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Impacts of Ultrasonic Waves on Seeds: A Mini-Review

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Abstract

Seeds are essential in rebuilding the production capacity of a crop, maintaining the germplasm, and improving species diversity. The ultrasound technology has been successfully used in many mass transfer processes in food, such as in drying, extraction, osmotic dehydration, desalting and hydration. However, during the recent years, ultrasonic waves have also vastly been applied as an efficient technique for breaking seed dormancy and improving the germination characteristics. This mini-review aimed to investigate the impacts of ultrasonic waves on seed germination percentage and speed of the different species. As the result of this mini-review, the ultrasonic waves positively affect the germination percentage in all the species except one case. However, the germination speed in all the species increases through application of the ultrasounds. The reasons for the positive effects of the ultrasounds on the seeds are also discussed.

Introduction

Seeds are essential in rebuilding the production capacity of a crop, maintaining the germplasm, and improving species diversity. On the one hand, seed germination is the vital period of plant establishment [1], and on the other hand, rapid germination and seedling emergence are critical factors for successful plant establishment [2]. If plants achieve rapid germination and establishment, then the seedlings are able better to survive different environmental stresses [3]. Some different mechanisms (called dormancy) are used by plants to postpone germination and to protect the seeds until the favorable conditions for seedling are provided. Seed dormancy is defined as the ways of hindering germination for an intact viable seed. Some seeds, especially those which are produced in natural conditions, show different levels of seed dormancy. Dormancy breaking and germination stimulation are important for proliferation and early production of important plants [4]. Different methods have been applied to overcome the seed dormancy such as regulatory hormones [5], salinity, temperature, and humidity [6], light and seed scarification, seed stratification [7] and fertilizers [8-9]. Beside technology, development of new techniques is suggested for breaking the seed dormancy such as magnetic water [10] and Nano-compounds [11]. Recently, use of ultrasonic waves as a safe, easy, and time-saving technique for seed dormancy breaking has attracted the researcher's attention [4,12-14].

Ultrasonic waves are mechanical waves of a frequency higher than 20000 Hz, which are not detectable by human's audiation system. The ultrasound technology has been successfully used in many mass transfer processes in food, such as in drying, extraction, osmotic dehydration, desalting and hydration [15]. However, during the recent years, ultrasonic waves have also vastly been applied as an efficient technique for breaking seed dormancy and improving the germination characteristics. The mechanisms of action of the ultrasound on seeds have also been manifested during the recent years more clearly. Despite the publication of many outstanding articles about the positive effects of ultrasonic waves on seed germination characteristics, no review has so far been accomplished on this interesting and important subject. This paper aims to investigate the available articles published on the effects of ultrasound on seeds. The mechanisms of action of ultrasonic waves on seeds are also explored here.

Germination Percentage

Seed germination is a very important stage of the plant life. Use of ultrasound as a promising technique for breaking seed dormancy and increasing the germination percentage has recently been highlighted by the researcher's. In a research on the effect of ultrasonic waves on pea (*Pisumsativum*),

ultrasound application resulted in a 13.1 % increase in the seed germination compared to the control treatment [16]. In another experiment on four crop specieschickpea (*Cicer arietinum*), wheat (*Triticumaestivum*), pepper (*Capsiumannuum*) and watermelon (*Citrullus vulgaris*) [17], investigated the effect of sonication on the seeds' germination percentage. The germination percentage of chickpea, wheat and watermelon was increased by 36 %, 2 % and 2%, respectively, in comparison with the control. But the seeds of pepper responded to ultrasound negatively and the germination percentage decreased by 19 %. It seems that exposure of some species' seeds to ultrasound could decreases the germination percentage. In this respect, It showed that exposure of fennel (*Foeniculum vulgare*) seeds to ultrasonic waves leads to a 30.5 % decrease in the germination percentage. In an *in vitro* experiment performed by Nazari [4], it was indicated which ultrasound enhances snail medick (*Medicagoscutellata* (L.) *Mill*) seed germination by 63.3 % compared to the control. In a similar experiment, it was shown that the seed germination of three important medicinal species respond to sonication positively; as the seed germination of big saltbush (*Atriplexlentiformis*), cumin (*Cuminumcyminum*) and caper beans (*Zygophyllumeurypterum*) was increased up to 28 %, 36 % and 35.7 %, respectively, compared to the control [1]. In another study on the effects of ultrasonic waves on sunflower (*Helianthus annuus L.*) seeds, the germination was increased by the maximum 43.38 % [18]. Further, Risca and Fartais 2009 showed that the germination percentage of Norway spruce (*Piceaabies L.*) Karsten seeds increase by 22%. It was also reported which sonication enhances the germination of wheat (*Triticumaestivum*) and lentils (*Lens culinaris, Med.*) seeds by 4 and 6 %, respectively [19]. In a very interesting research on aged grass seeds of tall fescue (*Festucaarundinacea*) and Russian wild rye (*Psathyrostaehysjuncea Nevski*) [14], indicated that the ultrasonic waves can increase the germination by 40 and 50 %, respectively. Moreover, it has been shown that exposure of Bird's-foot trefoil (*Lotus corniculatus L.*) seeds to ultrasonic waves increases the germination by 9% [20]. Another experiment was performed on barley (*Hordeum vulgar L.*) seeds showing that ultrasound increases the germination up to 6% [`12]. Ultrasound has also proved to enhance the germination percentage of terrestrial orchid (Calanthe discolor) seeds by 50% [21]. In agreement with the positive effects of ultrasonic waves on the seed germination, Wang et al. [22], revealed which sonication enhances the germination of switch grass (*Panicum virgatum L.*) seeds up to 23.2 %. Altogether, it is clearly seen that ultrasonic waves, in most cases, have the potential to improve seed germination of the tested species. However, germination speed is another characteristic that has shown to be increased by exposure of the seeds to ultrasounds. A summary of the findings about the effects of ultrasounds on seed germination percentage of the mentioned plant species has been provided (Table 1).

