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REVIEW ARTICLE

Physical seed treatment methods for enhancing pulse seed vigour and germination - A review

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Abstract

Pulses is the common term that refers to the edible seeds of the legume plant. Pulses belong to the family Fabaceae and include various crops like blackgram, green gram, peas, beans and lentils etc. They are cultivated primarily for human consumption, livestock forage and silage. Pulses are of great economic and environmental importance as they contribute to the soil ecosystem by fixing nitrogen and have high fibre and protein content. Pulses are considered as an essential source of plant-based protein. The primary disadvantage of pulse crops is their decreased productivity. The low productivity of pulse crops can be attributed to several factors. Amongst them, the hard seed coat is a significant factor. Cost-effective seed invigoration treatments are recommended to overcome the above problem in commercial seed production centres. Seed invigoration techniques are becoming more popular to increase the planting value of pulse crops and boost seed vigour. In this review, various physical treatments for pulse seeds, *viz.,* Hot water treatment, scarification, magnetic-treatment, plasma treatment and irradiation treatment, are discussed for the adoption of techniques to overcome the hardness of seed coat and boost productivity in pulse crop. Amongst all the treatments, plasma treatment is considered eco-friendly and induces germination by breaking dormancy associated with the seed coat of pulse crop.

Keywords: germination; invigouration; irradiation; pulses; scarification

Introduction

Pulses belong to the family Fabaceae. It is an important crop that includes peas, beans, lentils, etc. Pulses are necessary in common people's diets as good plant protein sources. Pulses are known as poor man's meat since they contain 20 %-30 % protein. India leads the world in both acreage and production. India stands first in acreage and production (31 % and 28 %, respectively), with over 28 million hectares under cultivation. The nutritive value of pulses is 15.51 % carbohydrates, 8.59 % to 10.93 % in fat and 20-30 % in protein (1). Economically, it is an essential crop with enormous potential as a foreign exchange earner. The major drawback of pulses is low productivity. This is because of the lack of adoption of improved varieties, the non-adoption of appropriate seed management practices, the non-availability of quality seeds, hard seeds and poor seed storage. Therefore, it is necessary to adopt appropriate seed invigouration techniques to enhance seed quality and increase productivity. Seed invigouration technologies enhance the planting value over a wider range of growing conditions. Seed invigouration treatments are critical for enhancing pulse seed germination, vigour and field performance. This review intends to present physical seed treatments for seed invigouration in pulses, *viz*., hot water treatment, scarification, magnetic treatment, irradiation treatment and plasma treatment. The application of physical methods in seed technology has increased because of the evil effect of inorganic materials on the environment, high labour requirements and costly techniques (2). Physical seed invigouration techniques are more efficient than chemical seed treatment because they are environment-friendly and can be used in sustainable agriculture practices. It reduces the usage of synthetic fertilizers and an additional benefit is that it can be employed to disinfect seeds before planting and throughout storage (2). Physical seed treatment exports energy into the targeted cells of seeds. It induces seed germination by activating enzymes and biochemical processes in a cost-effective and eco-friendly manner compared to chemical seed treatment. There are many physical treatments, such as radiation treatment, magnetic treatment, dry heat treatment, electromagnetic treatment, ultrasound and scarification seed treatments (3). The maintenance of eco-friendly conditions in agriculture mainly depends on the invention and adoption of new technologies that have less detrimental effects on the environment and also provide optimistic results (4) agricultural production (5). This study aims to contribute to the field by exploring three key objectives: First, different physical seed treatment methods are selected; second, physiological and biochemical changes caused by seed invigouration treatment are analyzed and finally, the most effective seed treatment is identified.

Methodology

To analyze the impact of various physical seed treatment methods like hot water treatment, scarification, magnetic treatment, irradiation treatment and plasma treatment on various pulse crops.

