable losses in yield. They have the potential to make MB a more viable rotational crop, enhance SF, decrease fallows, and offer farmers more money.

5. CONCLUSION

This article clearly presents how induced mutations can be utilized to enhance the genes of MB in order to ensure that it matures early. According to analysis of different research papers, genetic enhancement of MB to early maturity by way of induced mutation offers the most viable approach on the flexibility of this crop in RWCSs. The varieties that have been developed using the approach have not only been able to fit in between the two seasonal crops: rice and wheat but also have a similar yield and nutritional value. This rendered MB a good candidate in enhancing crop variety and sustainability in high production farmlands. However, in the process of analyzing the research articles, a limitation was established. Their early mature mutants may respond differently in the performance depending on the environmental conditions encountered in the area, including soil type, water availability, and temperatures. Multi-location trials were needed to ensure adaptability in a wide range of agro ecological areas. This is one of the limitations that future researchers ought to consider when undertaking further research on MB through multiple sites of trial. Therefore, effective implementation of MB during RW rotations can help achieve better SF, better use of resources and higher economic gains to farmers.

Future Scope

Genetic modification of mungbean (MB) to develop early maturity is a very promising practice towards enhancing productivity and sustainability of the Rice -Wheat Cropping Systems (RWCS). Multi-location and multi-season field trials will be required to condone the performance and stability of newly developed early-maturing MB mutants to cover different agro-ecological locations. Moreover, the use of the modern breeding methodology, including CRISPR/Cas9 genome editing, will be necessary to modify the gene structures more specific to activate early maturity and other beneficial agronomic features.

The incorporation of early maturing MB varieties into alternative farming systems other than RWCS should also be researched in further studies to diversify crops and improve soil health as well as optimize the utilization of resources. Development of climate-resistant MB varieties that are more tolerant to droughts, extreme heat, and other stresses caused by climate will be very important in the future sustainability. The other significant field of development is improvement of the nutritional value of MB, especially the protein and micronutrient level, and bioavailability with the aim of enhancing human health.

In addition, the adoption behaviour of the farmers and the development of best cultivation practices of the early-maturing MB varieties will be critical in the maximisation of the productivity and in the real-life application and acceptance. Finally, breeders, agronomists, soil scientists, and farmers will be involved in collaborative research to enhance the process of producing high yielding, nutritiously enriched, and environmental friendly early-maturing mungbean varieties to ensure agricultural sustainability at global level.

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Authors' contributions
DM carried out research work, participated in data collection, analysis and drafting of manuscript. AK, NKC and NR participated conceived of the study and participated in its design, participated in data collection, analysis and drafting of manuscript. RS and PB participated in writing manuscript and also participated in proofreading of manuscript. All the authors read and agreed for the final shape of manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no competing interests.

