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Ultrasonic Treatments to Enhance Seed Germination and Related Parameters

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Abstract To improve the germination activity and performance of seeds, many post-harvest applications such as physical, chemical and biological, etc. are carried out and these applications are called seed quality enhancing applications. With these practices, germination and emergence problems depending on seed quality are minimized, healthy and strong developed seedlings can be obtained, and the resistance and endurance of these seedlings to stress conditions can be increased. One of the applications used to improve seed performance is ultrasonic treatments. Ultrasound has been successfully used in many scientific fields such as biology, biochemistry, engineering, agriculture, dentistry, medicine, and different industrial sectors. This review summarizes studies on the effects of ultrasound applications on seed quality parameters such as seed germination and emergence.

Keywords ultrasound, seed quality, germination, emergence, water uptake

1. Introduction

Germination is one of the most important parameters of seed quality and it can vary based on the seed's viability and soil or environmental conditions in which they are sown. Rapid and homogenous seed germination, field emergence, and uniform seedling development are critical for successful plant establishment. If the seed germinates rapidly and uniformly, it will be better able to withstand the field's biotic and abiotic stress factors. Germination and emergence are not at the desired level, especially in early spring when soil temperatures and humidity are low. To eliminate germination and emergence problems caused by the seed itself and environmental conditions, seeds are exposed to various methods after harvesting and conditioning, but before they are sown known as seed enhancement [1]. These technologies are often used to speed up and synchronize germination, increase seed vigor, seedling emergence, and establishment, and facilitate mechanized seed distribution to the site by standardizing seed size and form [2]. They include hydration treatments such as priming (3), coating technologies (pelleting, film coating, etc.) and seed conditioning [1], and physical methods such as magnetic field, microwave irradiation, gamma radiation, and ultrasound [4].

Seed priming is a procedure that controls germination and can partially hydrate seeds, allowing the germination process to start but not finish. Seed priming techniques include hydropriming, halopriming, osmopriming, thermopriming, solid-matrix priming, and biopriming [5]. However, these techniques require significant time and labor costs [6]. The ultrasonic application uses low to medium-frequency waves (20-100 kHz), and this technology has multiple emerging uses in agriculture, the food business, chemical and applied industries [7-9]. Ultrasound is cost-effective, easy to use, safe, and produces a variety of impacts on seeds, including heat, mechanical, and chemical effects, in a short period and environmentally friendly way to increase seed germination and crop growth [6,10]. The seed has to absorb enough water to germinate and the characteristics of the seed coat come to the fore among the factors that control water uptake during seed germination. The impermeable or hard seed coat is a physiological phenomenon that forces seeds into dormancy in many species [11]. One of the applications used to eliminate hard seed coat dormancy in seeds and regulate germination and emergence is ultrasonic treatments [12]. In recent years, ultrasonic treatment has been used to stimulate germination, water uptake, breaking seed dormancy, and seed hygiene by researchers in many species' seeds, including carrot, castor bean, maize, barley, wheat, rice, sunflower, soybean, radish, okra, etc. [12-22].

Many remarkable publications concerning the beneficial effects of ultrasonic waves on seed germination characteristics have been published by researchers on this interesting and important topic. This review examined the effects of ultrasound applications on germination and related parameters in different seed species.

2. Ultrasound mechanism and its impact on seeds

Ultrasound is a type of energy that generates sound at frequencies greater than 20 kHz and transmits it in the form of waves via air or water [23]. High-pressure and low-pressure waves occur in the liquid to which ultrasound is applied. Ultrasonic waves generate small vacuum bubbles during low-pressure wave production, and when these bubbles reach a volume where they cannot absorb any more energy, high-pressure wave formation begins, and they burst inward. This phenomenon is known as cavitation [23,24]. Ultrasound's cavitation causes mechanical pressure on seeds and the vibrations alter the physicochemical properties of seeds; the permeability of the cell membranes increases significantly, causing the seeds to swell more quickly, and then the metabolic process begins, with some enzymatic processes are activated while other enzyme systems are blocked. As a result, the sowing quality of seeds increases, particularly the energy of germination; this increases the viability of plants established from seeds [16,25].

3. Effects of ultrasound on seed germination and related parameters

Germination is a process that begins with the seed absorbing water and oxygen under suitable conditions, followed by the radicle emergence and a shoot containing the leaves and stem. Ultrasound is gaining popularity among researchers due to its ease of usage. The beneficial effect of ultrasound applications on seed germination is explained by the fact that these applications accelerate the seed's water uptake due to the microcracks and fractures created on the seed coat, facilitate the transport of water and nutrients to the embryonic axis, and, as a result, increase radicle growth following the application [21,26].