Hot water treatment

Hot water treatment is the old and traditional method of seed treatment. In this treatment, the seeds are subjected to hot water for a specific period, killing seed-borne pathogens but not damaging the seed essential structure compared to ultrasound and dry heat treatment (6). High-temperature hot water treatment breaks dormancy and enhances germination (4). The effect of high temperature will collapse the cell wall of the fungi and make them inactive and it also weakens the hard portion of the seed coat and enhances the growth of the seedlings (7). The occurrence of hard seeds is the major problem that inhibits the germination of the seedling. Delayed, erratic germination and emergence, poor stand, slow early seedling growth rate and non-uniform maturity often limit crop production in crops due to dormant seeds, which can be overcome by hot water treatment (8). Hot water treatment also enhances the seedling emergence as compared to the control. Hot water treatment increases the germination percentage because the seed coat becomes permeable to water and air exchange (9). Hot water treatment affects not only the germination percentage but also the biochemical characteristics of the seed, such as increased antioxidant activity, dehydrogenase activity and vigour index. Blackgram seeds were treated at 50 °C hot water for 10, 20 and 30 min. The highest germination percentage was observed in seeds treated for 10 min at 50 °C hot water and Snake bean (*Vigna unguiculate ssp. Sesquipedalis*) seeds were treated in hot water at 100°C for 0, 5, 10, 15 and 20 min and highest germination percentage was observed in seeds treated for 10 min because of mild rupture of hard seed coat which enhances shoot protrusion in both blackgram and snake bean seeds. (10) (Fig. 1. & Table 1).

Scarification

Scarification is an eco-friendly method of treatment that is non-harmful to the environment. Scarification can be broadly classified into two parts: chemical and mechanical scarification. According to ISTA, scarification is a seed dormancy-breaking treatment that promotes germination

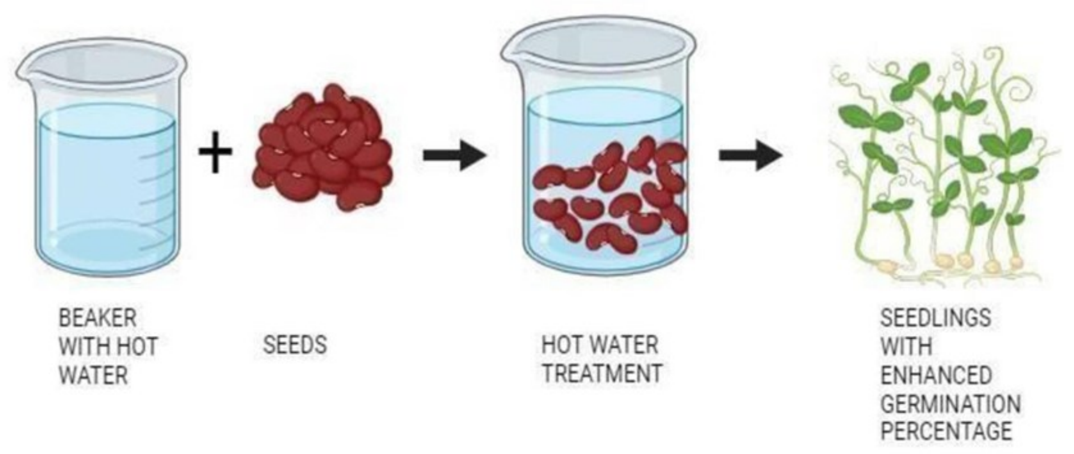

Fig. 1. Hot water treatment.