Table 1: Effect of ultrasonic waves on seed germination percentage of the reviewed species.

Author (s)	Species	Germination %	
		Control	Ultrasound
Chiu & Sung [16]	*Pisum Sativum*	85	98.1*
Goussous et al. [17]	*Cicer arietinum*	61	97*
Goussous et al. [17]	*Triticum aestivum*	98	100*
Goussous et al. [17]	*Citrullus vulgaris*	98	100*
Goussous et al. [17]	*Capsium annuum*	72	53*
Fateh et al. [10]	*Foeniculum vulgare*	90	59.5*
Nazari et al. [4]	*Medicago scutellata (L.) Mill*	33.3	96.6**
Sharififar et al. [1]	*Atriplex lentiformis*	40	68**
Sharififar et al. [1]	*Cuminum cyminum*	44	80**
Sharififar et al. [1]	*Zygophyllum eurypterum*	37.5	73.3**
Machikowa et al. [18]	*Helianthus annuus L.*	54.6	98*
Machikowa et al. [18]	*Picea abies (L.) Karsten*	46	68*
Aladjadjiyan [19]	*Triticum aestivum*	90	94*
Aladjadjiyan [19]	*Lens culinaris, Med.*	92	98*
Liu et al. [14]	*Festuca arundinacea*	38.7	78.7*
Liu et al. [14]	*Psathyrostaehys juncea Nevski*	39.3	89.3*
Toth [20]	*Lotus corniculatus L.*	77.1	86.1*
Wang et al. [22]	*Panicum virgatum L.*	66.9	90.1*
Yaldagard et al. [26]	*Hordeum vulgare L.*	93	99*
Miyoshi & Mii [21]	*Calanthe discolor*	10	60*

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Germination speed

Germination speed is a very important factor in proper establishment of plants in natural habitats or in the field. A quickly germinating seed can use the available nutrients and water more timely and more efficiently [23]. Many techniques are available for increasing the germination speed of different species. Acid sulfuric and cold stratification are the two widely used methods. Ultrasound, as a new and easy-to-use technique, has recently attracted the researchers' attention. In a research on pea (*Pisumsativum*) [16], indicated that treating the seeds with ultrasonic waves increases the germination speed by 93 %. In another study, it was shown that ultrasound enhances the germination speed of chickpea, wheat, watermelon and pepper seeds up to 20, 36, 16 and 1.8 %, respectively [17]. In a recently published article [15], revealed which sonication can increase the germination speed of mung bean (*Vigna radiata*) seeds by 25 %.Further, in a study on the effects of sonication on barley seeds, the germination speed increased by 45 % significantly [12]. To sum up, in all the species investigated so far, sonication significantly increases the seed germination. However, it should be clear that how ultrasonic waves improve the germination speed as well as the germination percentage. A summary of the findings about the effects of ultrasounds on seed germination speed of the mentioned plant species has been provided (Table 2).

Table 2: Effect of ultrasonic waves on seed germination speed of the reviewed species.