Ethical issues: None

REFERENCES
1. Ali B, Konjengbam NS, Ahmad F, Sanasam S, Kumawat R. Ascertaining LD50 and simultaneous effect of EMS and sodium azide on seedling characters in mungbean genotypes ‘Pusa 1031’ and ‘Pusa 1431’. Legume Res. 2024;47(2):1-7.
2. Anuragi H, Yadav R, Sheoran R. Gamma-rays and EMS induced resistance to mungbean yellow mosaic India virus in mungbean [Vigna radiata (L.) R. Wilczek] and its validation using linked molecular markers. Int J Radiat Biol. 2022;98(1):1-13.
3. Arulselvi S, Suresh S, Manonmani K, Dhole VJ, Jebaraj S. Morphological variation in mungbean (Vigna radiata (L.) Wilczek) induced through gamma irradiation. J Food Legumes. 2016;29(1):1-4.
4. Azam MG, Hossain MA, Sarker U, Alam AKMM, Nair RM, Roychowdhury R, et al. Genetic analyses of mungbean [Vigna radiata (L.) Wilczek] breeding traits for selecting superior genotype(s) using multivariate and multi-traits indexing approaches. Plants. 2023;12(9):1812.
5. Aziz-ur-Rehman, Khan ME, Kaukab S, Saeed S, Aqeel M, Riasat G, et al. Prospects of mungbean as an additional crop in rice–wheat system of Punjab, Pakistan. Universal J Agric Res. 2019;7(1):1-6.
6. Bangladesh Wheat and Maize Research Institute. BWMRI annual research report. Dinajpur: BWMRI; 2019.
7. Batzer JC, Singh A, Rairdin A, Chiteri K, Mueller DS. Mungbean: A preview of disease management challenges for an alternative U.S. cash crop. J Integr Pest Manag. 2022;13(1):1-21.
8. Beerling DJ, Leake JR, Long SP, Scholes JD, Ton J, Nelson PN, et al. Farming with crops and rocks to address global climate, food and soil security. Nat Plants. 2018;4(3):138-147.
9. Belay F, Meresa H, Syum S, Gebresilasie A. Evaluation of improved mung bean (Vigna radiata L.) varieties for yield in the moisture stress conditions of Abergelle areas, Northern Ethiopia. J Agric Sci Pract. 2019;4(1):1-5.
10. Bhati TK, Kumar S, Haileslassie A, Whitbread AM. Assessment of agricultural technologies for dryland systems in South Asia: A case study of Western Rajasthan, India. Patancheru: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); 2017. p. 1-71. Report No.: Research Report No. 71.
11. Chakraborty S, Mahapatra S, Hooi A, Ali N, Satdive R. Determination of median lethal (LD50) and growth reduction (GR50) dose of gamma irradiation for induced mutation in wheat. Braz Arch Biol Technol. 2023;66:e23220516.
12. Dahiya PK, Linnemann AR, Van Boekel MAJS, Khetarpaul N, Grewal RB, Nout MJR. Mung bean: Technological and nutritional potential. Crit Rev Food Sci Nutr. 2015;55(5):670-688.
13. Das A, Devi MT, Babu S, Ansari M, Layek J, Bhowmick SN, et al. Cereal–legume cropping system in Indian Himalayan region for food and environmental sustainability. In: Meena RS, editor. Legumes for soil health and sustainable management. Singapore: Springer; 2018. p. 1-44.
14. Depenbusch L, Farnworth CR, Schreinemachers P, et al. When machines take the beans: Ex-ante socioeconomic impact evaluation of mechanized harvesting of mungbean in Bangladesh and Myanmar. Agronomy. 2021;11(11):2305.
15. Dewanjee S, Sarkar KK. Evaluation of performance of induced mutants in mungbean [Vigna radiata (L.) Wilczek]. Legume Res. 2018;41(1):1-5.
16. Dhole VJ, Reddy KS. Genetic analysis and variability studies in mutants induced through electron beam and gamma rays in mungbean (Vigna radiata L. Wilczek). Electron J Plant Breed. 2018;9(1):1-9.
17. Diatta AA. Mungbean [Vigna radiata (L.) Wilczek]: Protein-rich legume for improving soil fertility and diversifying cropping systems [Master’s thesis]. Blacksburg: Virginia Polytechnic Institute and State University; 2020.