Table 1. Effect of hot water treatment in pulses

S.no	Crop	Method of treatment	Result	Reference
1	Bean (*Phaseolus vulgaris*)	Hot water treatments at 50 °C for 45-60 min	Reduction in seed germination for seeds soaked for 60 min.	(11)
2	Pea (*Pisum sativum*)	Dry heat at 65 °C for 72 h and soaking in water for 5 min.	Significant reduction of pathogen contamination, but the germination percentage lowered.	(12)
3	Chick pea (*Cicer arietinum*)	Chickpea seeds were subjected to hot water treatment at 50 °C for 5,10, 15 and 20 min and a control was maintained.	The highest germination percentage was seen in control seeds than in treated seeds.	(13)
4	Horse gram (*Macrotyloma uniflorum*)	Horse gram seeds were subjected to hot water treatment at 50 °C for 5,10,15 and 20 min and control was maintained.	Control seeds showed the highest germination percentage than treated seeds.	(13)
5	Pigeonpea (*Cajanus cajan*)	Seeds are treated in hot water at 20 °C, 40 °C and 60 °C for 10 min.	Germination percentage was highest for seeds treated at 40°C and 60°C.	(14)
6	Cowpea (*Vigna unguiculate*)	Seeds are treated in hot water at 48°C, 50°C, 52° C, 54 °C and 56 °C for 5 and 10 mins respectively.	Germination percentage was high for non-treated seeds compared to treated seeds.	(15)
7	Snake bean (*Vigna unguiculata ssp.Sesquipedalis*)	Seeds are treated in hot water at 100 °C for 0, 5, 10, 15 and 20 min.	Seeds treated in hot water at10 min showed the highest germination percentage.	(16)
8	Soybean (*Glycine max*)	Soybean seeds are treated in hot water at 40,60 and 80 °C for 20 min for three varieties: TGX 1935- 3F, TGX 1448-2E and TGX 1951- 3F.	Germination percentage was high in seeds treated at 80°C for 20 min in variety TGX 1951-3F.	(17)

(18). There are various methods under mechanical scarification, such as rubbing, disturbing, nicking, cracking and piercing the seed coat. Seed coats of hard seeds can be made permeable using scarification treatments such as acid immersion, heating, freezing and mechanical abrasion (19). Acid scarification has effectively broken hard seeds in crops like black Gram, green Gram and asparagus. One of the essential reasons behind the poor germination percentage of pulse seeds is the hard seed coat that the scarification process can overcome. Physical dormancy in legumes is the result of an impermeable seed coat caused by the presence of one or more palisade layers of lignified cells (20). Seeds of some winged bean varieties have slow germination due to the presence of water-impermeable hard seeds (21). Chemical scarification uses H_2SO_4, KNO_3 and HCl to break dormancy and enhance germination. Scarification of the seeds softens the seed coat, makes it permeable to water and oxygen and induces germination and increased antioxidant activity. A combination of chemical and mechanical treatment is not commercialized (22). Scarification is the physical treatment involved in seed invigouration techniques. This optimistic effect of physical methods like scarification on seed germination was due to the rupture of lignified layers in the testate, which are compactly packed with each other and contain water-repelling chemicals (20). Scarification enhances the speed of germination and germination percentage. Sandpaper treatment completely removed the hardness of the seeds and achieved 100 % germination in winged beans (21) (Fig. 2. & Table 2).