In studies conducted so far, the effects of ultrasound applications on germination and related parameters in many species have been investigated. It was found that sonication can increase the germination of switch grass seeds by up to 23.2%, which is consistent with the beneficial effects of ultrasonic waves on seed germination [6]. In another study, sonication increased the germination percentage of chickpeas (36%), wheat (2%), and watermelon (2%), compared to the control. However, the germination percentage of pepper seeds was reduced by 19% [12]. It has been demonstrated that ultrasonic stimulates germination and the fresh weight of shoots in carrots [13]. Due to the enhanced germination rate by up to 6%, ultrasound treatment improved barley seed alpha-amylase activity. Ultrasound stimulation of barley germination is caused by an increase in the size of the pores in the seed's shell, which allows for greater hydration [16]. The ultrasonic waves contribute to the swelling processes in barley seed exposure and help oxygen penetrate the seed and improve barley seed germination in the field by providing adequate hydration during the growing season in difficult soil and climatic circumstances [27]. As a result, ultrasonic technology can improve barley seeds' hydration process without compromising seed quality [17]. In research on radish [21], ultrasonic irradiation accelerated the germination and growth of seeds sunk under water. Ultrasound has been shown to increase the germination of terrestrial orchid seeds by 50 % [26]. In another study on Paphiopedilum orchids, ultrasound treatment for 2-8 minutes, increased the germination rate compared with the control and 6 or 8 minutes resulted in the highest TTC staining (18.3 and 20.0%), as well as germination (53.1 and 54.03%) but prolonged ultrasonication (10 minutes) damaged embryos and reduced germination [28]. In a study on the influence of ultrasonic waves on peas, ultrasound application resulted in a 13.1% increase in seed germination compared to the control [29]. It was found that in an in vitro experiment [30], ultrasound improves the germination of snail medick seeds by 63.3% compared to the control treatment. It was demonstrated that sonication has a positive effect on the seed germination of big saltbush, cumin, and caper beans increased by 28%, 36%, and 35.7%, respectively, compared to the control [31]. A study on sunflower seeds found that ultrasonic waves improved germination by up to 43% [32]. In another study on the effects of ultrasonic waves, the germination rate of Norway spruce seedlings increased by 22% [33]. The germination period for soybean and sunflower was shortened by approximately 33.34% compared to the control after ultrasonic treatment [34]. Germination percentage, root and shoot lengths, seedling dry matter, and vigor index of the three soybean varieties increased by ultrasonic treatment [35]. Ultrasonic waves increased the germination and establishment of seedlings from old soybean seeds via modulating antioxidant defense and gluconeogenesis [36]. It has also been shown that sonication improves the germination of wheat and lentil seeds by 4% and 6%, respectively [37]. A study on old grass seeds of tall fescue and Russian wild rye suggested that ultrasonic waves can accelerate germination by 40 and 50%, respectively [38]. Ultrasound boosted germination in watermelon (13%), carrot (11%), pepper (13%), leek (10%), and pepper (7%) compared to control and hydro-primed seeds, with a greater beneficial effect on seedling emergence than germination [39]. In another study, sonication improved the final germination of wild yam species (*Dioscorea* spp.) by 7-10% [40]. Ultrasonic wave treatment enhanced seed germination, root length, shoot length, and seedling height compared to the control, however, the dill crop responded more than the tomato [41]. A combination of ultrasound and heat treatments increased the germination of bird's-foot trefoil seeds up to 94.5% compared to the control germination level of 57.8% [42].

Researchers have revealed that exposing the seeds to ultrasound increases hydration. Ultrasound treatment increased seed moisture content by up to 21% and radicle length by up to 1.4 cm of okra seeds compared to the control treatment [22]. After ultrasonication, the soybean seed coat developed significant cracks and holes, resulting in faster water absorption [43]. Seed moisture levels were much greater for switchgrass seeds soaked in water and treated with ultrasound (47.70% and 91.88%, respectively) than for control seeds [44].

Some studies have found that ultrasonic applications are effective against biotic and abiotic stresses. Ultrasound treatment improved GPmax and GR50 in castor bean seeds, both old and non-aged, across all water stress situations. This suggests it could be utilized as a pretreatment to improve germination characteristics, especially under stressful conditions [14]. Water in an appropriate irrigation system is necessary for plant growth since excessive floods or submergence damages the plants. Ultrasound treatment of wet rice seeds significantly increased the seedling emergence rate under waterlogging stress conditions [45]. Sonication or hydropriming treatments boosted wheat germination and increased GABA (γ-aminobutyric acid) metabolism to maintain C:N metabolic balance, particularly during cold stress [18]. Exposing garden cress seeds to ultrasonic vibrations, particularly for 20 minutes resulted in a significant increase in seed germination at 35°C compared to the control treatment [46]. Ultrasound treatments improved seed water absorption of sesame seed and also germination performance and seedling growth at low temperatures were enhanced with a mild exposure time, as evidenced by a better germination percentage and rate [47]. Pathogens cause seed decay, which reduces yield and quality in agricultural production. Ultrasound treatment of roselle seeds for 60 min remarkably reduced the seed decay caused by *Fusarium solani* up to 3.33% compared to control seeds without any adverse effects on seed germination indices [48]. In common winter wheat, sonication of seed with 42 kHz in a water bath has been shown as a good alternative for destroying fungi in seeds and accelerating the growth rate of young shoots, which improves their competitiveness against weeds and eliminates the need for herbicides as an alternative to organic farming [49]. Cadmium (Cd) disrupts normal plant metabolism, reducing crop growth and productivity. The ultrasonic seed treatment boosted germination rate, shoot and root length, and rapeseed yield while reducing Cd accumulation in several plant sections of rapeseed grown in Cd-contaminated soil [50].

4. Conclusion

In general, the study's findings revealed that ultrasound applications boost seed water intake, reduce germination time, and, as a result, increase germination rate compared to controls. According to the results of ultrasonic seed treatments that have been done by researchers, the effects of ultrasonic sound waves on seed germination depend on the frequency, time of application, and water temperature during application and vary widely among different species and varieties. As a result, ultrasonography is clearly a promising technology in seed science and that can be utilized as a priming technique to alleviate germination and emergence problems caused by seeds and other factors, as well as improve seed quality.

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