Author (s)	Species	Increase in germination speed (%)
Chiu & Sung [16]	*Pisum Sativum*	93*
Goussous et al. [17]	*Cicer arietinum*	20*
Goussous et al. [17]	*Triticum aestivum*	43*
Goussous et al. [17]	*Citrullus vulgaris*	16*
Goussous et al. [17]	*Capsium annuum*	1.8*
Dutheil et al. [31]	*Hordeum vulgare L.*	20*
Claudio Miano et al. [15]	*Vigna radiata*	25*
Yaldagard et al. [26]	*Hordeum vulgare L.*	45*

Mechanisms of Action

The impacts of ultrasonic waves on seed germination of the different species have so far been investigated. However, there has been scattered views in terms of the action mechanisms of ultrasounds on seeds.

Ultrasounds are mechanical waves of a frequency higher than 20000Hz. Water is used as a medium for treating the seeds by ultrasounds [4]. Seeds of the desired species are placed in to an ultrasonic wave emitting apparatus containing water [1].

Water uptake and oxygen availability are the essentials of seed germination. Therefore, ultrasonic waves should alter the seed's characteristics through which more water and oxygen are available. In water, ultrasonic waves lead to cavitation [24-26], Cavitation is a phenomenon by which micro-bubbles are created in water. The cavitation created by the ultrasound causes a mechanical pressure on the seeds [26,27]. This mechanical pressure then leads to the cell wall fluidity [26], and to the creation of micro-pores and micro-cracks on the cell wall [28]. It has also been shown that the porosity of mung bean seeds increase by ultrasonic waves [15]. The creation of micro-pores and micro-cracks caused by sonication means that the seeds are more permeable to water and oxygen entry [15]. Researchers have indicated that exposure of the seeds to the ultrasound enhances hydration [29,30,26,15]. It seems that increase in hydration of the seeds treated with ultrasonic waves results in an increase in enzymatic activities especially alpha-amylase [1,15,26]. Consequently, the starch hydrolysis is enhanced followed by increase in the seed germination percentage and speed [1,26]. A schematic representation of the processes by which ultrasonic waves affect the seeds has been provided (Figure 1) [31].

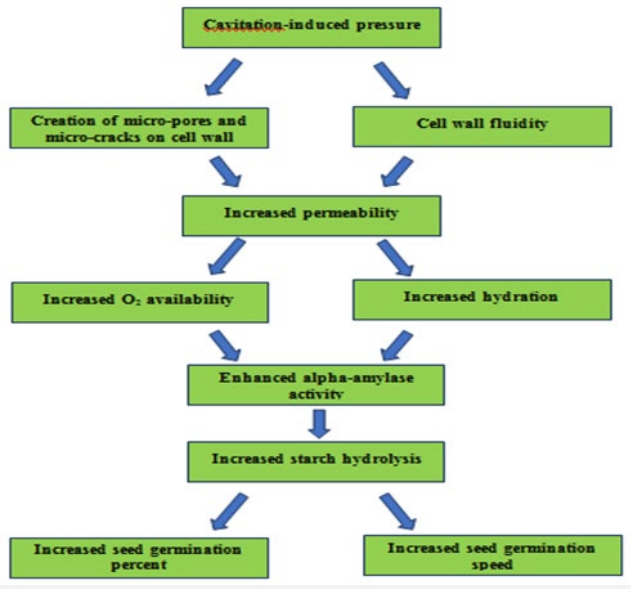

Figure 1: Schematic representation of the processes by which ultrasounds affect seeds..

Conclusion

In this mini-review, the effects of ultrasonic waves on seed germination percentage and speed of the different species were

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evaluated. Moreover, the mechanisms by which the ultrasounds impact the seeds were investigated. As it was investigated, in all the species (except two of them), the ultrasound can enhance seed germination percentage. It also can increase seed germination speed in all the species surveyed. About the action mechanisms, it is concluded that the ultrasounds impose a mechanical pressure on the seed's cell wall. This pressure increases the seed's porosity, and consequently rises the seed's permeability to oxygen and water. After this, the alpha-amylase activity inside the seed increases which leads to increased hydrolysis of the starch. Finally, the germination percentage and speed are enhanced. At the end, the authors would like to advise the investigation of more other species affected by ultrasonic waves.

Advantages and Disadvantages of the Method

Ultrasound, as a seed priming technique, seems to be applied easier compared to the other methods like sand scarification, acid scarification, and other available methods. Moreover, the ultrasounds only impose mechanical pressure on seeds to break the dormancy; therefore, no chemicals would contaminate the seeds. The disadvantage of application of ultrasonic waves in seed industries is the small size of the available apparatuses. A scaling-up is required in order to manufacture huge ultrasound-emitting sets specialized for seed priming purposes.

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