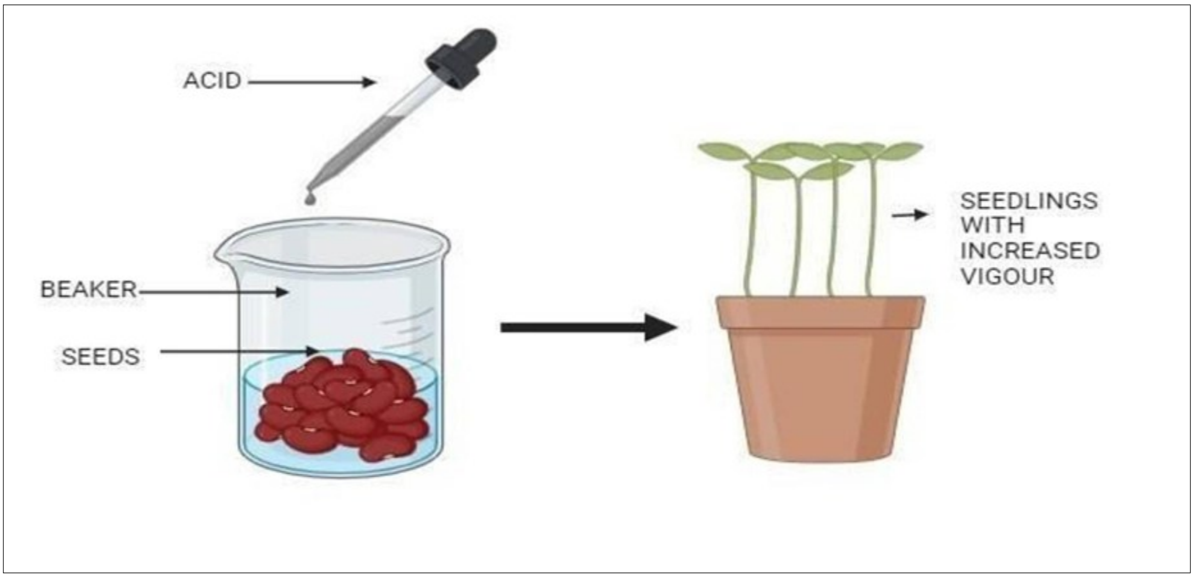

Fig. 2. Acid scarification treatment.

Table 2. Effect of scarification in pulses

S No	Crop	Method of treatment	Result	Reference
1	Winged bean (*Psophocar pus tetragonolo bus*)	Seeds are treated with concentrated sulfuric acid for 0 min, 5 min, 15 min and 25 min.	Seeds treated with conc. sulfuric acid for 15 min showed the highest germination percentage.	(21)
2	Green gram (*Vigna radiata*)	Seeds were treated with concentrated sulfuric acid for 0min,1min and 2min. Treatment with conc. Nitric acid for 0 min, 1min, 2min. Sand scarification for 2min, 4min. For three varieties, KKM - 3, WGG-42 and TRCRM-147.	Seeds treated with conc. sulfuric acid for 2min showed the highest germination percentage and seedling vigour index.	(23)
3	Wild cowpea (*Vigna vexillata*)	Seeds are treated with concentrated sulfuric acid for 0 min, 3 min, 6 min, 9 min, 12 min and 15 min.	Seeds treated with conc. Sulfuric acid for 15 min showed lowest hard seed percentage and germination percentage was high.	(24)
4	Black gram (*Vigna mungo*)	Seeds are treated with conc. Nitric acid was used for 60 sec, 90 sec and 120 sec and was treated with conc. Sulfuric acid was for 60 sec, 90 sec and 120 sec and was sacrificed for 2 min.	Seeds treated with conc. Sulfuric seeds for 60 sec showed the highest germination percentage than those treated with conc. Nitric acid and scarification.	(25)
5	Long bean (*Vigna sinensis*)	Seeds are treated with different scarification methods: sanding, wounding, soaking in sulfuric acid, soaking in warm water and treating them in the oven at 55 °C for 10 min.	Seeds treated in the oven at 55°C for 10 min showed the highest germination percentage.	(26)
6	Pigeon pea (*Cajanus cajan*)	Seeds are treated with sulfuric acid for 30 min, 60 min and 90 min.	Seeds treated with sulfuric acid for 30 min showed the highest germination percentage.	(14)
7	Pigeon pea (*Cajanus cajan*)	Seeds are scarified for 3 min, 6 min and 9 min.	Seed scarified for 9 min showed the highest germination percentage.	(14)
9	Black gram (*Vigna mungo*)	Seeds are treated with concentrated sulfuric acid for 30 and 60 sec.	Seeds treated for 60 sec have been more effective in breaking hard seed coat dormancy.	(27)
10	African locust bean (*Parkia biglobosa*)	Seeds are treated with concentrated hydrochloric acid and mechanical scarification is done.	Mechanically scarified seeds showed a higher germination percentage.	(28)

Magnetic treatment

Amongst all the physical treatment, magnetic and electromagnetic treatment usage has gained importance in recent years. Pre-sowing seed treatment with different mechanisms increases the germination percentage. In magnetic treatment, seeds are subjected to a magnetic field generated by permanent magnets or by PRISMA- magnetic coil and electromagnetic field generated by electrical objects (29, 30). It is proven that magnetic treatment has a significant impact on various seed characteristics like seed germination, plant tissue development capacity, nutrient uptake and chlorophyll synthesis. Pea varieties' emergence and sprouting were positively impacted by the magnetic stimulation of seeds (31). Exposure of chickpea seeds to different magnetic fields showed an overall stimulating effect concerning all germination characteristics like germination percentage, speed of germination and vigour index (32). It is reported that significant increases in plant growth parameters and greatly improved root characteristics in the plants from magnetically treated seeds were observed in chickpea (33). Uniform plant emergence was obtained in seeds treated in the magnetic field in broad bean varieties (34). Magnetic field-treated maize and soybean seeds recorded a higher germination percentage and vigour index than the control under stress conditions (Fig. 3. & Table 3).