18. Dinesh GK, Sharma DK, Jat SL, et al. Residue retention and precision nitrogen management effects on soil physiochemical properties and productivity of maize–wheat–mungbean system in Indo-Gangetic Plains. Front Sustain Food Syst. 2024;8:1322049.
19. Geetika G, Hammer G, Smith M, Singh V, Collins M, Mellor V, et al. Quantifying physiological determinants of potential yield in mungbean (Vigna radiata (L.) Wilczek). Field Crops Res. 2022; 287:108658.
20. Hazra KK, Nath CP, Ghosh PK, Swain DK. Inclusion of legumes in rice-wheat cropping for enhancing carbon sequestration. In: Ghosh PK, editor. Carbon management in tropical and sub-tropical terrestrial systems. Singapore: Springer; 2020. p. 1-15.
21. Hossain MM, Begum M, Bell RW. Land use, productivity, and profitability of traditional rice–wheat system could be improved by conservation agriculture. Res World Agric Econ. 2022;3(1):1-11.
22. Huppertz M, Manasa LS, Kachhap D, Dalai A, Yadav N, Baby D, et al. Exploring the potential of mung bean: From domestication and traditional selection to modern genetic and genomic technologies in a changing world. J Agric Food Res. 2023;14:100743.
23. Iqbal J, Yousaf U, Zia S, Asgher A, Afzal R, Ali M, et al. Pulses diseases: Important limiting factor in yield and their managements. Asian J Res Crop Sci. 2019;3(2):1-21.
24. Javed I, Ahsan M, Ahmad HM, Ali Q. Role of mutation breeding to improve mungbean (Vigna radiata L. Wilczek) yield: An overview. Nat Sci. 2016;14(6):1-15.
25. Kakraliya M, Jat HS, Kumar S, et al. Bundling subsurface drip irrigation with no-till provides a window to integrate mung bean with intensive cereal system for improving resource-use efficiency. Front Sustain Food Syst. 2024;8:1347000.
26. Kanishka RC, Gayacharan, Basavaraja T, Chandora R, Rana JC. Moth bean: A minor legume with major potential to address global agricultural challenges. Front Plant Sci. 2023;14:1161327.
27. Karaman R, Turkay C. Changes in germination and quality characteristics of mung bean seeds stored for different times. Anadolu Tarım Bilim Derg. 2023;38(1):1-17.
28. Kaur R, Shivay YS, Singh G, Virk HK, Sen S, Rajni. Increasing area under pulses and soil quality enhancement in pulse-based cropping systems: Retrospect and prospects. Indian J Agric Sci. 2018;88(1):3-14.
29. Kumar J, Singh B, Yadav DB, Yadav A, Yadav PK, Tallapragada S. Zero-tillage in mung bean–wheat cropping system: Impact on soil properties and crop productivity. Legume Res. 2023;46(5):1-8.
30. Laskar RA, Dowarah B, Sheikh N. Germplasm diversity and breeding approaches for genetic improvement of mungbean. In: Lone S, editor. Advanced crop improvement. Volume 2. Singapore: Springer Nature; 2023. p. 190-213.
31. Lawal RT. Effect of microbial fermentation on nutritional quality of mung bean (Vigna radiata) flour and its toxicological implications in Wistar rats [Master's thesis]. Ilorin: Kwara State University; 2021.
32. Manasa LS, Panigrahy M, Panigrahi KC, Mishra G, Panda SK, Rout GR. Cold tolerance mechanisms in mungbean (Vigna radiata L.) genotypes during germination. Agriculture. 2023;13(1):1-24.
33. Marwiyah S, Sutjahjo SH, Trikoesoemaningtyas, Wirnas D, Suwarno WB. High nonadditive gene action controls synchronous maturity in mung bean. SABRAO J Breed Genet. 2021;53(1):1-15.
34. Dahal, B., Bag, A. G., & Raut, S. (2024). Integrated nutrient management for lentil cultivation: Improving soil fertility, nutrient content, and economic returns. In Acta Biology Forum (Vol. 4, No. 1, pp. 24-34).
35. Mishra JS, Kumar R, Mondal S, et al. Tillage and crop establishment effects on weeds and productivity of a rice–wheat–mungbean rotation. Field Crops Res. 2022;284:108574.
36. Aparanjitha, R., Imran, G. M., & Mondal, K. (2023). Nano fertilizers: Revolutionizing agriculture for sustainable crop growth. Agriculture Archives, 2(3), 6-9.
37. Ranjan, A. R., & Pandey, S. R. Impact of Integrated Nutrient Management on Green Gram Growth, Soil Health, and Economics. Journal of Diversity Studies
38. Pathak R, Panchariya P, Choudhary M, Solanki K, Rani R, Kakani RK, et al. Morphophysiological and molecular diversity in mungbean (Vigna radiata L.). In: Physiology and molecular biology of abiotic stress tolerance. Singapore: Springer; 2023.
39. Quddus MA, Mian JA, Hashem MA, Naser HM, Hossain MA. System productivity, nutrient uptake and nutrient balance in the wheat–mungbean–T. aman rice cropping system. Bangladesh J Agric Res. 2017;42(1):1-12.
40. Ravshanova NA, Usmonov I, Chulliyev A, Isroilov B, Rahimova D, Usmanova Z, et al. Growth and development of mung bean depending on sowing methods. IOP Conf Ser: Earth Environ Sci. 2020;614(1):012117.
41. Rohman MM, Ahmed I, Molla MR, Hossain MA, Amiruzzaman M. Evaluation of salt tolerant mungbean (Vigna radiata L.) genotypes on growth through biomolecular approaches. Bangladesh J Agric Res. 2019;44(1):1-24.
42. Roslim DI, Herman, Fiatin I. Lethal dose 50 (LD50) of mungbean (Vigna radiata L. Wilczek) cultivar Kampar. SABRAO J Breed Genet. 2015;47(1):1-7.
43. Rukesh AG, Rahuman A, Latitia C, Packiaraj D. Impact of gamma irradiation induced mutation on morphological and yield contributing traits of two genotypes of green gram (Vigna radiata L.). J Pharmacogn Phytochem. 2017;6(5):1-6.