Irradiation treatment

Various forms of irradiation treatment are applied in agriculture to ensure increased germination percentage and crop yield. Lower doses of radiation enhance the germination and vigour in multiple crops, but higher doses adversely affect seeds (43). In pulses, UV radiation of three different wavelengths positively impacts germination and seedling vigour. Irradiations were more energetic and highly affected the external layer of plant cells and during the early stages of germination, they stimulated the activation of RNA or protein synthesis (44). Gamma irradiation can improve the germination and seedling parameters and increase some biochemical compounds, such as chlorophyll (45). UV (ultraviolet) irradiation has both positive and negative. Impact on seed germination depends on the seed type used, period of exposure and developmental stage of the

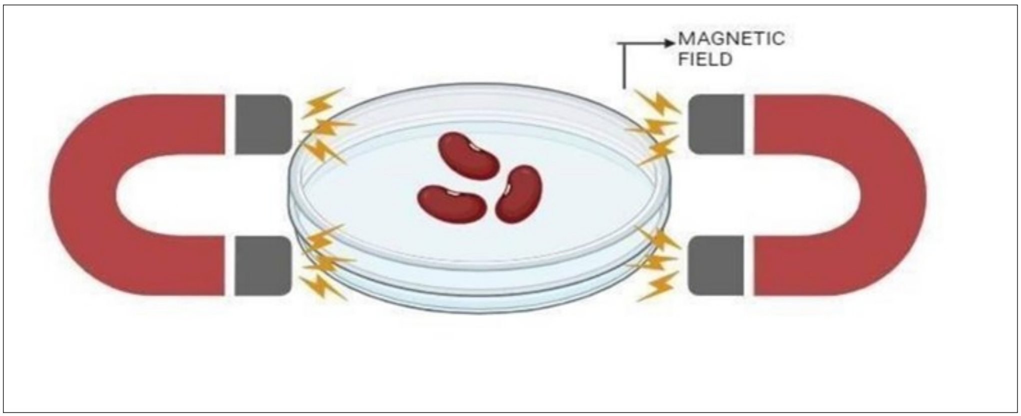

Fig. 3. Magnetic seed treatment.

Table 3. Effect of magnetic treatment in pulses

S No	Crop	Method of treatment	Result	Reference
1	Soybean (*Glycine max*)	Seeds are treated in the magnetic field at 0, 50, 100, 150, 200, 250 and 300 mT for 30, 60 and 90 min,	There was no effect on germination percentage due to magnetic field treatment, but germination speed	(35)
2	Chickpea (*Cicer arietinum*)	Seeds are treated in the magnetic field at 0, 50, 100, 150, 200, 250 mT	The germination percentage was higher for the seeds treated in the magnetic field at 100 mT.	(32)
3	Green gram (*Vigna radiata*)	Seeds are exposed to magnetic fields at 87-226 mT.	Increasing magnetic field intensity led to an increase in time and mean germination rate.	(36)
4	Pea (*Pisum sativum*)	Seeds are treated in a magnetic field for 5, 10, 15 min at 60, 120, 180 mT, respectively.	Shoot length and shoot dry mass were high when seeds were treated @ 180 mT for 5 min.	(37)
5	Chickpea (*Cicer arietinum*)	Seeds are treated in an electric field with an intensity of 27–107 kV/m for 15 min.	Seed treatment at 47 kV/m for 15 min caused increased mean germination time and improved root and shoot length.	(38)
6	Mung bean (*Vigna radiata*)	Seeds are exposed to the magnetic field of 1.5 mT for 15,20 and 25 min.	Seeds exposed to magnetic field at 1.5 mT for 25 min showed higher germination percentage and increased shoot and root length.	(39)
7	Chick pea (*Cicer arietinum*)	Seeds are treated at 3-12 V for 10 min for 100 days.	3-V and 6-V treatment resulted in early seed germination. The increase in the plant heights observed for 3, 6, and 9,12 V was 25.5, 30.5 and 11.8,17.1 %, respectively.	(40)
8	Chick pea (*Cicer arietinum*)	Seeds are treated in magnetic fields at 100 and 200mT for 1 hour.	Germination percentage was higher in seeds treated at 200 mT magnetic fields.	(41)
9	Green gram (*Vigna radiata*)	Seeds are exposed to the magnetic field at 5mT for 15, 30, 45, and 60 min.	Germination percentage was highest in seeds treated at 5 mT for 45 mins.	(42)
10	Faba bean (*Vicia faba*)	Seeds are treated in the magnetic field at 0, 30 and 85 mT for 15 sec.	Germination percentage was highest in seeds treated at 85 mT for 15 sec.	(31)

seed. Ultraviolet irradiation of seeds is an eco-friendly and low-cost approach to "awaken" the seeds from dormancy and increase germination (46). UV radiation under a low exposure period positively affects seed germination. Wheat seeds exposed to UV-C radiation showed increased germination.

UV-C radiation from 0 to 90 min and an intensity of 1.6 W m^{-2} significantly damage seed germination and growth (47). In soybean, sunflower and wheat, exposing seeds to UV-B and UV-C radiation positively influences the percentage of germination and initial seedling growth (48). Increased germination and respiration rates of *Apiacea*e spices were seen under a low UV-C light exposure period, indicating a seed's vitality and the initiation of metabolic activities (49). UV-C irradiated water-soaked groundnut seeds generally showed enhanced seed germination and all seedling growth parameters with increasing UV-C exposure up to 60 min compared to dry and soaked seed control at all sampling days (30, 60 and 90^{th} days) (50). Chlorophyll-a, b and total chlorophyll concentration of Bengal gram (*Cicer arietinum L.)* were higher than those found in horse gram (*Macrotyloma uniflorum* L.) after exposure to UV in different treatments (51). Applying shortwave length of UV-B radiation inhibits hypocotyl growth and reduces the elongation in cucumber seeds (52). The ultraviolet radiation reduces plant growth, seedlings and germination and increases chlorophyll content (53).

UV irradiation has an essential effect on the seed character, such as vigour, directly impacting the total crop production (54). Increased concentration of UV radiation and duration of treatment damage the seed coat integrity and leach out the internal material during storage, resulting in loss of vigour and viability in field conditions after sowing the seeds. The capacity of the seeds to establish healthy seedlings under favourable conditions is known as seed vigour. Compared to UV-B, th UV-A light supplementation presented here has a higher potential for use in nurseries once the plants show a higher vigour (55). There was a strong growth in seedlings of *cymposis* treated with UV radiation (56). When the dosage and duration of exposure to UV radiation increases, it leads to the leaching of the seeds' internal contents during storage, which causes the seed to vigour abruptly. Due to UV radiation absorption, seed quality degradation might be caused by modification and amino acid destruction (51, 57). Exposure of Bengal gram seeds to UV radiation caused the formation of toxic substances in the seed. Bengal Gram was adversely affected by exposure of seeds to UV radiation due to the formation of poisonous substances inside the seed. Due to excessive use of UV radiation on seeds, the physiology of the seed gets affected. The proper usage of UV radiation for the proper duration and dosage is necessary to increase the seeds' vigour and viability. Broad bean seeds exposed to gamma radiation showed a higher germination percentage (58). Pea seeds treated with gamma radiation showed poor germination and the germination percentage was very low compared to the untreated seeds (Fig. 4. & Table 4).