44. Salahin N, Alam K, Mondol ATMAI, Islam MS, Rashid H, Hoque MA. Effect of tillage and residue retention on soil properties and crop yields in wheat–mungbean–rice crop rotation under subtropical humid climate. Open J Soil Sci. 2017;7(1):1-18.
45. Sarkar M, Kundagrami S. Selection of high yielding, extra short duration lines of mungbean derived through gamma radiation. Indian J Genet Plant Breed. 2018;78(2):1-9.
46. Sehrawat N, Yadav M, Sharma AK, Kumar S, Singh M, Kumar V, et al. Mungbean as functional food, agronomic importance and breeding approach for development of climate resilience: Current status and future perspectives. Asian J Biol Life Sci. 2021;10(1):1-6.
47. Singh G, Kumar D, Sharma P. Effect of organics, biofertilizers and crop residue application on soil microbial activity in rice–wheat and rice–wheat–mungbean cropping systems in the Indo-Gangetic plains. Cogent Geosci. 2015;1(1):1-14.
48. Singh M. Assessing summer mungbean cultivation in Punjab: Status, economics, and perspectives for sustainable development. Int Interdiscip Bus Econ Adv J. 2023;4:1-5.
49. Singh N. Pulses: An overview. J Food Sci Technol. 2017;54(4):802-817.
50. Sofia S, Reddy DM, Reddy HPK, Reddy BR, Devi MS. Frequency and spectrum of viable mutations in mungbean (Vigna radiata (L.) Wilczek). J Food Legumes. 2023;36(1):1-13.
51. Sundesha DL, Patel MP, Bhadauria HS, Shreya. Effect of EMS on seed germination and seedling vigour in mungbean [Vigna radiata (L.)]. Int J Chem Stud. 2021;9(1):1-3.
52. Tasnim S, Alam J, Rahman M, Islam S, Sikdar SI. Response of mungbean growth and yield to GA_3 rate and time of application. Asian J Crop Soil Sci Plant Nutr. 2019;1(1):1-9.
53. Thounaojam AS, Patel KV, Solanki RU, Chaudhary RI, Chavda NK. Response of gamma irradiation on germination and seedling growth of green gram var. GAM 8. Environ Conserv J. 2024;25(1):1-7.
54. Tumaney AW. Current advances in food processing and preservation. IANCAS Bull. 2020;15(1):1-89.
55. Varadaraju A, Ramadoss BR, Gurunathan S, Balaram R, Ganesamurthy K, Ram SG. TILLING by sequencing reveals mutations in flowering control genes associated with altered plant architecture in mungbean (Vigna radiata (L.) R. Wilczek). Genet Resour Crop Evol. 2021;68(1):1-16.
56. Varma D, Meena RS, Kumar S. Response of mungbean to fertility and lime levels under soil acidity in an alley cropping system of Vindhyan Region, India. Int J Chem Stud. 2017;5(4):1-3.
57. Venkatesh KH. Mutation breeding in plants. In: Biotechnologies and genetics in plant mutation breeding. Vol 1. Palm Bay: Apple Academic Press; 2023. p. 20-140.
58. Vikhe A, Nehul J. Studies on mutagenic sensitivity of Vigna radiata (L.) Wilczek. J Soc Trop Plant Res. 2020;7(1):1-4.
59. Yomso J, Menon S, Sale MNA, Yumnam J. Performance of mung bean as influenced by different levels of fertilizers and cropping systems in the semi-arid region of India. J Appl Biol Biotechnol. 2023;11(3):1-5.
60. Zakir M. Mutation breeding and its application in crop improvement under current environmental situations for biotic and abiotic stresses. Int J Res Stud Agric Sci. 2018;4(10):1-10.