Plasma treatment

Plasma treatment can be an alternative to the traditional seed treatments of physical scratching, heat, or chemical

Table 4. Effect of irradiation in pulses

S. No.	Crop	Method of treatment	Result	Reference
1	Bengal Gram (*Cicer arietinum*)	Seeds are treated at 253nm for 1, 3, 5, 7, 9, 11, 13, 15 and 17 min.	Seeds treated at 253 nm for 17 min showed high total carbohydrate and protein content.	(51)
2	Peas (*Pisum sativum*)	For 7 days, pea seeds were exposed to UV radiation for 0 min, 30 min/day and 60 min.	Peas treated with UV irradiation @ 30 min/ day/7 days showed the highest seedling vigour index and total length.	(54)
3	Red bean (*Vigna umbellata*)	Red bean seeds were exposed to three different UV radiation wavelengths at 220-400nm.	Germination percentage and sprout growth rate are inversely related to the irradiation doses.	(58)
4	Chick pea (*Cicer arietinum*)	Chickpea seeds, both desi and kabuli varieties, were exposed to gamma radiation at 100-1000 Gy.	Radiation must be limited to 500Gy for the desi variety and 600Gy for the Kabuli variety, beyond which biochemical characters like protein and peroxidase begin to decrease.	(59)
5	Broad bean (*Vigna faba*)	Broad bean seeds were exposed to gamma radiation of dosage (mGy) control, 16.2, 48.5, 431 and 1070.	Seeds treated with gamma radiation at 48.5 mGy and 1070 mGy showed the highest germination.	(60)
6	Garden pea (*Pisum sativum*)	Seeds were exposed to gamma radiation of dosage (mGy) control, 16.2, 48.5, 431, 1070.	Seeds treated with gamma radiation @ 16.2 mGy showed a higher germination percentage.	(60)
7	Pea (*Pisum sativum*)	Seeds were exposed to gamma radiation of dosage at control, 1kR, 5kR, 10kR, 15kR, 20kR, 25 kR, 30kR and 35kR.	Seeds treated with gamma radiation showed the lowest germination percentage compared to the control. The lower dose (10kR), the highest plant height, was observed, possibly due to the stimulatory effect of irradiation treatment.	(61)
8	Pea of two varieties (*Pisum sativum var. hortense*) and (*Pisum sativum var. arvense*)	Seeds are treated with gamma radiation in dosages of 0 Gy, 50 Gy, 100 Gy, 150 Gy, 200 Gy, and 250 Gy.	Germination percentage was higher in untreated seeds than in treated seeds with different dosages for both varieties.	(62)
9	Cowpea (*Vigna unguiculata*)	Seeds are exposed to gamma radiation in dosages of 0, 150, 250 and 350Gy.	Maximum germination percentage was observed in the seeds treated at 150Gy.	(63)
10	Horse gram (*Macrotyloma uniflorum)*	UV irradiation treatment at 0, 1, 3, 5, 7, 9, 11, 13, 15 and 17 min.	Horse gram seeds treated with UV irradiation for 9 min showed the highest germination and plant stand.	(51)

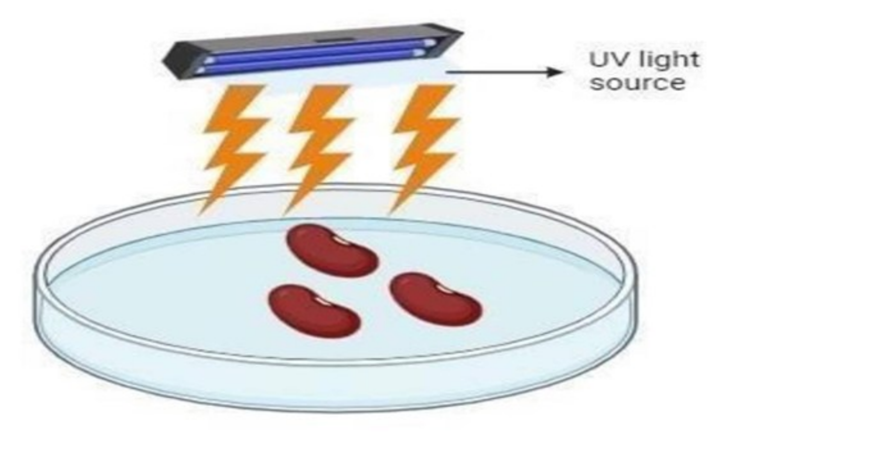

Fig. 4. Irradiation treatment.

treatment (64). Plasma treatment combines negatively charged ions, electrons, neutral atoms and molecules (65). Non-thermal plasma treatment on the plant seeds affects seed germination, seedling growth and plant yield. Cold atmospheric pressure plasma increases seed tolerance to stress, activates seed metabolism and promotes plant growth and development. *Phaseolus vulgaris* dormant seeds treated with CPJ have the potential to cause surface hydrophilization, corrugation and portion of the seed, which enhances the water uptake and imbibition of the seed. Thus, cold plasma induces pores in the seed surface and accelerates the imbibition process during germination (66). Soybean seeds treated with plasma showed increased germination percentage and vigour indices, indicating that plasma treatment has a more significant stimulatory effect on the germination of soybean seeds (3, 67) (Table 5). Thus, peas and soybean seeds treated with plasma showed an increased germination percentage.

Conclusion

Seed invigoration is an effective technique to enhance agricultural productivity and helps to achieve sustainable food security. Hot water treatment is the low-cost treatment among the different physical seed invigoration treatments reviewed. Irradiation treatments are quick, cost-effective and pollution-free, promoting seed germination. Irradiation and Cold plasma treatments were effective and highly recommended amongst all the other physical seed treatments. Following a well-planned procedure like selecting the irradiation source and dosage, employing the proper irradiation process and following safe post irradiation handling of the seeds, large-scale production of irradiated seeds can be done. Continued research and development of irradiation and cold plasma technologies will likely play a crucial role in addressing the challenges of modern agriculture, offering a pathway towards more resilient and sustainable food production systems worldwide.

Table 5. Effect of plasma treatment in pulses

S.no	Crop	Method of treatment	Result	Reference
1	Black bean (*Phaseolus vulgaris*)	Seeds were treated with cold plasma for 5, 10, 20 and 30 min.	Seeds treated with cold plasma for 5 min showed increased hypocotyl, radical length and speed of germination.	(68)
2	Mungbean (*Vigna radiata*)	Atmospheric pressure plasma jet (5 kV, 40 kHz, 750 W), 200 mL of PAW exposed 15-90 s.	Increased germination percentage, seedling growth and total phenolic and flavonoid compound than control.	(69)
3	Soybean (*Glycine max*)	For 15 sec, soybean seeds are treated with 0, 60, 80, 100 and 120 W cold plasma.	Seeds treated with 80 W Cold plasma showed increased seedling germination and vigour.	(67)
4	Blackgram (*Vigna mungo*)	Seeds are treated with 400 torr DBD air plasma with 5kV at different durations from 20-180 s	Germination rate (%), shoot and root length (cm) were high in seeds treated for 120 s.	(70)
5	Chickpea (*Cicer arietinum*)	Seeds are treated with cold air plasma for 0.5, 1, 2, 3, 4 and 5 min.	Increased seed germination, vigour and germination speed were seen in seeds treated for 1 min.	(71)
6	Pea (*Lathyrus oleraceus*)	Seeds are treated with cold plasma for 3,6 and 12 min.	3 and 6 min exposure to DBD showed increased germination and enhanced shoot and root parameters.	(72)
7	Mung bean (*Vigna radiata*)	Mung bean seeds were exposed to cold plasma @ control, 40 W, and 60 W, for 10, 15 and 20 min, respectively.	Seeds treated with cold plasma showed an increased germination rate compared to the control.	(73)
8	Bean (*Phaseolus vulgaris*)	Seeds are exposed to cold radiofrequency air plasma at 20 W for 2 min.	There is no significant difference between the germination percentage of plasma-treated and non-treated seeds. The speed of germination was higher for plasma-treated seeds.	(74)
9	Pea (*Lathyrus oleraceus*)	Seeds are treated with plasma-activated tap water (PATW) at pH 3, 5, 6, 7, 8 and 9.	Germination percentage was higher in seeds treated in PATW at pH 6.	(72)
10	Soybean (*Glycine max*)	Seeds were treated with cold atmospheric pressure plasma (CAPP) and control was maintained.	Seeds treated with CAPP showed a higher germination percentage than the untreated seeds.	(75)

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Authors' contributions

RL, VA, PM, KS and MG have contributed equally to data collection, analysis, writing the original manuscript draft, editing, and reviewing.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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